FAECAL SLUDGE CHARACTERISATION FOR ENHANCED SANITATION PROVISION IN PERI-URBAN AREAS OF LUSAKA

By

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of the requirements for the award of the degree of

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ABSTRACT

Lusaka city has over 70 percent of its population residing in peri-urban areas where more than 90 percent of the residents rely on pit latrines for excreta disposal. However, no Faecal Sludge Management (FSM) systems exist to manage the faecal sludge from these facilities. This situation results in faecal sludge ending up in the environment where it contributes to environmental degradation. The design of adequate FSM facilities requires availability of comprehensive faecal sludge quality data in addition to data on quantities. Non availability of the faecal sludge quality data for the city of Lusaka was therefore the main reason why this study was conceived. The study evaluated in detail, the sanitation practices in peri-urban areas that impact on faecal sludge quality, including faecal sludge quality characteristics that would impact on valorisation. The study also assessed the variability of the faecal sludge quality with depth and geological formations. Sanitation practices were evaluated through both qualitative and quantitative methods involving observations and Focus Group Discussions (FGDs) and household questionnaires. Data for the other aspects was collected using field surveys and laboratory experiments. A total of 100 pit latrines to serve as sampling points were selected using a stratified purposive sampling method. A total of 28 parameters falling within the physical, chemical, rheological and microbiological categories were analysed. Among the major findings were the following: there was no regulation on the design, construction and usage of sanitation facilities in peri-urban areas leading to practices that compromised the faecal sludge quality; the faecal sludge was found to have high valorization potential assessed from the high organic matter and nutrient content and low concentration of inhibitory substances. For the analysed top and bottom sludge samples, Total Volatile Solids (TVS) averaged 0.63±0.145 and 0.55±0.107g/g dry solids, Total Chemical Oxygen Demand (COD) averaged 129,407±55,088 and 112,052±51,467 mg O_2/L, and Biochemical Oxygen Demand (BOD) averaged 1,045±527 and 1,006±470 mg O_2/L, respectively. Microbiological parameters generally recorded high counts with the prevalence of viable Ascaris at 27 percent (n=100); there were statistically insignificant differences with depth among the means of the various parameters indicative of biodegradation except for TVS ($p=0.0005$), Viable Ascaris ($p=0.0021$) and *Cryptosporidium* ($p=0.0002$); and variability of the faecal sludge quality with differences in geological characteristics of the study areas analysed revealed statistically marginal differences for most of the parameters including Total COD ($p=0.05$). The statistically insignificant differences in the quality of faecal sludge quality with respect to depth and geological formations implies that universal measures could be instituted in the management of the sludge without giving consideration to the source. Based on the results, a responsive Operations Framework for enhanced FSM service delivery integrating faecal sludge quality with reuse initiatives, regulation and awareness creation was proposed. Some of the recommendations included replication of the study to cover the rain season and also evaluating the feasibility of the faecal sludge reuse initiatives from the local social-cultural perspective as this is a cardinal aspect in the operationalisation of the proposed framework.

Key words: Faecal Sludge; Characterisation; Peri-urban area; valorization.

DEDICATION

To my Late father Mr. Blessingtone Tembo. You left footprints of grace in our lives and you shall never be forgotten.

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TABLE OF CONTENTS

DECLARATION ..... **i**
COPYRIGHT ..... **ii**
APPROVAL ..... **iii**
ABSTRACT ..... **iv**
DEDICATION ..... **v**
ACKNOWLEDGEMENTS ..... **vi**
TABLE OF CONTENTS ..... **viii**
LIST OF TABLES ..... **xiv**
LIST OF FIGURES ..... **xvi**
LIST OF ACRONYMS ..... **xx**
OPERATIONAL DEFINITIONS ..... **xxiii**

CHAPTER 1 : INTRODUCTION **1**
1.1 Background 1
1.2 The Study Area: A Contextualisation 4
1.3 Statement of the Problem 6
1.4 Research Questions 8
1.5 Hypotheses 8
1.6 Research Aim 8
1.6.1 Objectives 9
1.7 Significance of the Study 9
1.8 Conceptual Framework 12
1.9 Theoretical Framework 13
1.10 Scope of the Study 16
1.11 Ethical Considerations 17
1.12 Study Assumptions 18
1.13 Study Limitations 18
1.14 Structure of the Thesis 18
1.15 Chapter Summary 19

CHAPTER 2 : LITERATURE REVIEW **20**
2.1 Introduction 20
2.2 General sanitation aspects 20
2.3 Sanitation: A global perspective 21
2.4 Sanitation Status in Zambia and in the project area 22

2.4.1 Institutional and regulatory framework for sanitation provision in peri-urban areas of Zambia 23
2.4.2 Policy Framework, Visions and Strategies and Legal Framework for the provision of Onsite Sanitation and FSM Services 27
2.4.2.1 Policy Framework, Visions and Strategies 27
2.4.2.2 Legal Framework 30
2.5 Faecal Sludge Management 33
2.5.1 FSM - A Global Perspective 34
2.5.1.1 Factors for implementation of successful FSM systems 35
2.5.2 Faecal Sludge Management in Zambia 39
2.5.3 Faecal Sludge Management in Lusaka City 41
2.5.3.1 Emptying and Transportation 41
2.5.3.2 Treatment 42
2.5.3.3 Disposal and Reuse 44
2.5.3.4 Status of shit flow in the study area 45
2.5.4 Future of FSM in Zambia 46
2.6 Availability of faecal sludge quality data in Zambia 48
2.7 The Pit Latrine and Processes that Occur therein 48
2.7.1 The Pit Latrine 48
2.7.2 Processes Occurring in Pit latrines 50
2.7.2.1 Organic matter 51
2.8 Factors affecting reactions in pit latrines 56
2.8.1 Temperature 56
2.8.2 pH 56
2.8.3 Nutrients 57
2.8.4 Inhibitory substances 57
2.8.4.1 Ammonia 57
2.8.4.2 Light Metals ions 58
2.8.4.3 Heavy Metals 59
2.8.5 Moisture Content 60
2.8.6 Residence time 61
2.8.7 Hydrogeological and soil characteristics of the surrounding environment 62
2.9 Faecal sludge Characterisation 62
2.10 Resource Potential of Faecal Sludge 62
2.10.1 Biogas generation using faecal sludge 64
2.10.2 Faecal sludge usage in agriculture 65
2.10.2.1 Composition and plant availability of nutrients in urine 66

2.10.2.2 Composition and plant availability of nutrients in faeces 66
2.10.3 Health and safety considerations in Faecal Sludge Reuse 67
2.10.3.1 Pathogenic health risks 67
2.10.3.2 Non-Pathogenic risks 68
2.11 Gap Analysis 69
2.12 Chapter summary 70

CHAPTER 3 : RESEARCH METHODOLOGY 71
3.1 Introduction 71
3.2 Philosophical orientation of the study 71
3.2.1 Ontology 72
3.2.2 Epistemology 73
3.2.3 Methodology 75
3.2.4 Summary of the research 76
3.3 Research Design 78
3.4 Study area selection 79
3.5 Entry strategy into research sites 81
3.5.1 Inaugural workshop with stakeholders at a city level 81
3.5.2 Workshops with community members in the study areas 83
3.6 Field surveys 83
3.6.1 Surveys for data collection from communities 84
3.6.2 Surveys for pit latrine data collection 85
3.6.3 Surveys for Faecal sludge sampling 88
3.6.3.1 Sampling for determination of grit and other forms of solid waste 88
3.6.3.2 Sampling for physical, chemical and microbiological parameters 93
3.6.3.3 Sampling for rheological parameters 94
3.7 Laboratory analysis of faecal sludge samples 96
3.7.1 Laboratory analyses for physical, chemical and microbiological parameters . 96
3.7.2 Laboratory analyses for rheological parameters 98
3.7.3 Summary of parameters analysed together with adopted method of analysis . 99
3.8 Analyses and Interpretation of the field and laboratory analytical data 100
3.8.1 Analysis of qualitative data 100
3.8.2 Analysis of quantitative data 100
3.8.3 Determination of distribution of the datasets 101
3.8.4 Determination of outliers 101
3.8.5 Statistical determination of levels of association among and between datasets 102

3.9 Summary of the methods with reference to specific objectives 103
3.10 Chapter Summary 103

CHAPTER 4 : RESULTS 104
4.1 Introduction 104
4.2 Sanitation Practices 104
4.2.1 Latrine design and construction 104
4.2.2 Latrine usage and operational aspects 106
4.2.2.1 Use of the latrines as receptors of excreta and sullage 107
4.2.2.2 Use of the latrines as receptors of solid waste 108
4.2.2.3 Addition of Chemicals to pit latrine contents 111
4.2.2.4 Desludging frequency of the latrines 112
4.3 Sludge depth in the sampled latrines 114
4.4 Results on valorisation potential of the faecal sludge 116
4.4.1 Results for physical characteristics of faecal sludge 117
4.4.1.1 Density 117
4.4.1.2 Moisture Content 118
4.4.1.3 Total Solids 118
4.4.1.4 Total Volatile Solids 119
4.4.2 Results for rheological characteristics of faecal sludge 120
4.4.2.1 Viscosity – Shear rate relationship 120
4.4.2.2 Variability of shear stress with moisture content 122
4.4.2.3 Variability of viscosity with moisture content 122
4.4.2.4 Variability of viscosity with depth 123
4.4.3 Results for chemical characteristics of faecal sludge 125
4.4.3.1 pH 125
4.4.3.2 Total Chemical Oxygen Demand 125
4.4.3.3 Soluble Chemical Oxygen Demand 126
4.4.3.4 Total Biochemical Oxygen Demand 127
4.4.3.5 Ammonia 128
4.4.3.6 Sulphates 128
4.4.3.7 Phosphates 129
4.4.4 Light metals 130
4.4.4.1 Potassium 130
4.4.4.2 Sodium 130
4.4.4.3 Calcium 131
4.4.4.4 Magnesium 132

4.4.5 Heavy metals 133
4.4.5.1 Zinc 133
4.4.5.2 Cadmium 133
4.4.5.3 Cobalt 134
4.4.5.4 Copper 135
4.4.5.5 Iron 136
4.4.5.6 Chromium 136
4.4.5.7 Lead 136
4.4.6 Results for microbiological characteristics of faecal sludge 137
4.4.6.1 Faecal Coliforms 137
4.4.6.2 Ascaris 140
4.4.6.3 Cryptosporidium 145
4.5 Variability in degree of biodegradation of faecal sludge with depth 148
4.6 Variability of faecal sludge quality with geological characteristics of the study areas 149
4.6.1 Results on differences in means from all the study areas 149
4.6.2 Results of the Mann-Whitney U test on parameters that registered significant differences 150
4.6.2.1 Moisture Content 151
4.6.2.2 Total solids 151
4.6.2.3 pH 151
4.6.2.4 Total Biochemical Oxygen Demand 152
4.6.2.5 Faecal Coliforms 152
4.6.3 Summary of the Mann-Whitney U Test on parameters that registered significant differences 153
4.7 Proposed Operations Framework for Enhanced FSM services Provision 153
4.8 Chapter Summary 155

CHAPTER 5 : DISCUSSION 156
5.1 Introduction 156
5.2 Sanitation practices and implications on faecal sludge quality 156
5.2.1 Latrine design and construction 156
5.2.2 Latrine usage and operational aspects 157
5.2.2.1 Use of the latrines as receptors of excreta and sullage 158
5.2.2.2 Use of the latrines as receptors of solid waste 159
5.2.2.3 Addition of Chemicals to pit latrine contents 162
5.2.2.4 Desludging frequency of the latrines 163

5.3 Valorisation potential of the faecal sludge 163
5.3.1 Valorisation potential – Physical parameters and organic matter 164
5.3.1.1 Density 164
5.3.1.2 Moisture and Total Solids content 165
5.3.1.3 Total Volatile Solids, COD and BOD 166
5.3.2 Rheological Characteristics 170
5.3.3 Nutrients (Phosphates, Ammonia and Potassium) 171
5.3.4 Inhibitory and toxic substances (Ammonia and heavy metals) 173
5.3.5 Microbiological quality 175
5.4 Variability of faecal sludge quality with depth of the pit latrines 176
5.5 Variability of faecal sludge quality with geological formation 178
5.6 The proposed Operations Framework for enhanced FSM provision 179
5.7 Implications of the study findings 180
5.8 Chapter Summary 181

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS 182
6.1 Introduction 182
6.2 Conclusions 182
6.3 Contribution to the body of knowledge 183
6.4 Generalisability 184
6.5 Validity and reliability 184
6.6 Recommendations 185
6.6.1 Recommendations based on study findings 185
6.6.2 Recommendations for future research work 186

REFERENCES 189

LIST OF TABLES

Table 1-1: Suggested maximum Sludge Accumulation Rates 6
Table 1-2: Parameters adopted for characterisation 17
Table 2-1: Functions of stakeholder ministries and institutions in sanitation provision in peri-urban areas 25
Table 2-2: Summary of factors for enhanced regulation 38
Table 2-3: Toxicity limits in anaerobic digesters 59
Table 2-4: Regional and International Guidelines for the maximum permissible heavy metals concentration in agricultural soils (mg/kg) 60
Table 2-5: Summary of potential resource recovery options from faecal sludge 63
Table 2-6: The GWP of GHGs produced in WWTPs 65
Table 2-7: Environmental conditions and how they need be manipulated to speed up the die-off rate of pathogens 68
Table 3-1: Summary of the categories of philosophical assumptions 72
Table 3-2: Four different ontologies 73
Table 3-3: Contrasts between positivism and social constructivism paradigms 74
Table 3-4: Comparisons between quantitative and qualitative approaches 76
Table 3-5: Central criteria of quantitative research 77
Table 3-6: Barrels to be collected for analysis depending on the number of barrels being desludged from a pit 89
Table 3-7: Sampling points and depths for rheological samples 95
Table 3-8: Parameters analysed in raw sludge and methods of analysis used. 99
Table 3-9: Summary of the methods and tools employed for each specific objective 103
Table 4-1: Solid waste content in pit latrine faecal sludge 109
Table 4-2: Quartile values for the grit and solid waste content results 110
Table 4-3: Results of the Mann-Whitney U Test on samples from latrines treated with chemicals and those where there was no addition of chemicals 112
Table 4-4: Status on desludging for the sampled pits 113
Table 4-5: Mann-Whitney U Test results on samples from latrines never desludged and those desludged within not more than a year prior to sampling 113
Table 4-6: Faecal sludge depths in the sampled pit latrines 114
Table 4-7: Summary of sludge depth in sampled latrines used in the analyses of the physical and chemical parameters 115
Table 4-8: Mean faecal sludge depths in sampled pit latrines 115
Table 4-9: Outlier pit latrines in terms of faecal sludge depth 116
Table 4-10: Variability of faecal sludge density with study areas 118
Table 4-11: Mean moisture content for samples from the four study areas 118
Table 4-12: Mean Total Solids content for samples from the four study areas 119
Table 4-13: Mean Total Volatile Solids for samples from the four study areas 120

Table 4-14: Mean pH values for samples from the four study areas 125
Table 4-15: Mean COD concentration for samples from the four study areas 126
Table 4-16: Mean Soluble COD concentration for samples from the four study areas 127
Table 4-17: Mean Total BOD concentration for samples from the four study areas 127
Table 4-18: Mean ammonia concentrations for samples from the four study areas 128
Table 4-19: Mean sulphate concentration for samples from the four study areas 129
Table 4-20: Mean phosphate concentration for samples from the four study areas 129
Table 4-21: Mean potassium concentration for samples from the four study areas 130
Table 4-22: Mean Sodium concentrations for samples from the four study areas 131
Table 4-23: Mean calcium concentration for samples from the four study areas 132
Table 4-24: Mean magnesium concentrations for samples from the four study areas 132
Table 4-25: Prevalence of zinc in the four study areas 133
Table 4-26: Prevalence of cadmium in the four study areas 134
Table 4-27: Prevalence of cobalt in the four study areas 135
Table 4-28: Prevalence of copper in the four study areas 135
Table 4-29: Prevalence of iron in the four study areas 136
Table 4-30: Proportions by percentage of latrines that recorded higher counts of faecal coliforms in the top and bottom sludge for the respective study sites. 138
Table 4-31: Prevalence of Ascaris in the four study areas 140
Table 4-32: Mean Cryptosporidium counts for the four study areas 145
Table 4-33: Summary of variability of the selected parameters with depth 148
Table 4-34: Significance of variance of mean results for selected parameters from the four study areas 149
Table 4-35: Summary of the Mann-Whitney U Test results for moisture content 151
Table 4-36: Summary of the Mann-Whitney U Test results for Total Solids 151
Table 4-37: Summary of the Mann-Whitney U Test results for pH 152
Table 4-38: Summary of the Mann-Whitney U Test results for BOD 152
Table 4-39: Summary of the Mann-Whitney U Test results for faecal coliforms 152
Table 5-1: A comparison of COD results from the study and those from other faecal sludge characterisation studies 168
Table 5-2: COD/BOD ratios for research results and other systems 169
Table 5-3: Ammonia concentration in faecal sludge from different systems 173
Table 5-4: Mean concentrations of heavy metals in samples and their prevalence 174
Table 5-5: Concentration of selected microbiological parameters in faecal sludge from different sources 175

LIST OF FIGURES

Figure 1-1: Map of Lusaka showing location of peri-urban areas in relation to other developments in the city....5
Figure1-2: Population of Lusaka over a 25-year period (Source: Plotted using data from CSO, 2016)....5
Figure 1-3: How faecal sludge data impacts on the sanitation service chain 10
Figure 1-4: Conceptual Framework for the study 12
Figure 1-5: The faecal sludge service chain....14
Figure 1-6: Comparison in faecal sludge management fees for a non incentivized and an incentivized faecal sludge value chain 15
Figure 1-7: Theoretical Framework anchored on the TWM 16
Figure 2-1: World and Regional Sanitation coverage between 1990 and 2015....21
Figure 2-2: Sanitation facilities in the city of Lusaka 23
Figure 2-3: Institutional synergies in sanitation provision in peri-urban areas....24
Figure 2-4: The effects of lack of onsite sanitation service regulation 40
Figure 2-5: Faecal sludge emptying and transportation. 42
Figure 2-6: State of the current existing infrastructure for receiving septage at Manchinchi Wastewater Treatment Plant 43
Figure 2-7: Sludge on drying beds at Manchinchi Wastewater Treatment Plant....44
Figure 2-8: Cooking at the Kanyama Water Trust using biogas from the faecal sludge treatment plant 44
Figure 2-9: Shit Flow Diagram (SFD) for the City of Lusaka, Zambia....45
Figure 2-10: SFD for the City of Lusaka, Zambia as compiled by LWSC (2015) 46
Figure 2-11: A pit latrine....49
Figure 2-12: Theorised layers in a pit latrine 50
Figure 2-13: Speciation of COD 53
Figure 2-14: Schematic diagram of the patterns of carbon flow in anaerobic digestion 55
Figure 3-1: Illustration on how the choice of ontology influences methods, epistemology, approach, strategy and data collection and analysis methods 76
Figure 3-2: Presentation of the main questions to consider in coming up with a research design....78
Figure 3-3: Graphical presentation of the research design for the study 79
Figure 3-4: Location of the study areas in relation to the City Centre....80
Figure 3-5: Part of the stakeholders who attended the inaugural workshop. 82
Figure 3-6: Community workshops in research sites 83
Figure 3-7: Collection of household demographic data and aspects of latrine operations and maintenance 87
Figure 3-8: Latrine data collection 88
Figure 3-9: Weighing of the barrel together with the faecal sludge before separation 90

Figure 3-10: Washing of faecal sludge to separate the sludge from grit and solid waste 91
Figure 3-11: Examples of some constituents from the fractionated solid waste 92
Figure 3-12: Faecal sludge sampling with the modified sampling tool 93
Figure 3-13: Faecal sludge sampling 94
Figure 3-14: Faecal sludge dilution 97
Figure 3-15 : Designed algorithm for determining suitable statistical tools to use in analysis of data 102
Figure 4-1: Geology type where selected latrines are located according to study areas 105
Figure 4-2: Latrine depth ranges in the study areas 105
Figure 4-3: Examples of pit latrines with elevated latrine vaults 106
Figure 4-4: Example of latrine construction where the pit follows the profile of the caverns 106
Figure 4-5: Comparative analysis of phosphates in latrines used for excreta disposal only and those used for both excreta and sullage disposal 107
Figure 4-6: Comparative analysis of moisture content in latrines used for excreta disposal only and those used for both excreta and sullage disposal. 108
Figure 4-7: Pit latrine contents showing presence of solid waste 109
Figure 4-8: A comparison between the mean and median values for solid waste and grit .110
Figure 4-9: Composition of the pit latrine faecal sludge based on the eight sampled pits..111
Figure 4-10: Behaviour of faecal sludge in terms of viscosity under increasing shear rate. 121
Figure 4-11: A plot of Shear stress against shear rate exhibiting shear thinning. 121
Figure 4-12: Relationship between shear stress and moisture content at minimum and maximum shear rates 122
Figure 4-13: Variability of viscosity with moisture content for pit C008 123
Figure 4-14: Graph presenting a case where a sample with higher moisture content had a comparatively higher viscosity 123
Figure 4-15: Viscosity results for pit M006 where the highest viscosity was recorded in the top layer and the least in the middle layer. 124
Figure 4-16: Viscosity results for pit G015 showing top layer with lower viscosity. 124
Figure 4-17: Mean faecal coliform counts for study areas 138
Figure 4-18: Prevalence of Faecal Coliforms in faecal sludge samples and its variability with depth in each of the four study areas 139
Figure 4-19: Variability of Ascaris counts in top and bottom sludge for latrines that registered positive counts 141
Figure 4-20: Prevalence of Ascaris in sludge samples and its variability with depth in each of the four study areas 142
Figure 4-21: Prevalence of viable Ascaris in faecal sludge samples and its variability with depth in each of the four study areas 144

Figure 4-22: Proportion of latrines with higher counts of Cryptosporidium in top and bottom sludge, respectively. 146
Figure 4-23 : Prevalence of Cryptosporidium in faecal sludge samples and its variability with depth. 147
Figure 4-24: Summary of appearances by percentage in combinations of results from the different study areas that accounted for the statistically different results in the pair-wise comparisons. 153
Figure 4-25: Proposed Operations Framework for FSM based on study findings..... 154
Figure 5-1: Example of interfaces that discourage direct latrine usage by children 160
Figure 5-2: The pit latrine desludging process (Note the possible mixing of the sludge with the loose sand from the newly dug pit 160
Figure 5-3: Illustration of variability of shear stress with depth in pit latrines 171

LIST OF APPENDICES

APPENDIX A: The Focus Group Discussion Guide.....211
APPENDIX B: Google Maps for Study areas showing location of the sampling points 213
APPENDIX C: Latrine Data Collection Tool and Results 217
APPENDIX E: Results for the analysed physical parameters 233
APPENDIX F: Rheological Results 240
APPENDIX G: Results for the analysed chemical parameters 293
APPENDIX H: Results for light metals 307
APPENDIX I: Results for heavy metals 315
APPENDIX J: Results for Analysed Microbiological Parameters 329
APPENDIX K: Graphical Presentation for Physical and Chemical Parameters 338
APPENDIX L: Results on Selected Parameters used to Compare Significance of Addition of Chemicals to Pit Latrine Contents.....348
APPENDIX M: Results on Selected Parameters used to Compare Significance of Desludging Pit Latrine Contents.....349
APPENDIX N: Publications arising from this Research 350

LIST OF ACRONYMS

ABR	Anaerobic Baffle Reactor
AIT	Asia Institute of technology
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
BORDA	Bremen Overseas Research Development Agency
CAP	Chapter
CBD	Central Business District
CBE	Community Based Enterprise
CBoH	Central Board of Health
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
CSO	Central Statistical Office
CU	Commercial Utility
DRC	Democratic Republic of Congo
DTF	Devolution Trust Fund
FGD	Focus Group Discussion
FSM	Faecal Sludge Management
GHG	Green House Gas
GIDD	Gender in Development Division
GRZ	Government of the Republic of Zambia
GWP	Global Warming Potential
IWRM	Integrated Water Resources Management
JICA	Japan International Corporation Agency
JMP	Joint Monitoring Programme
LHS	Left Hand Side
LSP	Lusaka Sanitation Program
LWSC	Lusaka Water and Sewerage Company Limited
MCDSS	Ministry of Community Development and Social Services
MDG	Millennium Development Goal
MLG	Ministry of Local Government
MLGH	Ministry of Local Government and Housing
MNDP	Ministry of National Development and Planning

MoF	Ministry of Finance
MOGE	Ministry of General Education
MoH	Ministry of Health
MWDSEP	Ministry of Water Development, Sanitation and Environmental Protection
NECOS	Network for Environmental Concerns and Solutions
NGO	Non Governmental Organisation
NHC	Neighbourhood Health Committee
NWASCO	National Water and Sanitation Council of Zambia
O & M	Operations and Maintenance
OD	Open Defeacation
RHS	Right Hand Side
SADC	Southern Africa Development Community
SAR	Sludge Accumulation Rate
SDG	Sustainable Development Goals
SMEC	Snowy Mountains Engineering Consultants
SMP	Sanitation Master Plan
SeNDP	Seventh National Development Plan
SFD	Shit Flow Diagram
SNDP	Sixth National development Plan
SPSS	Statistical Package for Social Scientists
STP	Standard Temperature and Pressure
TS	Total Solids
TVS	Total Volatile
TWM	Theory of Waste Management
UDDT	Urine Diversion Dry Toilet
UNICEF	United Nations International Children's Fund
VIP	Ventilated Improved Pit Latrine
WASH	Water Sanitation and Hygiene
WASHE	Water Sanitation and Hygiene Education
WDC	Ward Development Committee
WID	Women in Development
WHO	World Health Organisation
WRC	Water Research Commission

WASAZA	Water and Sanitation Association of Zambia
WSS	Water Supply and Sanitation Services
WSUP	Water and Sanitation for the Urban Poor
WWTP	Wastewater Treatment Plant
ZABS	Zambia Bureau of Standards
ZEMA	Zambia Environmental Management Agency

OPERATIONAL DEFINITIONS

The following are the operational definitions applicable to this study:

Faecal sludge: Excreta which comes from onsite facilities and has not been transported through a sewer (Strande et al., 2014)

Peri-urban areas: Areas within the jurisdiction of the Local Authority, having high population density and low cost housing units lacking basic services such as water supply, roads and sewerage (MLGH, 2015; NWASCO/DTF, 2005).

Faecal Sludge Management: A management system that safely collects, transports, and treats faecal sludge from pit latrines, septic tanks or other onsite sanitation facilities (Strande et al., 2014).

Formal FSM Enterprises: Entities that operate in accordance with the conventional standards and guidelines for health and environmental protection.

Informal Operators: Persons who provide desludging services informally without adequate tools and protective attire.

Sanitation chain: A term that describes the five stages involved in FSM which include: capture and containment; collection; transportation; treatment; and disposal/reuse.

End-use Industries: Stakeholders in the sanitation chain who make use of the inherent useful aspects of faecal sludge like nutrients, energy potential and bulking properties for beneficial purposes (Strande et al., 2014).

Back-end user: Same as End-use Industries.

Water Trust: A community enterprise entrusted with the management of water supply and FSM services delivery in peri-urban areas.

Single pit latrine: A pit latrine designed to serve one household.

Unimproved Pit Latrines: Pit latrines that do not ensure hygienic separation of human excreta from human contact and include pit latrines without a slab or platform (WHO/UNICEF, 2013).

Improved Sanitation: Sanitation that includes sanitation facilities that ensure hygienic separation of human excreta from human contact (WHO/UNICEF, 2012).

Sanplat: Short form of sanitation platform which refers to the floor/slab of a latrine (Grimason et al., 2000),

Lysis: Dissolution or destruction of cells

Inhibitory substance: A material that causes an adverse shift in the microbial population or inhibition of microbial growth.

Combined nutrients: Nutrients present in larger particles not soluble in water

Ward Development Committee: A community structure created by the local authority to assist in providing oversight of wards in terms of developmental projects.

Community Based Enterprises: Organisations/institutions providing services in peri-urban areas for the purpose of making a profit.

Open Defeacation: Excretion or disposal of excreta in fields, forests, bushes, water bodies or other open spaces, or disposal of human faeces with other forms of solid waste (WHO/UNICEF, 2012).

Onsite sanitation system: A sanitation system that collects, stores, treats and disposes of excreta/wastewater on or near the site of generation (Tilley et al., 2014).

Offsite sanitation system: A sanitation system that collects, conveys, treats and disposes of wastewater at a site away from the point of generation (Tilley et al., 2014).

CHAPTER 1 : INTRODUCTION

1.1 Background

The management of faecal sludge has continued to pose challenges in high density areas of Sub-Sahara African countries (Semiyaga et al., 2015). This is despite the majority of the population in these areas accessing sanitation services through onsite facilities. Strande et al. (2014) reports that between 65 and 100 percent of the urban population in most Sub-Sahara African countries access sanitation exclusively through onsite systems. Of the onsite facilities used, pit latrines are the most prevalent especially in peri-urban areas of large cities (Jenkins et al., 2015; Templeton et al., 2015; WHO/UNICEF, 2014; Thye et al., 2011). Pit latrines are also the cheapest means of excreta management and provide the most inexpensive means of improving sanitation coverage especially in developing countries (Graham and Polizzotto, 2013). According to O'Riordan (2009), usage of pit latrines in most peri-urban areas of developing countries has continued to rise.

Although pit latrines are the cheapest and most common means of excreta management, they have one drawback in that they get full after some time. When this happens, they become unusable (Murungi and van Dijk, 2014; Still and O'Riordan, 2012; Still et al., 2005). The full latrine can either be buried or replaced with a new one or if it is desired to continue using the same latrine, it can then be emptied and put back into service (Jenkins et al., 2015; Still and O'Riordan, 2012; Pickford and Shaw, 1997). The option of burying works well in areas where there is sufficient space that allows for digging of new replacement latrines. For peri-urban areas in large cities, pit emptying is a more practical option since most of these areas are normally faced with lack of space (Akumuntu et al., 2017). In addition to space constraints, high costs associated with the construction of a decent new latrine superstructure make emptying a more attractive option (O'Riordan, 2009; Muller and Rijnsburger, 1994). The cost of the substructure can also be prohibitive especially if its construction has to adhere to standard specifications which include lining. In some cases, this is exacerbated by unfavourable geological characteristics requiring special excavation methods as the case is in rocky areas and areas prone to inundation.

The success of pit emptying in any locality requires the availability of a viable Faecal Sludge Management (FSM) system which is a mechanism that ensures (Jenkins et al., 2015; Strande et al., 2014):

- adequate containment of faecal sludge at the point of generation;
- safe collection or emptying of the sludge from the containment facility and its subsequent transportation to a treatment facility;
- adequate treatment of the faecal sludge; and
- safe disposal or/and reuse of the treated sludge.

The process of faecal sludge emptying can either be through the use of manual or mechanised systems. Manual systems exclusively depend on the use of hand tools while mechanised systems use either manually operated mechanical tools like gulpers and manual diaphragm pumps or exclusively mechanical equipment like vacuum trucks, pumping systems and mechanical augers (Strande et al., 2014). Mechanised systems are mostly preferred as they are efficient and minimise contact with faecal sludge. However, formal FSM enterprises which can manage to acquire and maintain mechanised systems are usually not available in low cost areas (WRC, 2015). This is mainly due to lack of incentives associated with faecal sludge service provision in these areas (Strauss et al., 2002). As such, FSM, in these areas is a matter that is usually left to be dealt with at individual household level. This situation catalyses informal means of desludging and in African countries, these normally take the form of unhygienic manual emptying (Blackett et al., 2014).

Where pit emptying is done formally, care is taken to ensure that personnel are protected from safety and health hazards associated with the process of emptying, transportation, treatment and disposal which include (Strande et al. 2014):

- physical (which comprise slips, trips and falls, exposure to sharps, ergonometric issues; etc);
- chemical (including direct and indirect oral, nasal and dermal exposure to faecal sludge and exposure to harmful gases); and
- biological (including exposure to multiple types of pathogens in faecal sludge).

Where desludging is done informally (i.e. by informal operators), the emptiers usually work without adequate protective attire and hence are at risk of being infected (Murungi and van Dijk, 2014). Secondly, there is usually a tendency to cut down on haulage costs by disposing of the faecal sludge in close proximity to the emptied facility. In other cases, it is just technically not possible for the emptiers to transport the sludge leading to indiscriminate disposal into the environment (Strauss, 2002). Places of such type of disposal include nearest surface water bodies, drainage channels and on the streets (Schaub-Jones et al., 2006).

The indiscriminate and unregulated disposal of faecal sludge results in environmental pollution. This consequently compromises public health of nearby and surrounding communities in addition to aesthetically degrading the environment (Akumuntu et al., 2017). Despite the adverse impacts associated with the absence of FSM services in peri-urban areas, the situation has to a large extent remained unchanged in many countries. Local authorities as well as local entrepreneurs who are usually the major stakeholders in the business of faecal sludge emptying (O'Riordan, 2009) are not attracted to venture into this arena of service delivery due to lack of incentives (Strauss et al., 2002). For the city of Lusaka, WSUP (2018) identifies inadequacies in access to facilities and uncertainties on profitability of FSM service if provided to peri-urban areas as some of the reasons why this service is unavailable in these areas. It states in part: "*Those offering on-site FSM services using vacuum tankers (the majority of which are run by private businesses) only tend to do so in central districts. This is partly due to ease of access, as these planned districts are more spacious and have better roads than their peri-urban counterparts, but also because vacuum tanker owners feel more certain that they will recoup their costs if they concentrate on those living in more 'formal' areas"*. The lack of incentives is also linked to a number of challenges associated with FSM service provision in peri-urban areas including (Strauss et al., 2002):

- the low priority that is usually given to FSM on the authorities' agenda;
- inadequate legal and regulatory framework to support FSM; and
- lack of collaboration among stakeholders concerned with FSM services provision including those that have a role to play in the sanitation chain.

From the foregoing, it is apparent that lack of incentives play a major role in the observed low levels of service provision in FSM. Diener et al. (2014) contend that solving the current sanitation challenges requires dynamic approaches in infrastructure, technology and cost recovery. Murray and Ray (2010) suggest that sustainable provision of sanitation services would be greatly enhanced if the design and operations of FSM systems are integrated with resource recovery initiatives. However, it should be clear that implementation of resource recovery initiatives require a sound database of faecal sludge quality characteristics.

It should be realised that quality plays a role at all stages of the sanitation value chain as well as in the anticipated beneficiation prospects. Knowledge of quality characteristics of the sludge is essential for the adequate design of desludging tools and treatment facilities (Strande et al., 2014; Bassan et al., 2013). The concentration of certain parameters in the sludge will inform the treatment process on what measures need to be instituted in order for it to attain the required treatment. Similarly, known quality characteristics of the sludge will inform the end users on its appropriate uses. This implies that quality determination can generate demand for faecal sludge and its derivatives. This can in turn trigger incentivisation of the sanitation value chain and ultimately contribute to enhanced sanitation provision.

This study was therefore provoked by the need to generate pit latrine faecal sludge quality data which can augment the design of various measures to enhance FSM service provision in peri-urban areas and ultimately contribute to enhanced sanitation provision.

1.2 The Study Area: A Contextualisation

The study area, Lusaka, is the capital city of Zambia. It is located 15° 25' 0" south of the equator and 28° 17' 0" east of the Greenwich Meridian. It is the largest city in the country and covers an area of approximately 360 km^2 (LCC, 2019). The major built-up area consists of the Central Business District (CBD) in the city centre, organized residential areas located mostly on the eastern side of the CBD, a conglomerate of industries on the western part of the CBD and peri-urban areas occupying the rest of the city (Figure 1-1).

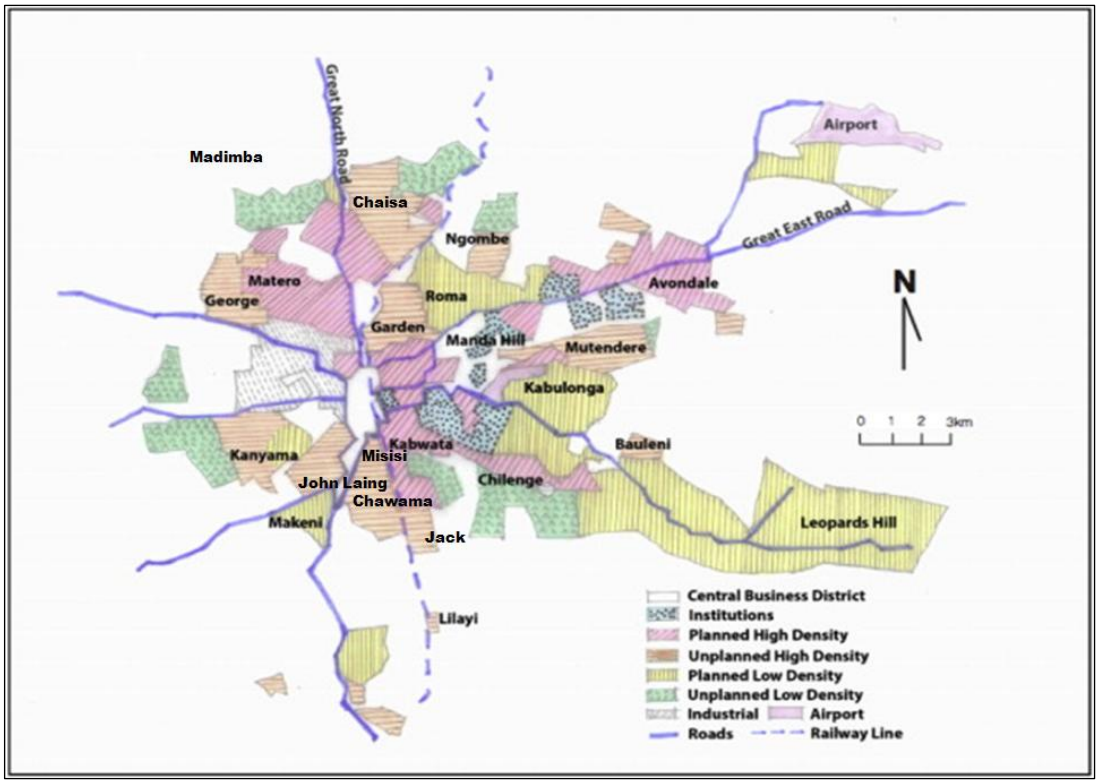


Figure 1-1: Map of Lusaka showing location of peri-urban areas in relation to other developments in the city (Peri-urban areas are here referred to as unplanned high density areas (Source: Wragg and Lim, 2015))

The city has a population of about 2,330,200 which is growing at a rate of 4.9 percent (CSO, 2016). The population has more than tripled over the past 25 years (Figure 1-2).

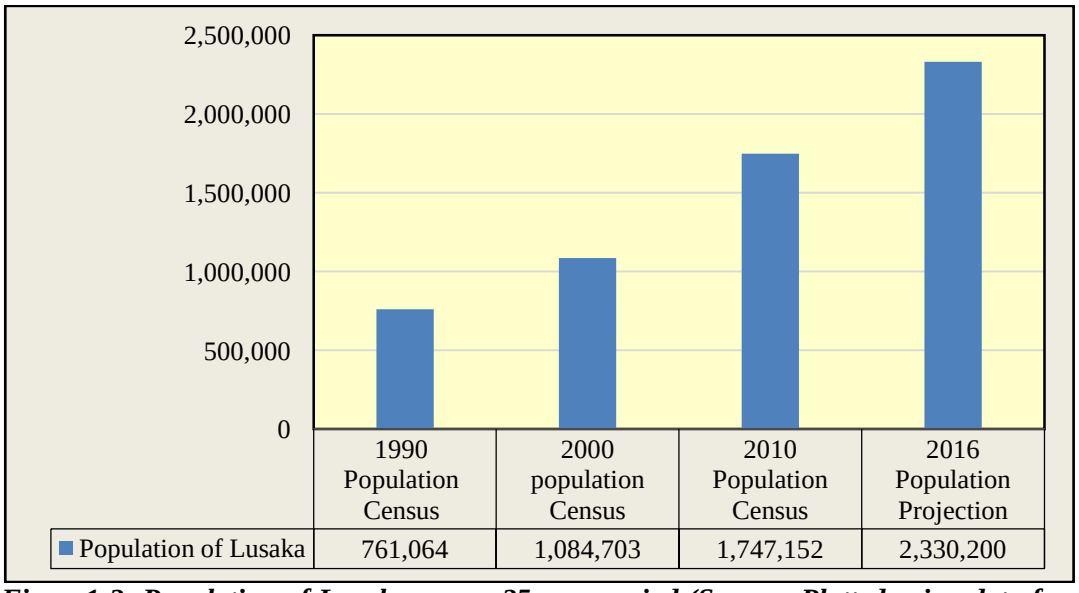


Figure1-2: Population of Lusaka over a 25-year period (Source: Plotted using data from CSO, 2016)

The proportion of this population residing in peri-urban areas is in the vicinity of 70 percent (MLGH, 2015; Marco et al., 2009; JICA, 2009). Over 90 percent of people residing in peri-urban areas use unimproved pit latrines (SMEC, 2016). This translates to about 1.5 million people employing pit latrines as a means of excreta disposal in the city. With an estimated excreta generation rate of 1.5 liters per capita per day (Koné and Peter, 2008), approximately 2,220,000 million liters of excreta is deposited in pit latrines across the city on a daily basis. In terms of faecal sludge, approximately 165,000 liters of faecal sludge accumulates in the city's pit latrines every day assuming a maximum faecal sludge accumulation rate of 40 liters per capita per year as postulated by Franceys et al. (1992) (Table 1-1). It should be noted that this accumulation rate does not take into account the solid waste that usually ends up in pit latrines as well.

Table 1-1: Suggested maximum Sludge Accumulation Rates (SAR)

Environment within the pit where the faecal sludge is accumulating and anal type of cleansing material used	**SAR liters/capita.year**
Wastes retained in water where degradable anal cleaning materials are used	40
Wastes retained in water where non-degradable anal cleaning materials are used	60
Waste retained in dry conditions where degradable anal cleaning materials are used	60
Wastes retained in dry conditions where non degradable anal cleaning materials are used	90

(Source: Adapted from Franceys et al., 1992)

Therefore, from the foregoing, it is apparent that without plans to adequately manage this faecal sludge, it could continue adding to the sanitation challenges the city has perpetually been facing.

1.3 Statement of the Problem

Management of faecal sludge in low cost areas, especially the peri-urban areas of Lusaka has continued to be a challenge to sanitation services providers. There is limited formal FSM services provision in these areas and this is partly due to low investment in the sub-sector which can partly be blamed on low incentives associated with FSM service provision in peri-urban areas. Until as recently as 2016,

most utilities in Zambia were only concerned with reticulated sewerage systems and wastewater sludge. The gap for FSM service provision (emptying of on-site facilities) in affluent areas which are mostly on septic tanks is currently bridged up by the private sector. This is because service provision in these areas is associated with monetary incentives and access to facilities is not a challenge as the layout of the areas is properly planned. In peri-urban areas, where access is a challenge and provision of the service cannot attract monetary incentives, residents have been left to come up with their own initiatives to manage the faecal sludge problems inherent from their systems.

The lack of adequate FSM systems in the city has resulted in environmental and public health challenges. Unregulated FSM has lead to high pollution of groundwater especially for areas located on dolomite/limestone geology utilising onsite sanitation. In a study on nitrate contamination of groundwater in Lusaka, it was found that the concentration of nitrates and faecal coliforms in groundwater sources for areas sited on dolomitic/limestone geology utilising onsite sanitation facilities for excreta disposal were above the Zambian Standards for Drinking Water as prescribed in ZS 190 (1990), (Tembo et al., 2017). The situation was worse for peri-urban areas whose excreta disposal facilities are pit latrines. Reports on cholera outbreak in 2018 in the city correlated with the same areas. This therefore clearly shows the strong linkage between lack of FSM facilities in peri-urban areas, environmental pollution and the perpetual outbreaks of enteric diseases.

As intimated in section 1.1, one way to improve the management of faecal sludge is to promote usage of faecal sludge derived end products that may transform the sludge into a resource or a raw material. This needs to be backed up by evidence in form of faecal sludge quality data which can serve to inform the potential usage of the sludge. However, this data is currently not available. The problem statement for this study can therefore be summarised as follows:

> "***There is lack of comprehensive scientific data on the quality of faecal sludge from pit latrines to aid the design of measures for enhancing the sanitation value chain and hence contribute to improved sanitation in peri-urban areas."***

This study therefore sought to generate faecal sludge quality data inherent with pit latrines from peri-urban areas of Lusaka.

1.4 Research Questions

The research sought to answer the following questions:

i) What sanitation practices in peri-urban areas impact on faecal sludge quality?

ii) What is the content/concentration of parameters critical to valorisation in the pit latrine faecal sludge;

iii) How do the faecal sludge parameters indicative of biodegradation vary with depth in pit latrines?

iv) Do geological conditions have significant impacts on the quality of the faecal sludge in the latrines? and

v) Based on the faecal sludge quality results, how best can FSM be operationalised in PUA to enhance service provision and hence contribute to improved sanitation provision?

1.5 Hypotheses

This study had four hypotheses as follows:

i) The quality of faecal sludge in pit latrines is significantly affected by sanitation practices employed by the users;

ii) The quality of the raw sludge in the pit latrines has potential for valorisation;

iii) In the pit latrine, parameters linked to biodegradation exhibit a significantly higher degree of stabilisation for bottom sludge compared to top sludge; and

iv) Faecal sludge quality significantly differs for pit latrines located in areas with different geological formations.

1.6 Research Aim

The aim of this study was to characterise pit latrine faecal sludge in order to generate faecal sludge quality data that can be used in the design of intervention measures for enhanced FSM in peri-urban areas. In order to address this aim, four objectives were developed and are presented in Section 1.6.1.

1.6.1 Objectives

i) To establish sanitation practices in peri-urban areas that impact on faecal sludge quality;

ii) To determine the faecal sludge quality characteristics in pit latrines from a valorisation perspective;

iii) To determine whether parameters linked to faecal sludge parameters indicative of the degree of biodegradation differ significantly with faecal sludge depth in pit latrines;

iv) To determine whether faecal sludge quality is significantly affected by geological characteristics of the area; and

v) Based on the findings of the study, to design an operations framework for enhanced FSM in peri-urban areas taking into account the quality and reuse potential of the sludge.

1.7 Significance of the Study

The purpose, to which faecal sludge is put, whether in its untreated or treated form, is dependent on its quality. This study was therefore motivated by the need to generate data on the quality of faecal sludge from pit latrines which is currently not available. Lack of this data negatively impacts on FSM. For example, it is difficult to design faecal sludge treatment facilities without this data (Bassan et al., 2013). At utilisation stage, it is imperative that quality parameters of the faecal sludge are known as the sludge can contain potentially toxic elements. The toxic parameters may be detrimental to both the public health and crops when the faecal sludge is used in agricultural activities (Naveedullah et al., 2013; Usman et el., 2006). In biogas generation, toxic parameters may upset the microbiological process thereby disturbing the methane production processes (Chen et al., 2008).

This study has generated data on pit latrine faecal sludge quality. The generated data will serve as a basis for the design of other intervention measures requiring analytical quantitative data for implementation (Figure 1-3).

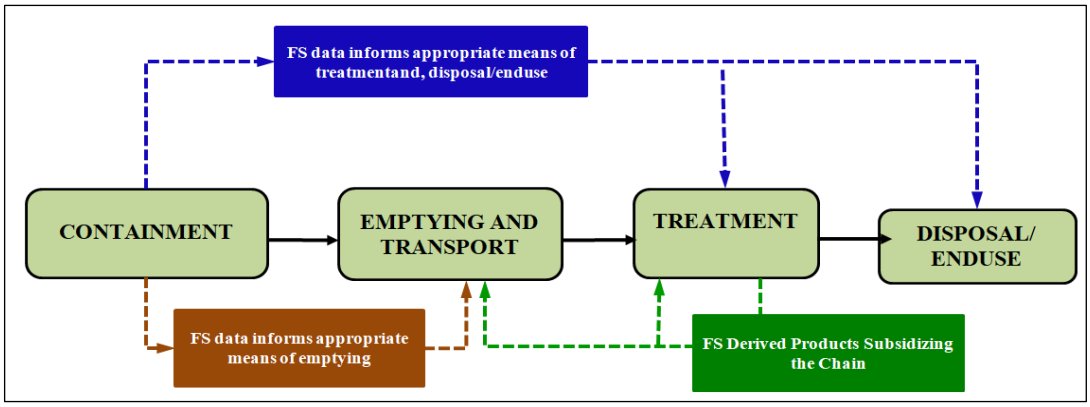


Figure 1-3: How faecal sludge data impacts on the sanitation service chain (Source: Author)

Globally, data on pit latrine faecal sludge characteristics is also not readily available (Strande et al., 2014). The available data, which is mostly from septic tanks, also shows high variability making it difficult to make any comparisons or predictions (Schoebitz et al., 2014; Strande et al., 2014). This is an understood phenomenon as faecal sludge characteristics are dependent on a number of factors including the socioeconomic status of the community and traditions and customs (Esrey et al., 1998). Based on their findings on faecal sludge characteristics in Ouagadougou, Bassan et al. (2013) concluded that faecal sludge estimations and characterisation based on literature is not reliable due to high variability of faecal sludge parameters. They recommended that characterization studies for the local context be conducted prior to designing faecal sludge facilities. Strande et al. (2014) also echo the importance of understanding faecal sludge quality from the local context prior to designing faecal sludge treatment facilities. This study therefore contributes to the knowledge gap on faecal sludge quality characteristics at the local level as well as adding to the global faecal sludge quality database.

Beyond making a contribution to the faecal sludge quality database, the study will also directly and indirectly contribute to the attainment of various global and local pronouncements and strategies. At the global level, the study will contribute to the attainment of Goal 2 of the Sustainable Development Goals (SDG) which aims at achieving food security and improved nutrition and promotion of sustainable agriculture. This will be through the study's push for resource recovery and reuse which in this case has potential to improve food productivity. This will lead to sustainable agriculture in line with the Goal's objectives. The findings of this study

will also contribute to reducing environmental contamination thereby directly contributing to the attainment of Goal 3 target 3.9 of the SDGs which talks of substantially reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination. The study will also contribute to the attainment of Target 2 of the Goal 6 which partly aims to improve access to adequate and equitable sanitation and hygiene for all and end open defecation. It also responds to the need for addressing some of the challenges highlighted in the Africa Water Vision for 2025 one of which is on inadequate sanitation provision. The Africa Water Vision 2025 aims at increasing access to basic sanitation to at least 95 percent of the continents population. The anticipated improved sanitation that the study aims at fostering will also contribute to the attainment of Goal 11 whose aim is to make cities and human settlements inclusive, safe, resilient and sustainable. This is especially the case from the perspective of Target 11.6 which aims at reducing the per capita environmental impacts of cities partly through municipal and other waste management initiatives since this study aims at improving the management of faecal sludge in peri-urban areas which is currently an environmental and public health nuisance.

At the local level, the study will contribute to almost all the visions, policies and strategies that have been put in place with regards sanitation. For example, Vision 2030 talks of improving access to appropriate, environmental friendly sanitation by all Zambians with a target of at least 90 percent having access by 2030. The National Urban Sanitation Strategy (MLGH, 2015) aims to "provide adequate, safe and cost-effective sanitation services to 90 percent of the urban population by 2030" with some of its objectives being: to improve access to adequate and safe sanitation; to manage sanitation facilities so as to reduce the incidence of water and vector-borne diseases and parasitic infestations; and to mitigate environmental degradation, through safe disposal of wastewater and sludge. The study, through the data generated and some proposed recommendations will contribute to all these pronouncements ultimately contributing to improved sanitation in peri-urban areas of the city.

1.8 Conceptual Framework

A conceptual framework can be viewed as an analytical tool with several variations and contexts used to make conceptual distinctions and organize ideas. Several scholars have defined conceptual framework differently although the general meaning, to some extent, is the same. For example, Shields and Rangarajan (2013), in their book entitled *"A Playbook for Research Methods: Integrating Conceptual Frameworks and Management"*, define a conceptual framework as "the way ideas are organized to achieve a research project's purpose." Miles and Huberman (1994) define it as a visual or written product, one that "explains, either graphically or in narrative form, the main things to be studied including key factors, concepts, or variables and the presumed relationships among them". Based on these definitions, a conceptual framework of the study was designed (Figure 1-4).

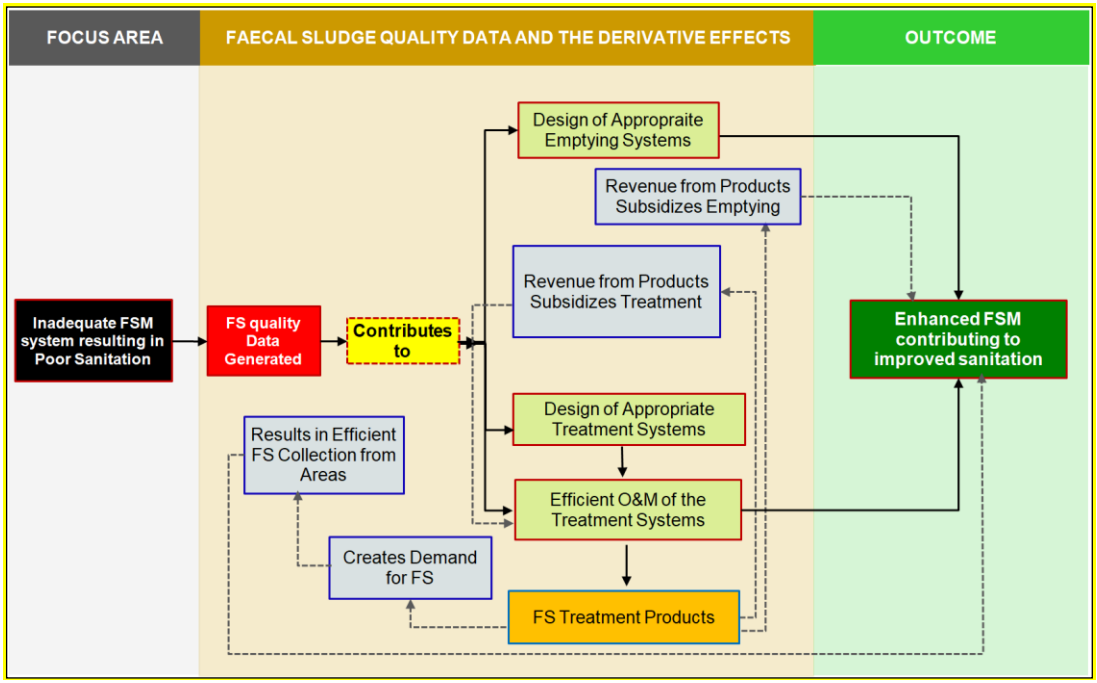


Figure 1-4: Conceptual Framework for the study (Source: Author)

The framework presented in Figure 1-4 highlights interactions between availability of faecal sludge quality data and its derivative "products" including how these relate to each other to ultimately generate the desired outcome. The assumptions are that with the generated faecal sludge quality data, appropriate means of desludging will be designed. The design, together with the operational and maintenance aspects of the treatment plants will also be enhanced. These will directly lead to improved FSM ultimately contributing to improved sanitation provision.

As FSM is resource recovery oriented, there will be generation of bye-products at the treatment stage including biogas and treated faecal sludge. These bye-products if well marketed have the potential to generated income which can subsidise the desludging and treatment costs of the faecal sludge. Generation of the bye-products may also positively contribute to the adequate and efficient collection of the faecal sludge from the areas of generation. This is because there will be demand for faecal sludge as a raw material or feedstock in the treatment process. Ultimately, this will lead to improved collection of the faecal sludge from the areas of generation leading to improved sanitary conditions in the areas of generation.

1.9 Theoretical Framework

The theoretical framework for this study is anchored on the Theory of Waste Management (TWM). Pongrácz et al. (2004) present the TWM as "*a unified body of knowledge about waste and waste management, and it is founded on the premise that waste management is intended to prevent waste from causing harm to human health and the environment and promote resource use optimization*." Pongrácz further indicates that the TWM is based on the hypothesis that: "*the way we describe a target prescribes action upon it."* This means the way we view a waste product will determine measures we put in place for its management. Relating this hypothesis to faecal sludge implies that viewing the sludge as a waste would offer disposal as the only means for its management whereas viewing it as a resource brings in a wide array of options.

It has been established that the majority of the urban population in most Sub-Sahara African countries are exclusively serviced by onsite systems (Strande et al., 2014) which implies high faecal sludge generation rates. Yet, less than 20 percent of this waste is safely collected and treated before disposal (WWAP, 2009). In their research on FSM in 12 cities, Blackett et al. (2014) concluded that only 22 percent of the faecal sludge generated is safely disposed of. This implies that this waste ends up in the environment contributing to pollution. Diener et al. (2014) submit that the lack of financially viable options in FSM is a major hindrance to service provision. This has resulted in a situation where when the need to have a latrine desludged arises, the pit owner has to fund the full cost associated with the full faecal sludge service chain (Figure 1-5), making the service very expensive. From the context of

the TWM, the high cost of the service can be attributed to the definition that has been assigned to the faecal sludge which in this case is 'waste'. With this definition, the only means available for the management of this sludge is disposal.

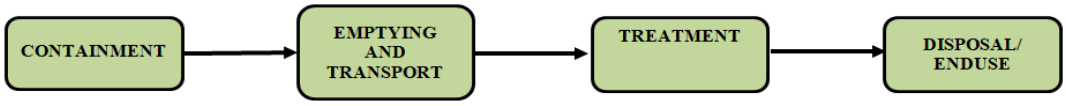


Figure 1-5: The faecal sludge service chain (Adapted from WSP, 2014)

Unarguably, new paradigms are required to change this atrocious sanitation situation. Diener contends that solving the current sanitation problem requires innovative approaches in infrastructure, technology and cost recovery. Murray and Ray (2010) suggest that sustainable provision of sanitation services would be greatly enhanced if the design and operation of FSM systems incorporate resource recovery which is also advocated by the TWM. They suggest that reuse-oriented sanitation would not only help to achieve environmental sustainability, but would also lead to long-term operational and financial sustainability which would mainly be due to subsidization of the chain from waste derived products. This assertion is also supported by other scholars including Diener et al. (2014) and Bates (2007) and no contrary views to this have been encountered in this study.

There is need to always consider Enduse Industries in the design of FSM systems when resource recovery is an underpinning factor in the design (Diener et al., 2014). The idea is to ensure that the sludge generated is taken as a resource by enduse stakeholders thereby ensuring a ready market for its disposal thereby subsidizing the sanitation service chain (Figure 1-6). Semiyaga et al. (2015) indicates that identifying small usages of faecal sludge in peri-urban areas can result in faecal sludge switching from being a management problem to a raw material for valuable products.

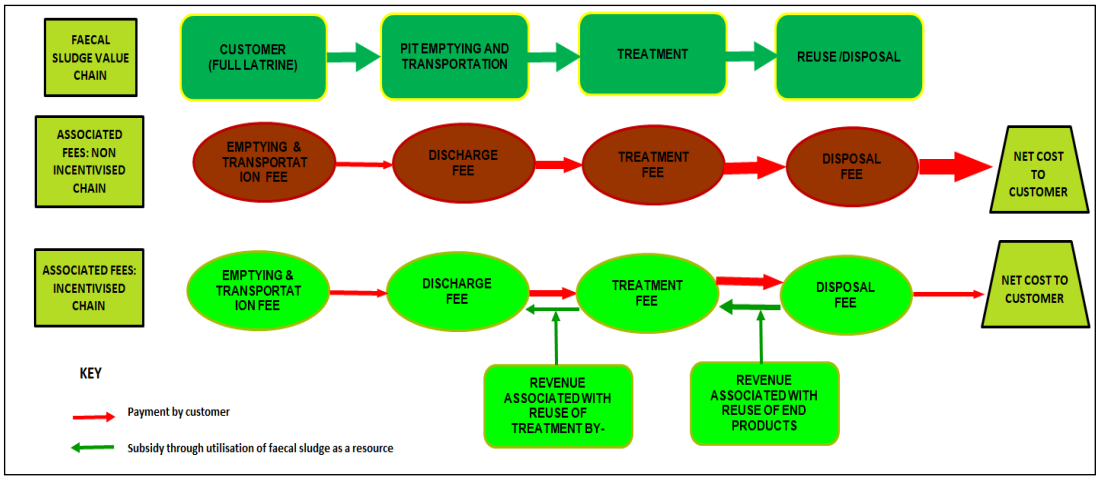


Figure 1-6: Comparison in faecal sludge management fees for a non incentivized and an incentivized faecal sludge value chain (Adapted from Strande et al., 2014).

All literature on this subject is generally in agreement with each other. All suggest that FSM service provision that also incorporates resource recovery strategies would be more sustainable. In line with the TWM, it means viewing the faecal sludge as a resource as opposed to a waste product would greatly enhance FSM services provision. A number of factors are essential for this proposition to work and one of them is the faecal sludge quality data. This data is important at all stages of the chain for effective utilisation of the sludge by Enduse Stakeholders. Murray and Ray (2010) states that: *"To capture back-end user demand requires targeting potential customers before the system is designed and tailoring sanitation schemes such that the outputs meet the specific needs of those customers in terms of their final location, quality, and state"*. From this statement, it is evident that faecal quality determination is an important aspect in the FSM paradigm aimed at generating waste-derived end-products as it brings out the quality aspect of the faecal sludge and its derived end-products. It is also a take-off point for the design of appropriate measures for enhanced FSM service provision.

Based on this theory and literature from other scholars, a theoretical framework for this study, in relation to how an understanding of the faecal sludge quality would enhance FSM and ultimately, sanitation service provision was designed and is presented in Figure 1-7. The framework is anchored on the TWM and has three main pillars namely: the quality aspects; the FSM chain; and the perceived benefits, all which have been discussed from the perspective of quality as it relates to use and reuse optimization.

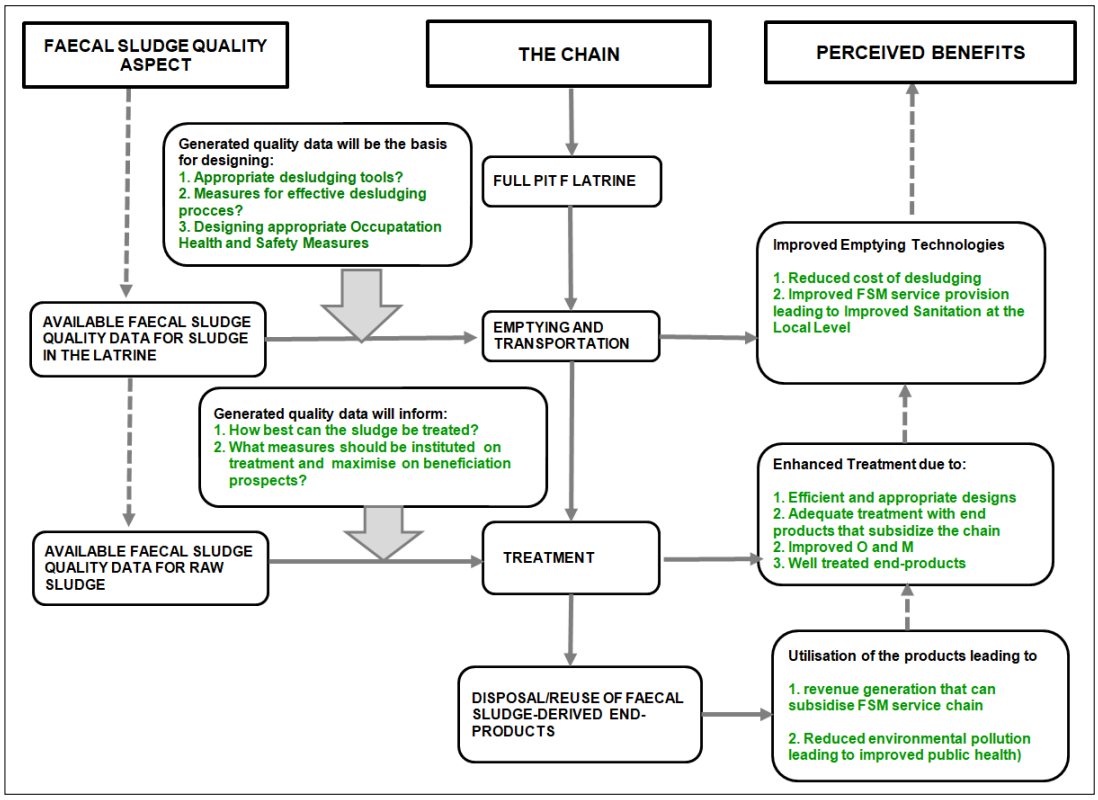


Figure 1-7: Theoretical Framework anchored on the TWM (Source: Author)

This framework (Figure 1-7) suggests that availability of faecal sludge quality data would enhance FSM service provision in peri-urban areas and consequently contribute to improved sanitation provision.

1.10 Scope of the Study

The study was restricted to peri-urban areas in the city of Lusaka. Four settlements within Lusaka namely Chaisa, George, Madimba and Kanyama were used as study areas. The sanitation facilities that were adopted for the study were restricted to single pit latrines.

The study partly aimed at establishing the faecal sludge quality characteristics with respect to resource recovery. This means parameters analysed were those relevant to valorisation prospects including parameters that affect the process of desludging. These parameters are presented in Table 1-2.

Table 1-2: Parameters adopted for characterisation

Category	**Parameter**
Rheological	Shear Stress and Viscosity
Physical	Density, Total Solids and Total Volatile Solids (TVS), Moisture content
Chemical	pH, Ammonia, Sulphates, Ortho- Phosphates, Total and Soluble Chemical Oxygen Demand (COD)
	Light Metals (Potassium, Sodium, Calcium and Magnesium)
	Heavy Metals (Iron, Cobalt, Copper, Lead, Chromium, Zinc and Cadmium)
Microbiological	Faecal Coliforms, *Ascaris*, *Cryptosporidium*, Total Biochemical Oxygen Demand (BOD)

All the samples were collected in the dry seasons of 2016 and 2017. Samples for physical, chemical and microbiological parameters were collected between July and October, 2016 while those for rheology were collected in July of 2017. The study also had an aspect of data collection from stakeholders especially the users of the facilities. Respondents for this aspect were restricted to those within the study areas and required data from the respondents was collected during the same period sampling for physical, chemical and microbiological parameters was being conducted.

1.11 Ethical Considerations

The study involved administering questionnaires to participants with the aim of soliciting data on pit latrine design, construction and utilization. It also involved the collection of faecal sludge samples from private latrines. Before the commencement of the study, all the participants were therefore informed about the study process. The objectives of the study were clearly presented to the participants and they were clearly informed of the fact that their participation in the study was on a voluntary basis. In order to conceal their identity, identification of all questionnaires together with the latrines that were sampled was through codes rather than names.

In order to protect both the workers and residents from contamination of areas due to sampling activities, a protocol of ensuring adequate sanitization of the area after sampling was developed which included: ensuring the latrine was adequately cleaned with water and then disinfected; and ensuring all the equipment used and the

areas around the latrine were disinfected after the sampling was completed. Finally, all laboratory analysis on the faecal sludge was done following standard protocols to ensure that all people working on the samples were not exposed to risks associated with faecal sludge.

1.12 Study Assumptions

In the execution of the field work and ultimately, the synthesis of this thesis, two critical assumptions were made as follows:

- The socio-cultural and sanitation practices were the same for all the selected study areas and hence there was no need analyse include this dimension in the determination of the faecal sludge quality data for this study; and
- The sanitation practices in the study areas did not change with time.

1.13 Study Limitations

The study involved field and laboratory work. Due to the nature of the study which aimed at characterizing faecal sludge which is a relatively new field, a number of challenges were encountered as follows:

- Some parameters including Total and Kjedahl Nitrogen, Nitrates and Calorific parameters that would have been informative to the study could not be analysed due to lack of facilities;
- In some cases, it was impossible to collect samples from facilities due to the way the facilities were constructed which could not allow entry of the sampling tool into the pit. This was mostly due to small pit openings;
- The research design aimed at selecting facilities that would be available throughout the research period. However, some latrines got demolished, buried or modified during the study period making it impossible to maintain them as sampling points for the whole duration of the study; and
- Due to limited resources, the study could not be conducted to take seasonal variations into account. It was confined to the dry season only.

1.14 Structure of the Thesis

This thesis comprises six chapters as follows:

Chapter 1 – Introduction: Introduces the research background, problem statement, rationale, research questions, hypotheses, aim and objectives, conceptual and theoretical frameworks, and scope.

Chapter 2 – Literature Review: Gives a detailed review of literature focusing on the various aspects of sanitation and FSM from the general perspective and then from the Zambian context. The Chapter also reviews literature on pit latrine and associated factors that affect the processes and ends with a summary on reuse aspects of faecal sludge.

Chapter 3 – Research Methodology: Outlines the philosophical orientation of the research, articulates the research design and the methodology adopted.

Chapter 4 – Results: Presents the findings of the study in line with the outlined objectives.

Chapter 5 – Discussion: Discusses the findings of the study. Each finding is rigorously analysed relating it to existing literature where available and discusses possible reasons for results not in agreement with existing phenomena.

Chapter 6 – Conclusions and Recommendations: Presents the conclusions and recommendations arising from the key findings of the study.

1.15 Chapter Summary

This chapter set out to put the study in context. It therefore provided a background to the areas of research and provided a clear research problem that required to be addressed. The chapter also provided the conceptual and theoretical frameworks upon which the study is anchored. Research questions, hypothesis and objectives were outlined providing a contextual setting of the study. The following chapter provides a review of literature critical to the study.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This Chapter presents literature reviewed relevant to the study. It first highlights general aspects of sanitation and its level of coverage at both global and local levels including requisites for the design of responsive FSM systems. It then proceeds to delve into aspects of FSM and faecal sludge characterisation. Since a major component of the study was on faecal sludge characterisation from pit latrines, a section looking at a pit latrine and processes that occur therein follows. Towards the end, the chapter presents literature on aspects of faecal sludge valorisation especially from the context of biogas generation and application in agricultural activities.

2.2 General sanitation aspects

Generally, sanitation refers to the hygienic means of promoting health through breaking the contact route between humans and hazardous wastes. Hazards here can be physical, chemical, biological or microbiological. A publication by the Government of the Republic of Zambia (GRZ, 2015) defines sanitation as: *"the safe collection, containment, transportation, treatment and disposal or reuse of human excreta, domestic liquid waste and industrial effluents".* The World Health Organization (WHO) refers to it as: *"the provision of facilities and services for the safe disposal of human urine and faeces"*. WHO also further defines 'sanitation' as: *"the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal."* It further states that sanitation includes not only engineering infrastructural aspects for excreta management systems but also wastewater management systems; solid waste management systems; and storm water drainage (WHO, nd). In some cases, researchers confine the term 'sanitation' to excreta management. In such situations, sanitation may be defined as the maintenance of hygienic conditions through proper treatment and disposal of excreta where excreta is a combination of urine and faeces (Shubhra et al., 2017).

However, whichever definition is used, it is obvious that sanitation aims at breaking the diseases transmission routes between the hazard and the host. With respect to excreta, which is the focus of this study, sanitation systems aim at forming barriers

against the spread of diseases caused by pathogenic microorganisms found in human excreta.

2.3 Sanitation: A global perspective

The proportion of the population gaining access to sanitation has continued to increase globally. Worldwide, around 68 percent of the world's population had access to improved sanitation facilities in 2015 compared to only 54 percent in 1990 (WHO, 2016). However, the recorded progress fell short of meeting the 2015 Millennium Development Goal (MDG) target to halve the proportion of the population without access to improved sanitation facilities by almost 700 million people (WHO, 2016; UNICEF, 2016). According to the report by WHO/UNICEF (2015), around 2.4 billion people still remained without access to safe sanitary facilities by the end of 2015.

It has also been observed that improvements in sanitation exhibit huge disparities at both the regional and local levels. Sub-Sahara Africa has recorded the least improvements. As of 1990, world sanitation coverage was about 52.9 percent while that for Sub-Saharan Africa and Southern Asia was at 24 and 22 percent, respectively. By 2015, coverage in Southern Asia had more than doubled to 47 percent while that for Sub-Saharan Africa only rose to 30 percent (WHO, 2016) as graphically presented in Figure 2-1.

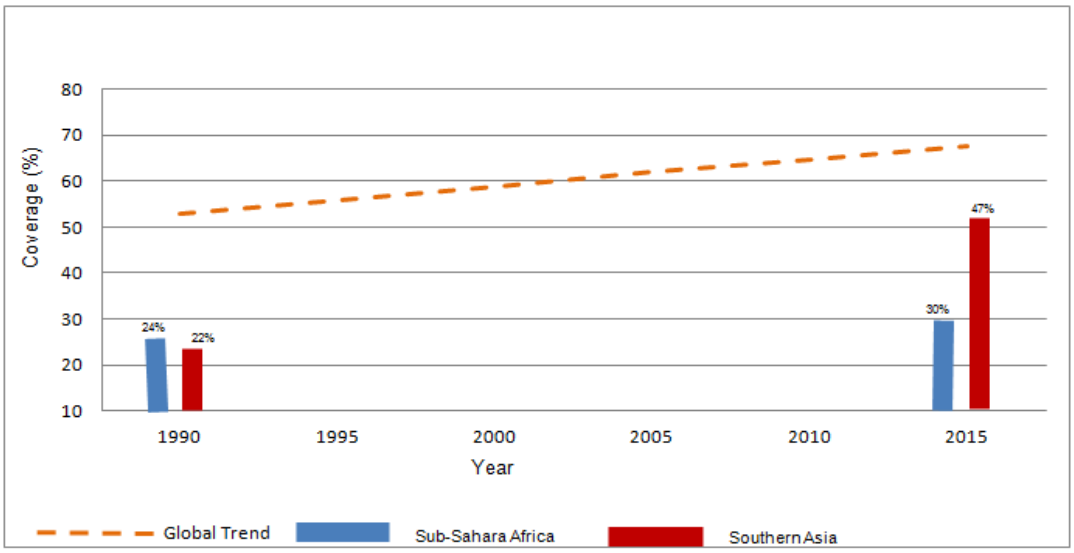


Figure 2-1: World and Regional Sanitation coverage between 1990 and 2015 (Source: WHO, (2016))

It should however be mentioned that in the majority of cases, improved sanitation is measured only by access to a sanitary facility. It does not look beyond what happens to the faecal sludge that accumulates in the facilities which O'Riordan (2009) refers to as "The full excreta storage dilemma". Peal et al., (2014) also contend that measuring sanitation through assessment of sanitation facilities alone conceals some important aspects critical to sound sanitation provision in residential areas including the fact that in most cases, even in areas where the facilities are categorised as "improved facilities", downstream management of the faecal sludge is severely neglected. Therefore, improved sanitation measured only from the perspective of containment structures may not be a sustainable solution in itself to improved sanitation.

2.4 Sanitation Status in Zambia and in the project area

As is the case with most countries in Sub-Saharan Africa, sanitation provision has continued to be a source of concern in Zambia. According to the Sixth National Development Plan (SNDP, 2011), the inadequate growth-enhancing infrastructure with respect to sanitation is one of the issues that have continued to afflict the health of the country's population, productivity and competitiveness of the country's economy. Some of the major contributing factors to this include (GRZ, 2015):

- Urbanization;
- Rapid population growth; and
- Inadequate planning.

According to WHO/UNICEF (2015), only 31 percent of the country's population had access to at least basic sanitation service as at 2015. The report also indicates that access by the urban population was considerably higher (at 49 percent) in comparison to access by the rural population (at 19 percent) with 15 percent still practicing Open Defeacation (OD). Assessments in most of the country's cities have revealed low coverage of less than 40 percent (GRZ, 2015).

The majority of the excreta disposal facilities in the country are onsite. For the study area, the city of Lusaka, onsite facilities serve an estimated 76.4 percent of the city's population (Figure 2-2).

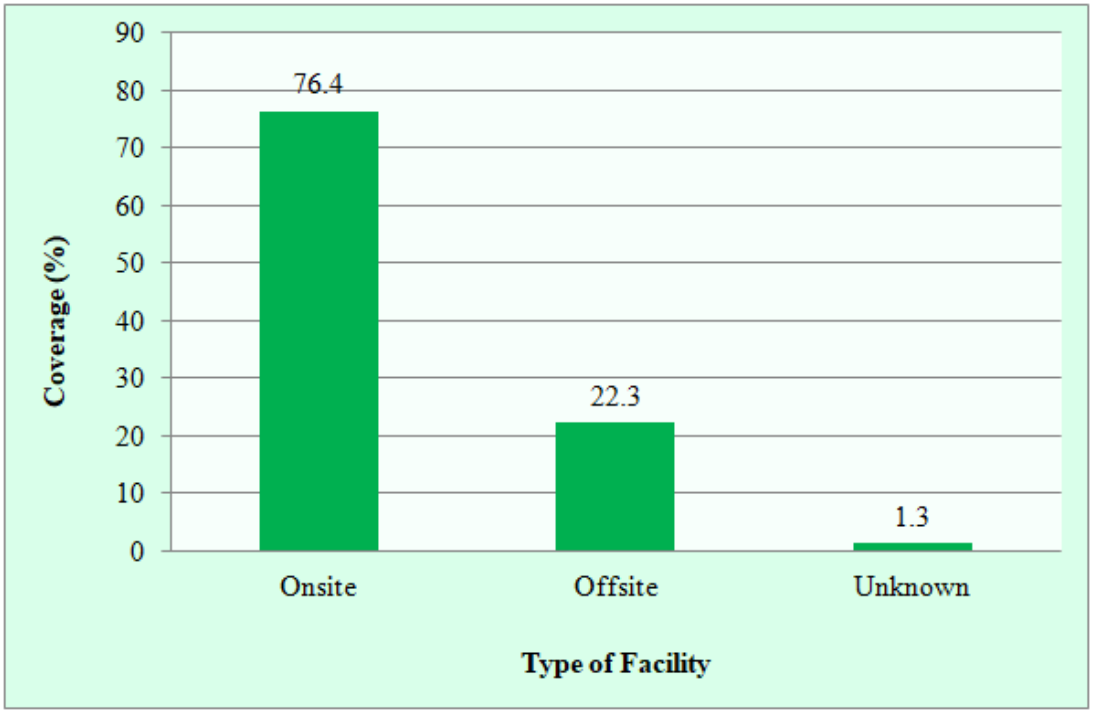


Figure 2-2: Sanitation facilities in the city of Lusaka (Source: Adapted from SMP, 2011)

The majority of the onsite facilities in the city are ordinary pit latrines which service 61.3 percent of the city's population (SMP, 2011). In peri-urban areas of the city, unimproved pit latrines service over 90 percent of the people (SMEC, 2016). The implication of this scenario is that a huge quantity of faecal sludge is generated in the city especially in peri-urban areas (refer to section 1.2).

2.4.1 Institutional and regulatory framework for sanitation provision in peri-urban areas of Zambia

Provision of sanitation in peri-urban areas is a matter that is dealt with by a number of institutions and organizations. These include:

- Ministry of Finance (MoF);
- Ministry of Water Development, Sanitation and Environmental Protection (MWDSEP);
- Ministry of Local Government (MLG);
- Ministry of Health (MoH);
- Ministry of Community Development and Social Services (MCDSS);
- Ministry of General Education (MOGE);
- National Water Supply and Sanitation council (NWASCO);
- The Local Authorities;

- Commercial Utilities (CUs);
- Zambia Environmental Management Agency (ZEMA)
- Devolution Trust Fund (DTF); and
- Local Level Organisations.

Each of these entities plays one or more distinct roles in sanitation provision in peri-urban areas which fall under the broad categories of financing, policy regulation/monitoring or service provision. Figure 2-3 below presents synergies and interactions among the above identified stakeholders.

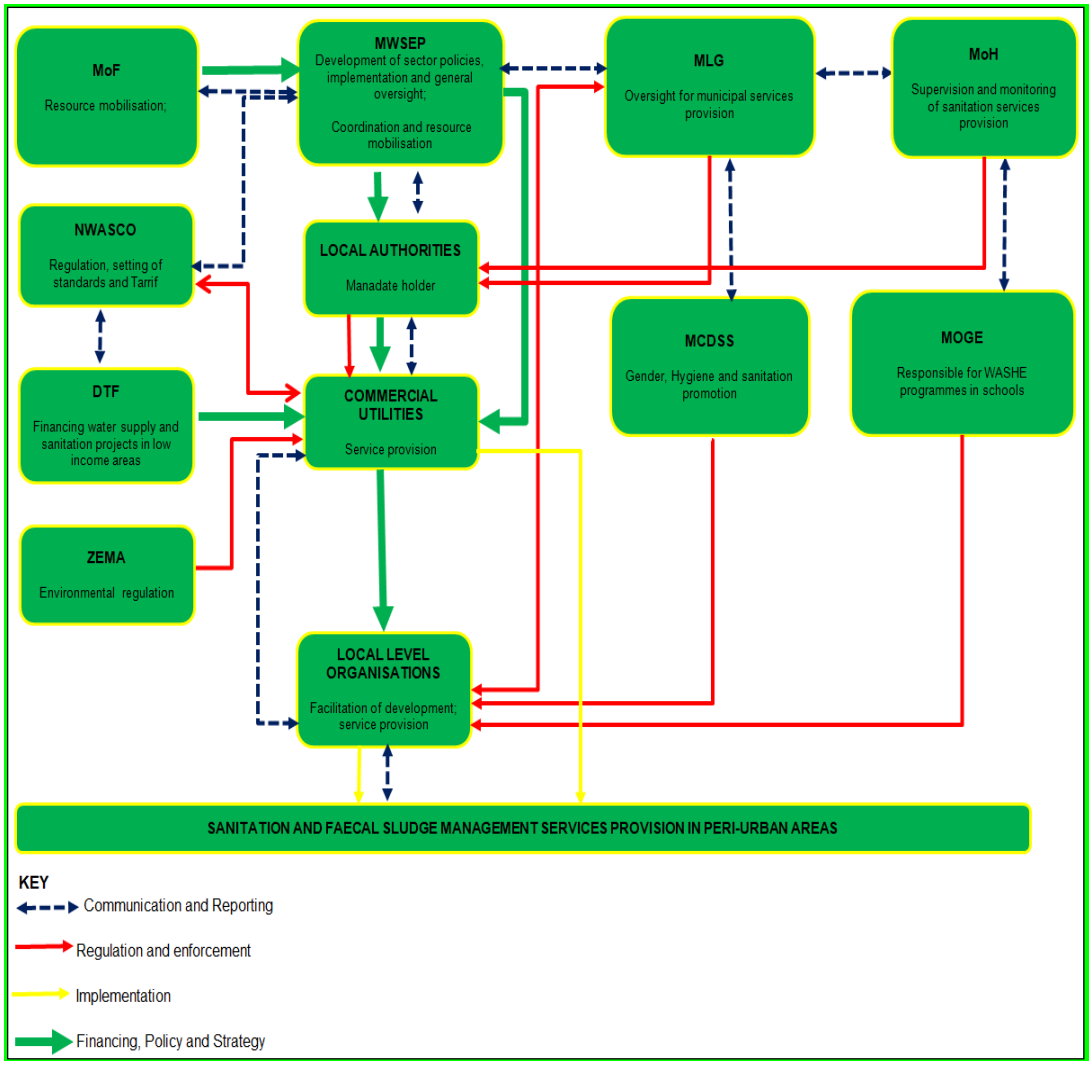


Figure 2-3: Institutional synergies in sanitation provision in peri-urban areas (Source: Adapted from GRZ, 2015)

The roles and responsibilities of each of the stakeholders from the perspective of sanitation provision in peri-urban areas is summarised in Table 2-1.

Table 2-1: Functions of stakeholder ministries and institutions in Sanitation provision in peri-urban areas

Name of Ministry /Institution	**Roles and responsibilities**
Ministry of Finance	Mobilises resources for sanitation provision and also manages the Government's budget for supporting infrastructure development and other activities to promote improved sanitation. The ministry therefore directly or indirectly supports sanitation projects in peri-urban areas through project financing.
Ministry of Water Development Sanitation and Environmental Protection	New Ministry created for the development and management of the water resources. The ministry is responsible for providing policy guidance in the water and environment sectors of the country and provides general oversight of the sectors.
Ministry of Local Government	Providing an oversight for the provision of municipal services
Ministry of Health (MoH)	• Works in close collaboration with the MLG on matters relating to public health in urban areas • Promotes provision of improved sanitation and hygiene behaviours. • Through the public health departments of the local authorities, upholding acceptable standards and general sanitary supervision and monitoring in line with the Public Health Act. CAP 295
Ministry of Community Development and Social Services	• Focuses on the needs of woman and children, and other vulnerable or marginalized groups • Promotes improved hygiene behaviours through community health workers and the Water Sanitation and Hygiene Education (WASHE) Committees Peri-urban areas are considered vulnerable and hence the ministry comes in on aspects of sanitation and hygiene promotion in these areas
Ministry of General Education	• Responsible for the WASHE Programmes, which focus on improved sanitation in schools • Promotes the involvement of school children in hygiene promotion activities

Table 2-1: Continued

Name of Ministry /Institution	**Roles and responsibilities**
National Water Supply and Sanitation Council	• Under the Water Supply and Sanitation Act 1997, mandated to advise, license and regulate sanitation services. Functions include: - ▪ Providing for the establishment, by local authorities, of water supply and sanitation utilities ▪ Providing for the efficient and sustainable supply of water and sanitation services under the general regulation of the body; ▪ Providing for matters connected or incidental to the foregoing; and ▪ Regulating the CUs with the aim to improve delivery, efficiency and sustainability of water supply and sanitation services.
Local Authorities	• Under the direction of MLG, Local Authorities are mandated to enforce the Ministry of Health regulations and, development of bi-laws on sanitation service provision through the Public Health Departments; • Also mandated to enforce and regulate sanitation relevant laws provided for by the Public Health Act including aspects of Latrine provision; • Regulation of collection, transportation and treatment of wastewater; and • Service provision related to the quality of the urban environment and therefore has a broader responsibility for sanitation that also includes solid waste management and storm water drainage.
Commercial Utilities	• Formed through the Water Supply and Sanitation Act (1997) which empowers local authorities to form water and sewerage companies under the Companies Act (1964) and the Companies Act (Amendment) CAP 388; • Operate along commercial principles for the provision of water and sanitation services; and • Their area of jurisdiction is referred to as the "Sanitation Service Area" and is prescribed by the operators' license provided by NWASCO.
Zambia Environmental Management Agency	• Responsible for applying the legal framework for the protection of the environment and the control of pollution; and • Under the Environmental Management Act No 12 of 2011, ZEMA regulates discharges into the environment and promotes water pollution monitoring and prevention programmes based on enforceable water quality guidelines and standards.

Table 2-1: Continued

Name of Ministry /Institution	**Roles and responsibilities**
Devolution Trust Fund	Responsible for funding water supply and sanitation projects in low income areas
Local level institutions (e.g.	• Responsible for facilitating developmental projects in beneficiary areas • Links funding institutions to the communities in beneficiary communities

Source: Compiled by author

2.4.2 Policy Framework, Visions and Strategies and Legal Framework for the provision of Onsite Sanitation and FSM Services

Sanitation provision in Zambia is guided by policies, plans, strategies and laws as briefly summarised below. It should be noted that the presentation in this section is skewed towards onsite sanitation and FSM to which the study was inclined.

2.4.2.1 Policy Framework, Visions and Strategies

Policies, plans and strategies exist that guide the provision of sanitation services in Zambia. However, with respect to onsite sanitation and FSM especially in relation to peri-urban areas, most of them are only applicable in the general context of sanitation (Holm et al., 2015) although initiatives are currently in place to incorporate aspects of onsite sanitation and FSM in the existing strategies as well as developing new and responsive frameworks. Applicable policies, visions and strategies include:

i. The 2004 National Decentralisation Policy;
ii. The Gender Policy;
iii. The Seventh National Development Plan (SeNDP);
iv. Vision 2030; and
v. The National Urban and Peri-urban Sanitation Strategy.

The sections below explain how each of the above policies apply to onsite sanitation and FSM.

i. The National Decentralisation Policy

The National Decentralization Policy (developed in 2002, launched in 2004) aims at decentralizing government responsibilities and functions to lower level government through "devolution". It reaffirms the local authorities as the institutions responsible for water supply and sanitation. This means the Local Authority is responsible for all sanitation aspects in peri-urban areas hence regulation and monitoring of onsite sanitation and FSM facilities is an aspect that falls within the mandate of the Local Authorities. However, it should be pointed out that the excreta management part of the sanitation is an aspect that is in the process of being transferred to the water utilities. New strategies on the operationalisation of this approach are currently under development.

ii. The Gender Policy

From time to time, government has been making attempts to mainstreaming gender in the different sectors in the country. In the 1980s, government adopted the Women in Development (WID) approach as a framework to incorporate gender issues in its developmental activities. In 1996, this approach was changed to Gender in Development Division (GIDD). In the year 2000, government launched the National Gender Policy which to date serves as a gender mainstreaming institutional framework for government ministries. In the year 2006, the government established the Ministry of Women's Affairs which was later changed to Ministry of Gender and Development to oversee the gender mainstreaming activities in the country.

This is a very important policy in sanitation especially in peri-urban areas where such issues are handled by communities. Women are very instrumental in most community projects and their involvement in sanitation provision is cardinal. With respect to onsite sanitation and FSM, private entrepreneurs are and will continue to be key players in this sub-sector (LWSC, 2017). This policy therefore guides the establishment and operations of such enterprises to ensure that women are not marginalized.

iii. Seventh National Development Plans

The Ministry of National Development Planning (MNDPF) developed the Seventh National Development Plan (SeNDP) which contains a chapter on water and

sanitation. The Plan states in part that: *"Access to water and sanitation services by all segments of the population is a key component of all aspects of sustainable development and this challenge becomes more important when the population growth by 2030 is factored in. All sectors require access to adequate water and sanitation services for their productivity to be enhanced."*

The SeNDP also identifies poor water supply and sanitation conditions as major contributors to the burden of disease and therefore advocates for increased levels of access to clean and safe water and sanitation services for people in rural and urban areas. In order to attain this aspiration, the SeNDP has devised strategies to facilitate water and sanitation services provision including:

- Enhancement of the provision of adequate safe water and sanitation;
- Improving availability of water and sanitation infrastructure;
- Enhancement of research in water supply and sanitation services; and
- Promotion of alternative financing mechanisms for water and sanitation.

The above strategies touch on all the important aspects of sanitation and FSM services provision in peri-urban areas. The aspect on enhancing research is what is partly being addressed by this study.

iv. Vision 2030

The Vision aims to provide secure access to safe potable water sources and improved sanitation facilities to 100 percent of the population in both urban and rural areas by the year 2030. Under sector goals, the Vision's aims relevant to sanitation are the following:

- Improve access to appropriate, environmental friendly sanitation by all Zambians; and
- Attainment of 68 percent access to sanitation to all by 2015 and 90 percent by 2030.

From the perspective of these goals, the vision therefore buttresses introduction of appropriate onsite sanitation technologies especially in peri-urban areas and also supports the promotion of FSM systems which are a requisite for improved sanitation in these areas.

v. The National Urban and Peri-urban Sanitation Strategy

The National Urban Sanitation Strategy aims to provide adequate, safe and cost-effective sanitation services to 90 percent of the urban population by 2030. In order to achieve this goal, the strategy has the following specific objectives:

- To improve access to adequate and safe sanitation;
- To manage sanitation facilities so as to reduce the incidence of water and vector-borne diseases and parasitic infestations;
- To promote improved hygiene practices (including menstrual hygiene management); and
- To mitigate environmental degradation, through safe disposal of wastewater and sludge.

The strategy identifies three action areas that need interventions for the enhanced implementation namely:

- Governance and institutional capacities at national, local and community levels;
- Legal and regulatory frameworks; and
- Mainstreaming of cross-cutting issues.

This strategy directly addresses the challenges of sanitation provision in peri-urban areas which were not addressed in earlier policies and other initiatives. It is a well known phenomenon that sanitation improvement especially with regards faecal sludge management requires an enabling environment (Luthi, 2011; Strande, 2014). This strategy takes cognisance of this requirement and provides for it through its action areas.

2.4.2.2 Legal Framework

Acts exist that guide the provision of sanitation services. Like policies and strategies, most of them are only applicable in the general context of sanitation provision. Applicable Acts include:

i. Environment Management Act of 2011;
ii. Water Resources Management Act of 2011;
iii. The Water Supply and Sanitation Act No. 28 of 1997;
iv. Public Health Act (CAP 295);

v. National Health Services Act (CAP 315); and

vi. Local Government Act (CAP 281).

The sections below explain how each of the above Acts applies to onsite sanitation and FSM especially as regards peri-urban areas.

i. Environment Management Act of 2011

The Act provides for the protection of the environment and the control of pollution. Under Section 24, the Act prohibits any person from polluting the water by discharging effluent or wastewater. It states that no person may discharge or apply any poisonous, toxic, obnoxious or obstructing matter, radiation or other pollutant or permit any person to dump or discharge such matter or pollutant into the aquatic environment in contravention of water pollution control standards established or prescribed by the Agency under this Part.

Indiscriminate disposal of waste is also prohibited by the Act under Section 50. It states that no person shall discharge waste so as to cause pollution in the environment. It further states that no person shall transport waste to any site other than in accordance with a license and to a disposal site established in accordance with a license. It also states in the amendment contained in Environmental Protection and Pollution Control (Amendment) Act No. 12 of 1999 that a person shall not operate a waste disposal site or plant or generate or store hazardous waste without a permit or license.

Based on these pronouncements, the emptying and transportation of the faecal sludge from pit latrines including the operations of FSM facilities and the ultimate disposal of the sludge are aspects that have to conform to this act.

ii. Water Resources Management Act of 2011

The Act establishes the Water Resources Management Authority and defines its functions and powers. It also repeals and replaces the Water Act of 1949. The Act consolidates and amends the law in respect of the ownership, control and use of water. It gives direction on the use, diversion and apportionment of water in the country. Of significance to onsite sanitation, especially desludging is the paragraph that reads:

"*Under this Act, any person who wilfully or through negligence pollutes or fouls any public water so as to render it harmful to man, beast, fish or vegetation shall be guilty of an offence and liable to a fine or imprisonment. It also empowers the Water Officers to call upon the person responsible therefore to take adequate measures to prevent such fouling or pollution within a specified period."*

On the aspect of desludging, if disposal of the contents is indiscriminate, the potential to pollute the water bodies becomes a reality. As such, all pit emptying practices including the disposal of the sludge are aspects that need to conform to this Act on the aspect of pollution abatement.

iii. The Water Supply and Sanitation Act No. 28 of 1997

This Act provides for the establishment of the National Water and Sanitation Council (NWASCO) which acts as a regulator in the provision of water supply and sanitation services. The Act mandates NWASCO to regulate the sector in a manner leading to improved delivery, efficiency and sustainability. The Act requires NWASCO to disseminate information to the public on matters relating to water supply and sanitation services. NWASCO would therefore regulate all desludging activities in areas that fall within the jurisdiction of the water utilities. This means most of these activities (emptying) would have to be regulated by NWASCO as peri-urban areas fall within the jurisdiction of the water utilities.

iv. Public Health Act (CAP 295)

The Act provides for the prevention and suppression of diseases and generally to regulate all matters connected to public health in Zambia. The Local Authority of any area is empowered by the Act to do and provide all such acts, matters and things as may be necessary for mitigating any disease, or aiding in the execution of regulations, or for executing the same, as the case may require. The duties of Local Authorities include maintenance of cleanliness and prevention of nuisances including those arising from unsuitable dwellings. Ideally, this means that all aspects of FSM should be operated in accordance with the stipulations of this Act. Currently, it is common to have the pit contents/septage ending up within the residential environment especially were the emptying is done informally.

v. National Health Services Act (CAP 315)

The Act established the Central Board of Health (CBoH) and provided for the procedures for establishing management boards for hospitals and health services. The Act defines functions and powers of such boards and their relationship and to provide for matters connected to or incidental to the foregoing. Where any Local Authority fails to deal with any outbreak or prevalence of any infectious, communicable or preventable diseases, the Board is mandated to take over the functions of the Local Authority in relation to public health and in such a case, will have all the powers of such a Local Authority as provided for under the Public Health Act. This Act therefore is significant to onsite sanitation and FSM as highlighted under the Public Health Act above.

vi. Local Government Act (CAP 281)

This Act provides for the establishment of Councils in districts which function as Local Authorities. The Act defines the functions of Local Authorities. Some of their functions relate to control of the development, use of land and buildings, erection of buildings, conservation of natural resources, prevention of soil erosion, protection of life, property and natural resources from damage by fire, control of grass weeds and wild vegetation, and maintenance of environmental health services. Other functions include control of the storage, sale and use of petroleum products, extermination of insects, rodents and snakes, dealing with all kinds of refuse and effluent, controlling the provision of drains and sewers, and conservation and the prevention of the pollution of supplies of water.

This Act is therefore significant to provision of onsite sanitation and FSM services especially on aspects which mandate the local authorities to regulate the developments and to maintain environmental health services, environmental conservation and prevention of pollution of water supply sources.

2.5 Faecal Sludge Management

This section reviews literature on FSM at different levels. It first presents FSM from a global perspective and highlights requirements for effective implementation of

FSM systems. It then delves into FSM at the local level where the country perspective is first presented and then the study area perspective is given.

2.5.1 FSM - A Global Perspective

FSM is a relatively new and fast developing field (Strande et al., 2014). The field is fast developing for two main reasons:

- The realization that universal sanitation, especially in peri-urban and low cost areas, cannot be attained through offsite systems alone. Onsite facilities need to be an integral component; and
- The majority of the urban population, especially in developing countries are on onsite sanitation.

Until recently, the perception was that onsite sanitation is a stop gap measure pending installation of reticulated sewerage systems which in the majority of cases never materialized. Infact, onsite facilities are neglected despite the fact that for most cities in developing countries, reticulated sewerage systems are simply not feasible or affordable (Koné and Strauss, 2004). It is worth noting that if onsite sanitation is managed appropriately and adequately, it can provide a sustainable solution to the sanitation challenges that are inherent with many developing countries. Dodane et al. (2012) undertook a comparative assessment of onsite and offsite sanitation systems in Dakar, Senegal and came to the conclusion that onsite sanitation systems were about five times less expensive compared to offsite systems. This enforces the need to change the perception towards onsite sanitation systems where they are regarded as a stop gap measure.

Considering onsite facilities as a stop gap measure is reflective from the sanitation policies, legislation and strategies for most countries which are not comprehensive on FSM (WRC, 2015). There is also a challenge with sanitation funding in many developing countries (OECD, 2011) which makes funding for FSM service provision almost impossible.

The recent push towards improved sanitation through onsite facilities including pit latrines has resulted in the problem of how to manage the faecal sludge inherent with these facilities (O'Riordan, 2009). Koné and Strauss (2004) report that of the faecal

sludge that is generated, only a small proportion is collected and safely disposed of. Klingel et al. (2002) observed that the majority of the generated faecal sludge gets discharged indiscriminately into the environment thereby posing a serious health risk. A number of factors are forwarded for the indiscriminate disposal including (Fanyin-Martin et al., 2017; Koottatep et al., 2012; Koné & Strauss, 2004):

- Long haulage distances to treatment and disposal sites;
- Inability to pay for services by facility owners due to poverty;
- Inaccessibility to facilities by mechanical and formal manual pit emptying services in densely-populated areas; and
- The high content of solid waste associated with faecal sludge which makes desludging difficult.

Where faecal sludge reaches a treatment or disposal site, it is rarely adequately treated. This is partly blamed on the poor state of treatment infrastructure and also on unavailability of faecal sludge quality data (Strande et al., 2014). Available research data also indicate high variability of faecal sludge quality in terms of physical, chemical and microbiological parameters making management of this waste more challenging than wastewater (Koottatep et al., 2012; Ingallinella et al., 2002). The high faecal sludge variability makes it difficult to have a prescriptive type of technology for its treatment. This implies that each stream of faecal sludge requires determination of its quality for suitable treatment to be prescribed (Bassan et al., 2013).

Lastly, research on faecal sludge management is still scanty at the global level (Strande et al., 2014). There is a general lack of scientific knowledge related to the accumulated faecal sludge in pit latrines. Comprehensive data on the quality of latrine faecal sludge is very sparse. Most disposal and treatment solutions are still in pilot stage, making it difficult for local authorities and private pit emptying service providers to make informed decisions (WRC, 2015).

2.5.1.1 Factors for implementation of successful FSM systems

Resource recovery is one way of solving the challenges inherent with the disposal faecal sludge from pit latrines (Semiyaga et al., 2015; Diener et al., 2014). As

indicated in Chapter one, implementation of resources recovery models require knowledge of faecal sludge quality data. However, a number of other factors also need to be considered especially if the reuse is being promoted in the context of FSM. Luthi et al. (2011) suggest that for effective and efficient implementation of FSM, an enabling environment is critical and defines the factors constituting an enabling environment as:

i) Government support;
ii) Skills and capacities;
iii) Financial arrangements;
iv) Socio-cultural acceptance;
v) Legal and regulatory framework; and
vi) Institutional arrangements.

The first four factors fall within what Strande et al. (2014) term "success factors" for the implementation of a successful FSM Framework. Although all the above factors are important, socio-cultural acceptance is very cardinal where the focus of the FSM includes resource recovery. Changing people's perceptions so that they embrace faecal sludge resources recovery may be one of the greatest challenges resource recovery initiatives can face. That is why it is always imperative that socio-cultural issues are addressed before implementation of any new sanitation technology. Failure to do this may lead to failure of the system (Myles, 2001). Feachem and Caincross (1978) state that: *"it is extremely difficult to achieve change in excreta disposal practices as they are part of the basic behavioural pattern of a community and are not readily modified."* This is true especially for rural areas where land, be it for latrine construction or for OD is readily available. Since communities in rural areas are in ethnic groupings with common cultural traditions, it becomes very difficult to change traditional and cultural beliefs.

In peri-urban areas, the situation may be different. To start with, in these areas, communities are heterogenic with people coming from different ethnic groupings with different cultural beliefs. Land is also usually in short supply for construction of latrines and access to sanitation is generally a challenge. Because of these challenges, new technologies may easily be embraced in these areas. In a review study for one of the peri-urban areas in Lusaka, high levels of acceptance for Urine

Diversion Dry Toilet (UDDT) facilities were recorded and one of the main drivers behind the high acceptance levels was the challenge the community was facing with respect to accessing sanitation facilities (Nyambe et al., 2010).

Acceptance is also enhanced if the proposed change has perceived benefits or incentives to the recipient community. In their study on excreta disposal in Dar-Es-Salaam, Chaggu et al. (2002) found that the lack of perceived benefits was behind the community's lack of appreciation for the need to change the sanitation disposal systems. This means that awareness creation among communities and stakeholders on perceived benefits of resource recovery initiatives is cardinal for them to succeed. Sometimes, lack of knowledge about a technology can lead to unwillingness by communities to embrace it (Strauss and Montangero, 2002).

Another important consideration for enhanced acceptance of new technologies in communities is community involvement in the whole cycle of such projects. Community involvement helps to develop a sense of ownership without which the community will not feel obliged to be part of the system (Bates, 2007). Communities need to be brought on board when introducing new concepts which are different from the already known norms and practices. Schertenleib and Morel (2003) and Heymans et al. (2004) both alluded to the fact that for any sanitation concept to succeed, it should be embraced by the beneficiary communities within which it is being implemented.

Enabling regulatory environment is also an important element in the successful implementation of an effective and responsive framework for FSM. It is imperative that national authorities foster the development, validation and dissemination of an array of policies and strategies, laws and standards that clearly spell out the roles of stakeholders, standards for disposal and reuse and procedures and penalties for non conformance (Strande et al., 2014). Strande identifies seven factors that contribute to effective regulation (Table 2-2).

Table 2-2: Summary of factors for enhanced regulation

Factor	**Significance/Reason**
Human and environmental health	The regulatory measures need to protect human health and preserve environmental integrity
Overall sanitation strategy	To ensure an integrated approach, a strategy spelling out management measures for both FSM and wastewater management should be designed to ensure an integrated approach.
City-wide approach	FSM strategic plans need to take on a city-wide approach in order to ensure that the protocols defined for implementation at a local level, take into account future urban development plans.
Complete service chain	Regulation should support the management of each step of the service chain in order to have a complete system.
Enforcement	Regulations need to be enforced at both national and city level by separate decrees. Without enforcement, designed systems and measures may not produce the desired outcome.
Permits and licenses	There is need for documentation to define the role(s) of stakeholders involved in the service chain and for stakeholders to only be allowed to implement aspects of the chain if they qualify.
Coordination	Structures and financial mechanisms need to be put in place for the coordination and evaluation of the entire FSM system.

Source: Compiled using data from Strande et al., (2014)

Lastly, clear institutional arrangement is key to foster the overall implementation of an effective FSM system. Overlapping and unclear allocation of responsibilities among stakeholders and a lack of incentives for efficient operation is one of the major reasons for the failure of FSM systems (Strande et al., 2014). Strande et al. (2014) also postulate that for effectiveness, allocation of responsibilities among stakeholders should take into consideration the strengths and weaknesses of each stakeholder involved in the service chain. However, a comprehensive approach incorporating multiple levels of institutional aspects is only possible if there is strong commitment by the government (Strauss and Montangero, 2003). Government's commitment is usually through provision of adequate sanitation policy that takes into account onsite sanitation and FSM in the short-, medium- or long-term (Strande et al., 2014). Koné (2010) identified lack of adequate attention to organisational aspects during project implementation and only concentrating on provision of physical infrastructure as a contributing factor to failure of FSM systems.

In summary, effective implementation of FSM systems requires that at least the following are taken into consideration (Strande et al., 2014):

- There should be realisation that sanitation is a series of interconnected services that need to function as a unit all the time. Dysfunctional of one stage in the series may render the whole system ineffective;
- There is need to have motivated people in institutions with well defined roles and responsibilities for the service delivery to be reliable;
- There is need for adequate planning, budgeting and monitoring for accountability and sustainability;
- There is need for FSM to be a formal, regulated, and city-wide and it should be explicitly recognized by bye-laws and regulations; and
- National policies, plans, funding arrangements and reporting mechanisms need to adequately support implementation of FSM.

2.5.2 Faecal Sludge Management in Zambia

Like in many other countries in the world, FSM is a new phenomenon in Zambia. Until recently, no framework existed for the management of faecal sludge. It is only in recent years that onsite sanitation systems and FSM service provision are being taken as integral components for sanitation provision. Eight key constraints to sanitation provision in the country of which three are directly linked to onsite sanitation and inadequate FSM were identified to be the following, (GRZ, 2015):

- Insufficient focus on sanitation and too much emphasis on reticulated sewerage;
- Limited investments in smaller scale infrastructure and onsite facilities; and
- Insufficient management models for delivery of decentralised sanitation services.

The Urban Onsite Sanitation and Faecal Sludge Management Framework for Provision and Regulation in Zambia (NWASCO, 2018) evaluated the existing service provision and regulation and concluded that there are gaps that have lead to several problems as follows:

- ZEMA regulates onsite sanitation for environmental protection purposes. However, the provision of onsite sanitation services is not regulated;
- Sanitation service provision tools such as service level guarantees and agreements between the regulator NWASCO and the commercial utilities (CUs), which were created to provide urban water supply and sanitation (WSS) services, does not include onsite sanitation and FSM;
- Onsite sanitation facilities such as pit latrines and septic tanks are not constructed to enable safe emptying and protection of the environment as there are no national standards for this purpose;
- ZEMA has developed effluent standards, but faecal sludge standards are not in place and ZEMA does not regulate community emptying either;
- Unsafe emptying of pit latrines, especially in peri-urban areas, results in public health risk and potential environmental pollution; and
- Existing building codes are outdated and require updating.

The Framework summarises impacts of the inadequacies in onsite sanitation and FSM service provision and regulation as presented in Figure 2-4.

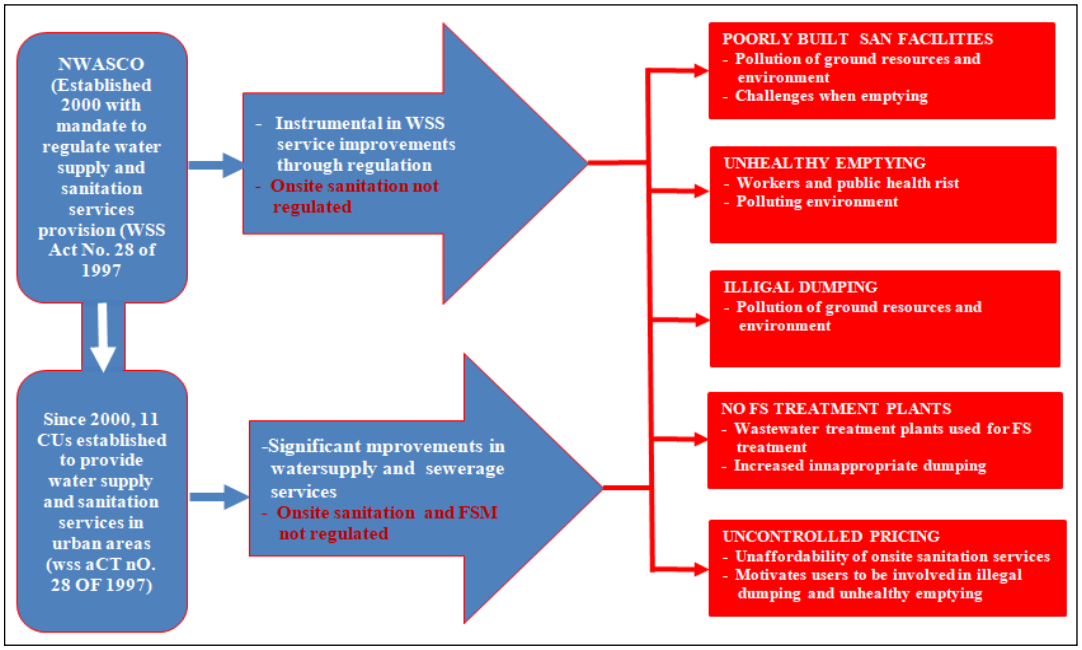


Figure 2-4: The effects of lack of onsite sanitation service regulation (Source: NWASCO, 2018)

Country-wide, it is mostly only faecal sludge from septic tanks which finds its way to treatment plants. In most such cases, the desludging services are provided by

registered private enterprises who own vacuum tankers. This service is generally confined to affluent areas where people have the ability to pay for the service. In low income areas and peri-urban areas, desludging of facilities is mostly done informally and in most such cases, faecal sludge is never transported from their areas of generation (LWSC, 2018; NWASCO, 2018). As already observed, informal desludging is usually unhygienic and disposal is always indiscriminate as the emptiers do not have the means to transport the faecal sludge to a treatment plant (Strande et al., 2014). Hence, it continues to accumulate within areas of generation where it continues to degrade the environment (BORDA, nd).

2.5.3 Faecal Sludge Management in Lusaka City

According to SMP, (2011), 76.4 percent of Lusaka city's population is serviced by onsite facilities (Section 2.4). However, despite the high reliance on onsite facilities, the FSM system for the city is still very rudimentary. The city's FSM systems in place are presented under the headings: emptying and transportation; treatment; and disposal and reuse.

2.5.3.1 Emptying and Transportation

Under emptying and transportation, there are three categories that exist in the city as follows (LWSC, 2018):

i) Informal manual emptying;
ii) Formal manual emptying mainly for latrines in peri-urban areas; and
iii) Formal mechanical emptying with vacuum tankers.

i. Informal manual emptying

Informal manual emptying services are prominent in peri-urban areas. These services are usually provided by individuals who, in most cases, are also residents of the areas in which they operate. Due to the inability of the emptiers to efficiently cart away the faecal sludge over long distances, the emptied sludge in this category is mostly discharged within the residential environment (LWSC, 2018).

ii. Formal manual emptying mainly for latrines in PUAs

The formal manual pit emptying and transportation for pit latrines is a new model still in pilot stage introduced through funding from the Water and Sanitation for the

Urban Poor (WSUP). This model took advantage of the already existing informal pit emptiers within communities where the piloting was taking place. The systems are managed by LWSC through the delegated management of the Water Trusts. This means that the emptiers operate as an enterprise under the Trusts. This system is operational only in two of the 33 peri-urban areas in the city. Under this system, desludging is through the use of modified garden tools. The desludged faecal sludge is put in 60 litter barrels which are then transported by use of push carts or light trucks to treatment plants (Figure 2-5).

Figure 2-5: Faecal sludge emptying and transportation (LHS: Scooping of sludge from a pit latrine through a hole on the side; RHS: Transportation of sludge using a hand cart)(Source: This study).

iii. Formal mechanical emptying with vacuum tankers

Emptying and transportation with vacuum tankers is usually confined to medium and high cost residential areas and some commercial and industrial establishments not connected to the sewerage system. Operators are not organised in any way but each individual vacuum tanker operator is registered as a formal company under the Companies Act. Their operations are guided by ZEMA through the Environmental Management Act (2011) with respect to collection and transportation of the sludge. All vacuum trucks are required to discharge their waste at Manchinchi Wastewater Treatment Plant – a conventional wastewater treatment plant utilising trickling filters.

2.5.3.2 Treatment

Like emptying and transportation, treatment of faecal sludge is also categorised according to whether it is sourced from pit latrines by formal manual emptiers or

from residential and commercial areas by vacuum tanker operators. Faecal sludge emptied by informal emptiers never gets to any treatment facility.

i. Treatment of faecal sludge from latrines in peri-urban areas

Pit latrine faecal sludge treatment in the city is currently that from two areas under pilot investigations (Kanyama and Chazanga compounds). In these two areas, treatment is through anaerobic digestion utilising anaerobic digesters. The effluent from the digester is channelled to an Anaerobic Baffle Reactor (ABR) and a Filter for polishing before final disposal into the environment. The resulting sludge from the anaerobic digester gets further stabilisation through drying on drying beds (LWSC, 2018). The two pilot plants just service portions of the areas in which they are located.

ii. Treatment of faecal and sludge collected by vacuum tankers

Sludge from septic tanks and some industrial and commercial establishments where desludging is through vacuum tankers is discharged and treated at Manchinchi Wastewater Treatment Plant. A receptor point exists at the plant where vacuum tankers discharge the septage. The point has a screen and a degriting chamber but these do not adequately treat the septage especially in terms of grit removal. The receiving bay also lacks a proper receiving chamber as the sludge is just discharged onto the area surrounding the receiving manhole and then allowed to flow into it by gravity (Figure 2-6). This process is unhygienic as there is usually wastewater that stagnates in the vicinity of the receiving manhole (LWSC, 2018).

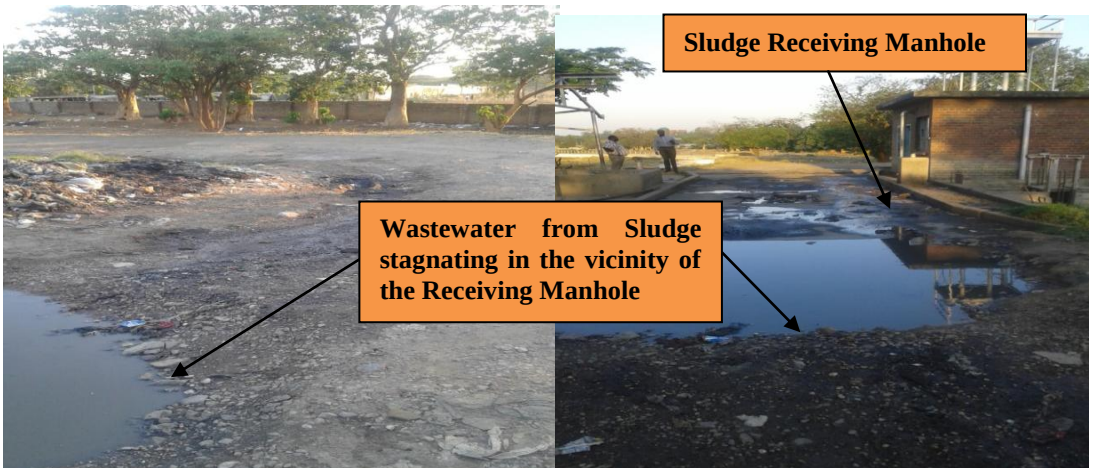


Figure 2-6: State of the current existing infrastructure for receiving septage at Manchinchi Wastewater Treatment Plant (Source: This study)

The septage from vacuum tankers is co-treated with the rest of the wastewater streams at the plant. The sludge gets stabilised through anaerobic digestion. After digestion, the sludge is dried on the sludge drying beds (Figure 2-7).

Figure 2-7: Sludge on drying beds at Manchinchi Wastewater Treatment Plant (Source: This study)

2.5.3.3 Disposal and Reuse

Since all the plants treating the faecal sludge employ anaerobic digestion, the by-products are biogas and stabilized sludge. At the pilot treatment plants in Kanyama and Chazanga, the biogas is captured but is only used for cooking purposes at the treatment plants (Figure 2-8). At the Manchinchi Wastewater Treatment Plant, the biogas is not captured.

Figure 2-8: Cooking at the Kanyama Water Trust using biogas from the faecal sludge treatment plant (Source: This study)

All the sludge from the treatment facilities (i.e. Chazanga, Kanyama and Manchinchi treatment plants) get absorbed into agricultural and horticultural activities. The dried sludge from the Kanyama and Chazanga treatment plants is

firstly pulverised and then packed in 25kg bags which are then sold at K12 per bag. For the sludge from Manchinchi Plant, the selling price is K7/ton (LWSC, 2018).

2.5.3.4 Status of shit flow in the study area

From the sections above, it is clear that the situation in terms of FSM in the city is far from satisfactory. It clearly shows that a major portion of the sludge remains within areas of generation hence the need for adequate FSM infrastructure which is currently lacking (GRZ, 2015). The Water and Sanitation Program (WSP) publication of 2014 acknowledges this fact (Figure 2-9).

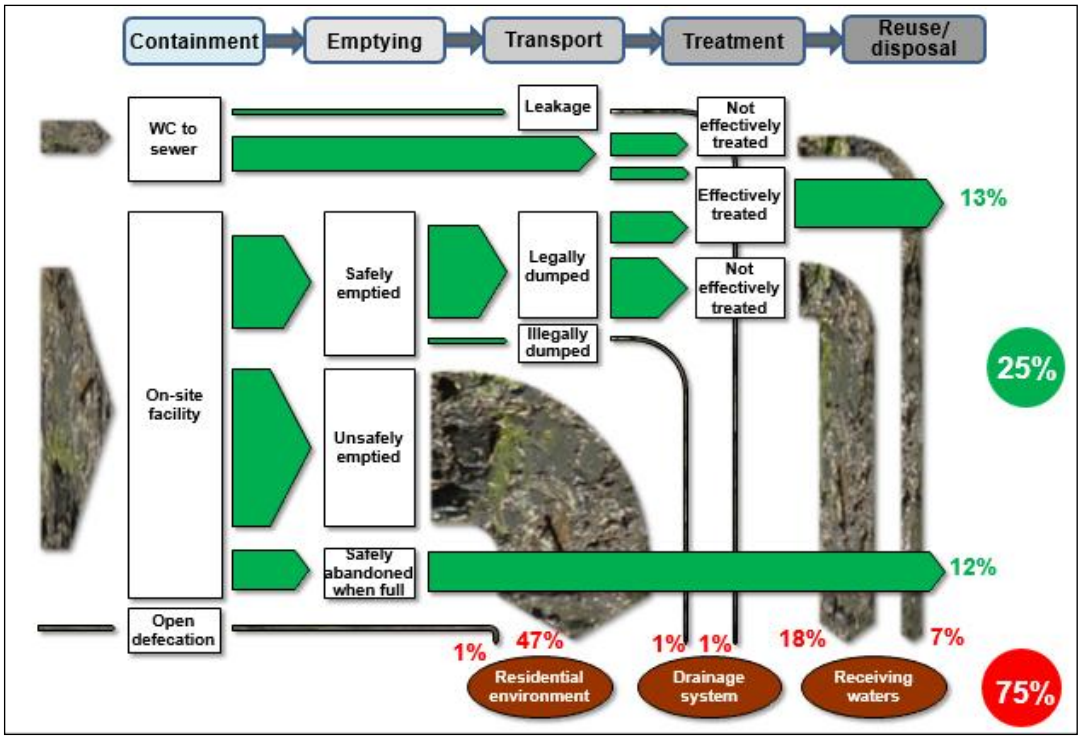


Figure 2-9: Shit Flow Diagram (SFD) for the City of Lusaka, Zambia (Source: WSP, 2014 in GRZ, 2015)

The Figure shows that of the total faecal sludge generated in Lusaka, a total of 47 percent remains within the residential environment where it contributes to environmental degradation. Only 25 percent is properly managed. LWSC under the Lusaka Sanitation Program (LSP), a program designed to increase access to sanitation services in selected areas of Lusaka and strengthen LWSC's capacity to manage sanitation services, generated a SFD which presents a more attractive picture in terms of FSM putting the percentage of the safely managed faecal sludge at 50 percent (Figure 2-10).

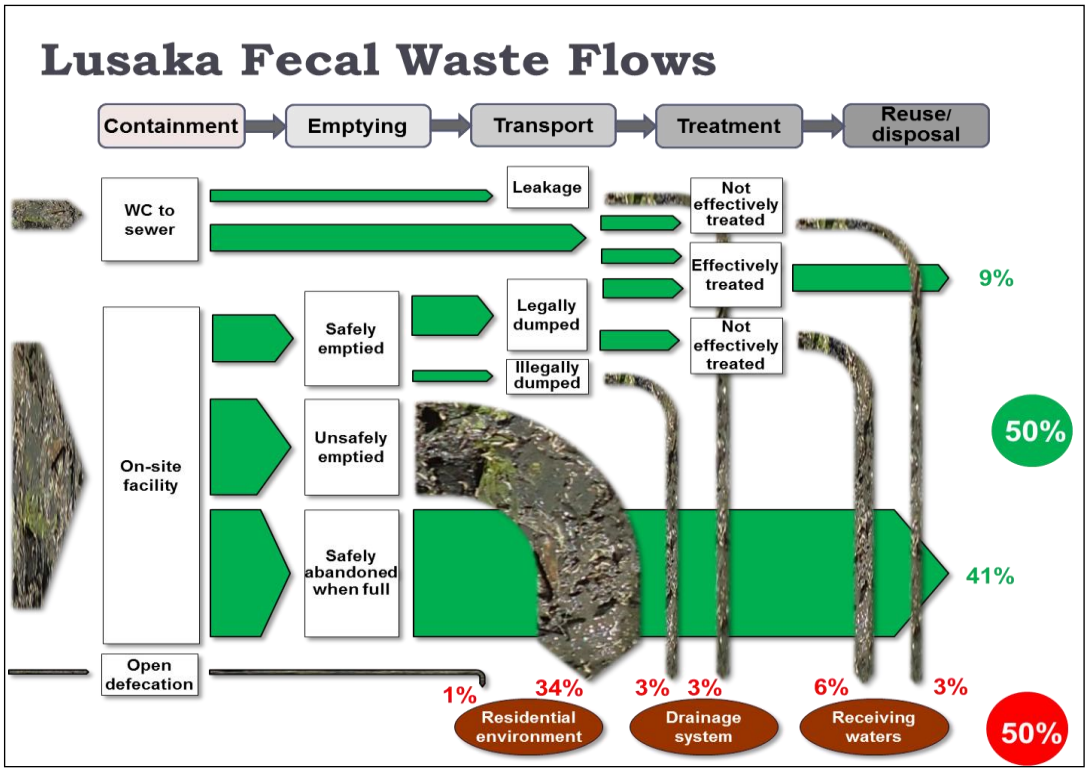


Figure 2-10: SFD for the City of Lusaka, Zambia as compiled by LWSC (2015)

The major difference between the two SFDs is on what is considered 'safely abandoned' when pit latrines get full. While this is considered to be only 12 percent in the SFD by the WSP, LWSC puts it at 41 percent. This is debatable when one considers the geology upon which most of the latrines are sited which is dolomite/limestone. Whereas covering may prevent transmission of faecal sludge related hazards by vectors, it obviously does not address the problem of groundwater contamination.

One may also argue that the situation may have changed over time for both scenarios. However, between the time the above SFDs were developed and the time of this thesis compilation, not much had changed although there were plans under the LSP to improve the FSM landscape.

2.5.4 Future of FSM in Zambia

The future of FSM in Zambia is promising. This has culminated from a number of government initiatives aimed at improving sanitation in the country. Recently, a framework for onsite service provision and FSM was concluded. This framework

gives a clear picture of the onsite sanitation and FSM status in the country and gives a clear roadmap for the required improvements (NWASCO, 2018).

The Vision 2030 which defines the country's roadmap to attaining the status of middle-income nation by 2030 identifies provision of improved and increased access to sanitation facilities as one of the recipes for economic development. Under the sector goals, the Vision talks of improving sanitation access to 90 percent by 2030 (GRZ, 2006). The National Urban Sanitation Strategy buttresses the need to improve sanitation and proposes to do so by promoting what it refers to as "safe and cost-effective sanitation services". It advocates for increased sanitation coverage to 90 percent of the urban population by 2030 with one of the objectives being "to mitigate environmental degradation, through safe disposal of wastewater and sludge" (GRZ, 2015). The "cost-effective sanitation services" being alluded to in the document refers to onsite sanitation systems together with the FSM services.

For the city of Lusaka, the pronouncements of the Vision 2030 and the National Urban Sanitation Strategy are already being actualised through a number of activities. The Sanitation Master Plan (SMP) for the city of Lusaka has recognised the need to incorporate improved onsite sanitation to improve coverage for the city. It has set a target of 100 percent sanitation coverage by 2035 and indicates that this will be achieved through extension and expansion of the sewerage system to service at least 50 percent of the population in the city with the remaining population to be serviced by onsite facilities (SMP, 2011). To this effect, LWSC has also developed an Onsite Sanitation Strategy Brief which guides the integration of onsite sanitation services within its overall business strategy (LWSC, 2017).

Most utilities in the country are taking up the mandate for provision of onsite sanitation and the associated FSM service provision. This is a very positive thrust towards effective and efficient implementation of FSM in the country. However, one critical element that has continued to hamper efforts of promoting FSM systems, especially with respect to design of treatment facilities and reuse of the faecal sludge derived products is the lack of comprehensive data on the quality of the faecal sludge as presented in Section 2.6 .

2.6 Availability of faecal sludge quality data in Zambia

Faecal sludge quality data is very critical in the design of both the treatment facilities as well as resource recovery initiatives. However, very little data exists on pit latrine faecal sludge quality in Zambia. Currently, the only available published data on faecal sludge quality was by Phiri et al., (2014) who undertook a study entitled: *"Characterization of biosolids and evaluating the effectiveness of plastic-covered sun drying beds as a biosolids stabilization method in Lusaka, Zambia".* However, this study only concentrated on treated sludge from conventional wastewater treatment plants and Ecosan facilities. It did not dwell on faecal sludge from pit latrines. Further, the study only considered pathogenic parameters which are just a component of parameters required if beneficiation prospects of the sludge are to be fully actualised. These parameters are also not sufficient to provide a sound basis for the design of treatment facilities.

2.7 The Pit Latrine and Processes that Occur therein

This study revolved around the pit latrine with the major works being characterisation of the pit latrine faecal sludge. It is therefore imperative to have a clear understanding of what constitutes a pit latrine and also to have a clear understanding of the processes that occur in these facilities. The sections below are therefore devoted to present critical information about the pit latrine and associated processes which are cardinal to this study.

2.7.1 The Pit Latrine

A pit latrine is designed to collect, store and treat human faeces in a hole in the ground. It does not usually need water to operate but may need not more than three liters where it is serving as a pour-flush pit latrine (Tilley et al., 2014). Pit latrines are the cheapest means of ensuring separation of excreta from people (Graham and Polizzotto, 2013; WHO, 1996).

In terms of construction, a pit latrine consists of three major parts (Figure 2-11): a hole in the ground; a slab or floor with a small hole; and a superstructure (Tilley et al., 2014).

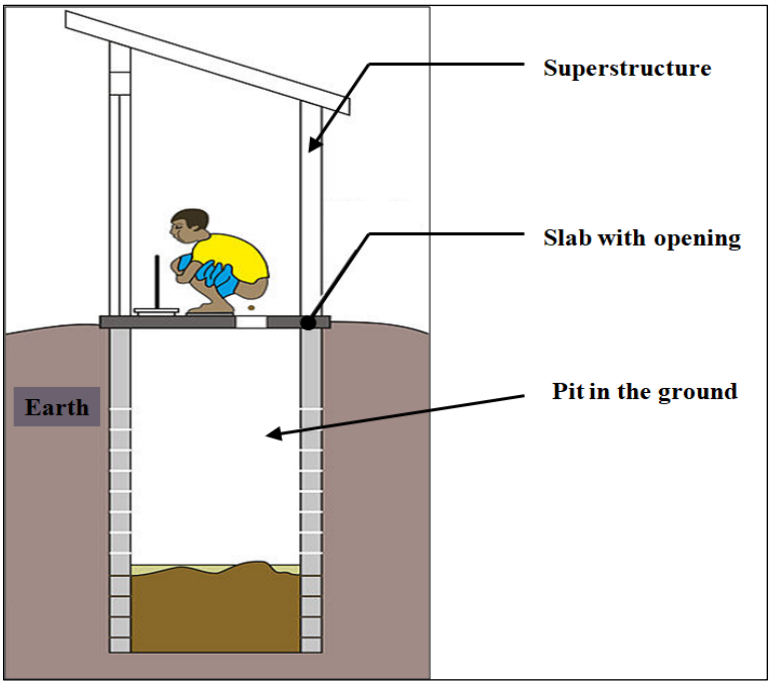


Figure 2-11: A pit latrine (Source: Adapted from Google images, (2018))

The hole in the ground serves as the vault for the excreta and provides space for its storage (Mara, 1996). The hole in the slab serves as the user interface, while the superstructure provides shelter and privacy for the user. The pit depth ranges from 3m to 5m with a radius or dimensions of between 1m and 1.5m (Brikké and Bredero, 2003). To prevent children from falling into the pit, WHO (1996) recommends that the hole in the slab should not exceed 25 centimeters.

A pit latrine can take the form of a basic/traditional pit latrine or an improved latrine. A traditional pit latrine is merely a pit in the ground with an earthen floor or Sanplat. Brikké and Bredero (2003) suggest that a traditional pit latrine can be improved in a number of ways as follows:

- Addition of a ventilation pipe from the pit to enhance movement of air hence decreasing smell of the latrine and prevalence of flies;
- Construction of the latrine floor to promote draining of fluids into the hole; and
- Reinforcing the upper part of the pit with bricks, blocks, or cement rings to improve stability.

2.7.2 Processes Occurring in Pit latrines

Pit latrines, as defined in Section 2.7.1 are facilities provided for the accumulation and storage of excreta. Not much information exists on the processes that occur in these facilities. However, data from a few of researchers who have delved into the dynamics of the processes that occur in pit latrines agree that the predominant process is anaerobic digestion of excreta. It is assumed that aerobic digestion also takes place but is only restricted to the top layer of the excreta in the pit (Still, 2002; Mara, 1984). Buckley et al. (2008) theorises four layers within a pit latrine (Figure 2-12).

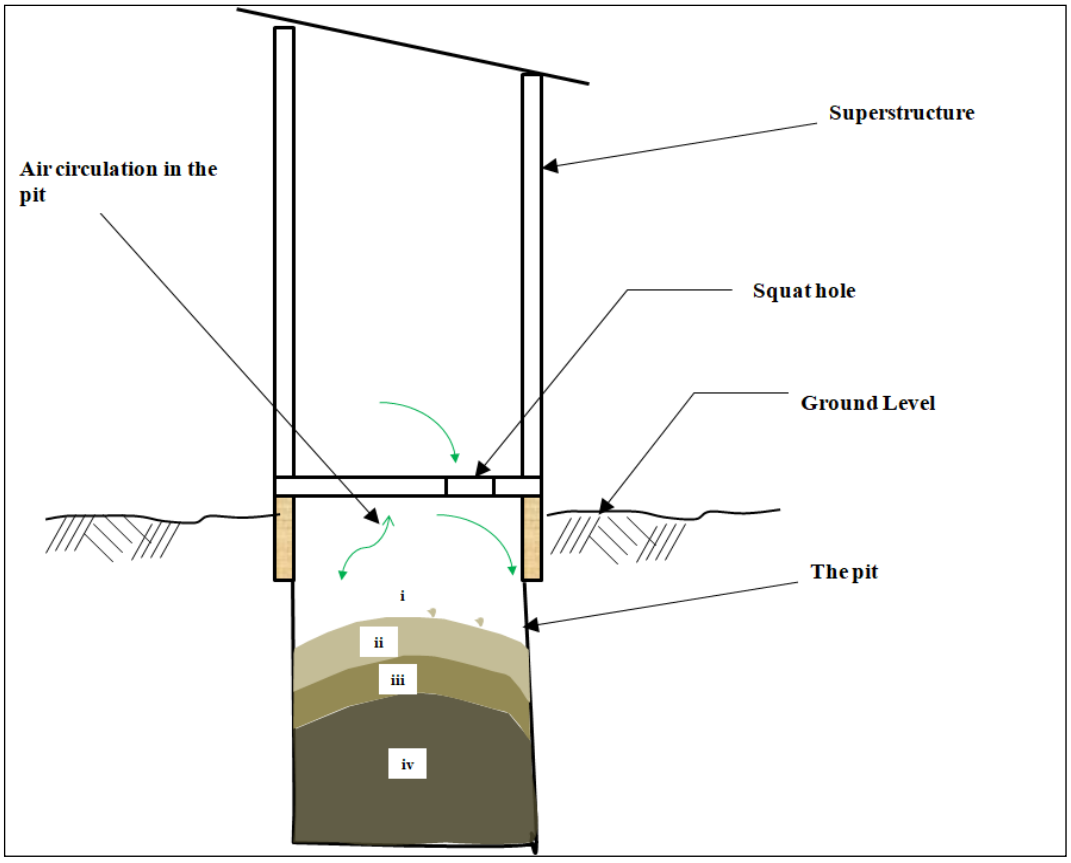


Figure 2-12: Theorised layers in a pit latrine (Source: Modified from Buckley et al., 2008)

The four layers are explained as follows (Buckley et al., 2008):

i) The top most layer (Layer i) is a layer containing fresh excreta which is exposed to the environment where aerobic processes are predominant;

ii) The first inner layer (Layer ii) is a layer containing hydrolysable organic matter in which aerobic degradation takes place at a rate limited by aerobic hydrolysis of complex organic material to simpler compounds;

iii) The second inner layer (Layer iii) is a layer where the processes are predominantly anaerobic as oxygen is not able to penetrated to this layer; and

iv) The last layer (Layer iv) is a layer comprising stabilised sludge.

It is worth to note that this theory is based on Ventilated Improved Pit (VIP) latrines where excreta is layered according to age in the latrine. This may not hold true for very wet latrines where there is mixing of the excreta with other forms of water like sullage and flushing water. Where the water content is so much such that the pit contents are completely submerged in water, the latrine may function like a septic tank with anaerobic processes being the only biodegradation processes. It is important to note that the processes that take place in pit latrines are linked to organic matter content which is the major component of excreta. The section below describes some of the main characteristics of organic matter.

2.7.2.1 Organic matter

Organic matter is simply a chemical compound that contains carbon (Spencer and Michael, 2004). It is also defined as any compound that contains carbon compounds that were formed by living organisms or is matter that has come from a recently living organism and is capable of undergoing the process of biodegradation or is a product of biodegradation. Spencer and Michael (2004) indicate that a concise definition of organic matter remains elusive and likely arbitrary but indicates that it is traditionally limited to compounds containing a carbon-hydrogen bond. Organic matter is a major constituent of faecal sludge.

Organic matter is usually measured using either the Biological Oxygen Demand (BOD), sometimes referred to as Biochemical Oxygen Demand test or the Chemical Oxygen Demand (COD) test. BOD measures the biologically oxidizable organic matter content by estimating the amount of dissolved oxygen required by microorganisms to aerobically decompose the organic matter present in a sample in a specified incubation period (APHA, 1998). According to Metcalf & Eddy (1991), BOD is a parameter that is widely used to indicate organic pollution for both wastewater and surface water. However, the Method has limitations such as the incomplete determination of all the organics and also generates irreproducible

results. For example, BOD_5 does not represent the total biodegradable fraction of the organic matter. Depending on the type of wastewater, it may only represent 50 to 95 percent of the biodegradable organic matter (Roeleveld and van Loosdrecht, 2002). This big margin can therefore be a source of errors.

The COD, like BOD, is also an indicator of organic matter content. However, unlike BOD which only measures biologically oxidizable organic matter, COD measures total oxidizable organic matter including all other oxidizable compounds in a sample. Strande et al. (2014) defines COD as *"the oxygen equivalent of the organic matter that can be oxidised chemically with dichromate, a powerful chemical oxidant."* The amount of oxidant required is reported in terms of the amount of oxygen required in the oxidation process. Because COD measures all oxidizable compounds in a sample, it is always higher than BOD.

The COD present in any wastewater sample can be speciated. This is because the COD value takes into consideration a variety of different qualities of organic matter. A mass balance for total COD (COD_T) in wastewater can be summarised as in the equation below (Henze et al., 1997).

$$COD_T = Ss + S_I + Xs + X_I \quad \text{----------} \quad \textbf{(Equation 1)}$$

Where

S_S = Dissolved easily biodegradable organic matter

S_I = Dissolved inert biological organic matter

X_S = Suspended slowly biodegradable organic matter

X_I = Suspended inert biological organic matter

Equation 1 takes cognisance of the fact that COD is present in any sample in either particulate or soluble state. The equation is summarised graphically in Figure 2-13.

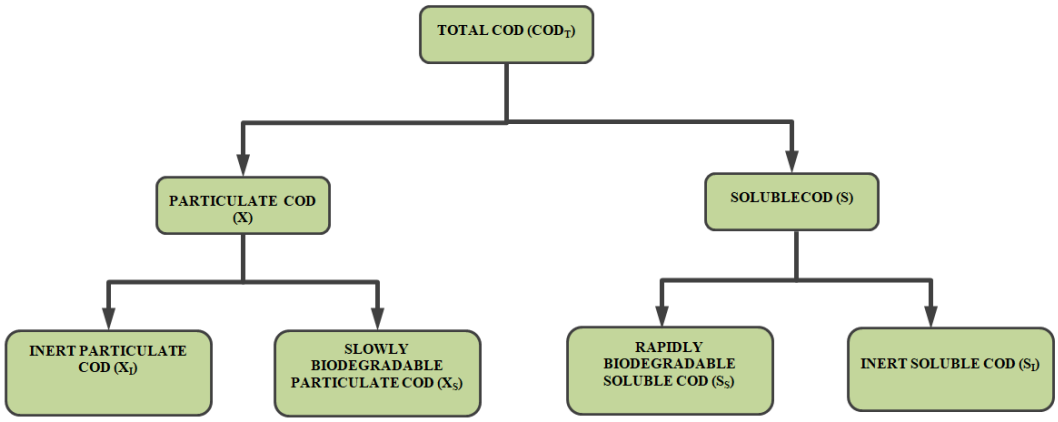


Figure 2-13: Speciation of COD (Source: Henze et al., 1997)

Having defined organic matter and the methods used for its quantification, the next two sub sections will be dedicated to providing information on the two major processes inherent with the biodegradation of organic matter namely the aerobic and anaerobic digestion processes.

i) **Aerobic digestion process**

Aerobic degradation is the consumption of biodegradable organic material in the presence of oxygen (Foxon, 2008). Gray et al. (1971) defines it as the process that involves the biochemical breakdown of biodegradable organic material by microbes in the presence of sufficient oxygen resulting in an increase in temperature and production of carbon dioxide, water and cellular protoplasm. Aerobic digestion processes are performed by a wide range of micro-organisms and the rate of these reactions are far more rapid than those in anaerobic digestion processes (Henze et al., 1997). Aerobic digestion process by micro-organisms typically has cell yields in the order of 45 to 80 percent on a COD basis. The rate of aerobic digestion is limited by one of the three factors (Foxon, 2008):

- The number of aerobic micro-organisms present;
- The slowest biochemical step in the digestion process which is the hydrolysis of large molecules to smaller molecules; and
- The rate at which oxygen is supplied.

Aerobic conversion of organic matter by microorganisms occurs in two stages (Wang et al., 2007). The first stage involves the conversion of organic matter by

microorganisms to produce more microorganisms and other end products as summarised in equation 2.

$$Organic\ Matter + O_2 \xrightarrow{Bacteria} CO_2 + NH_3 + Cellular\ Material + Other\ End\ products$$ ---------- [***Equation 2***]

Being organic in nature, the produced cellular material, together with cells already present in the sludge will eventually undergo the process of endogenous respiration or lysis releasing protoplasm and degradable and non degradable materials. The protoplasm and degradable materials will serve as a source of energy for other microorganisms as presented in equation 3.

$$Cellular\ Material + O_2 \xrightarrow{Bacteria} CO_2 + NH_3 + 2H_2O + Energy$$ --- ***[Equation 3]***

ii) Anaerobic digestion process

Anaerobic digestion is a biological process in which complex organic substrates are converted into biogas and a digestate by microbial action in the absence of oxygen through four main steps, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis (Ariunbaatar et al., 2014). Metcalf and Eddy (1991) define it as a process involving the decomposition of organic and inorganic matter in an environment devoid of molecular oxygen. Kelleher et al. (2002) and Chen et al. (2008) define it as a process through which organic matter is biodegraded anaerobically with the help of anaerobic microorganisms leading to the formation of methane, biomass and inorganic products. Kelleher et al. (2002) goes further to summarise this definition as follows:

$$Organic\ Matter + H_2O \xrightarrow{\textbf{Anaerobes}} CH_4 + CO_2 + Biomass + NH_3 + H_2S + Heat$$ --- ---------- ***[Equation 4]***

In this process, complex refractory organic compounds are broken down so that they may further be degraded anaerobically or be completely mineralised (Tracey et al., 1989). The whole process is driven by a complex ecosystem of anaerobic bacteria that biodegrade the organic matter (Steyer et al., 2002). The process occurs in several steps. Firstly, hydrolysis of higher molecular-mass compounds occurs. In

this stage solubilisation of particulate organic matter takes place converting it to soluble products that can then be hydrolyzed to simple organics. Through this process, higher molecular-mass compounds are converted into soluble compounds (Adrianus et al., 1994) suitable for use as a source of energy and cellular carbon by microorganisms. Solubilisation is an important step because most of the organic matter in the sludge is in particulate form (Zhidong and Wenjing, 2009). This is followed by a step referred to as acidogenesis. In this step, the compounds resulting from the first step are converted by bacteria into identifiable lower-molecular-mass intermediate compounds such as volatile fatty acids, alcohols, lactic acid, carbon dioxide, ammonia and hydrogen sulphide (Anderson and Uyanik, 2003; Adrianus et al., 1994). The volatile fatty acids then get converted to final products for methane production, acetate, carbon dioxide and hydrogen, in a process known as acetogenesis (Adrianus et al., 1994). The resulting compounds feed into the last step called methanogenesis where bacteria convert the intermediate compounds into simpler end products, principally carbon dioxide and methane (Anderson and Uyanik, 2003; Adrianus et al., 1994; Metcalf and Eddy, 1991). Figure 2-14 summarises the steps involved in the anaerobic microbiological process.

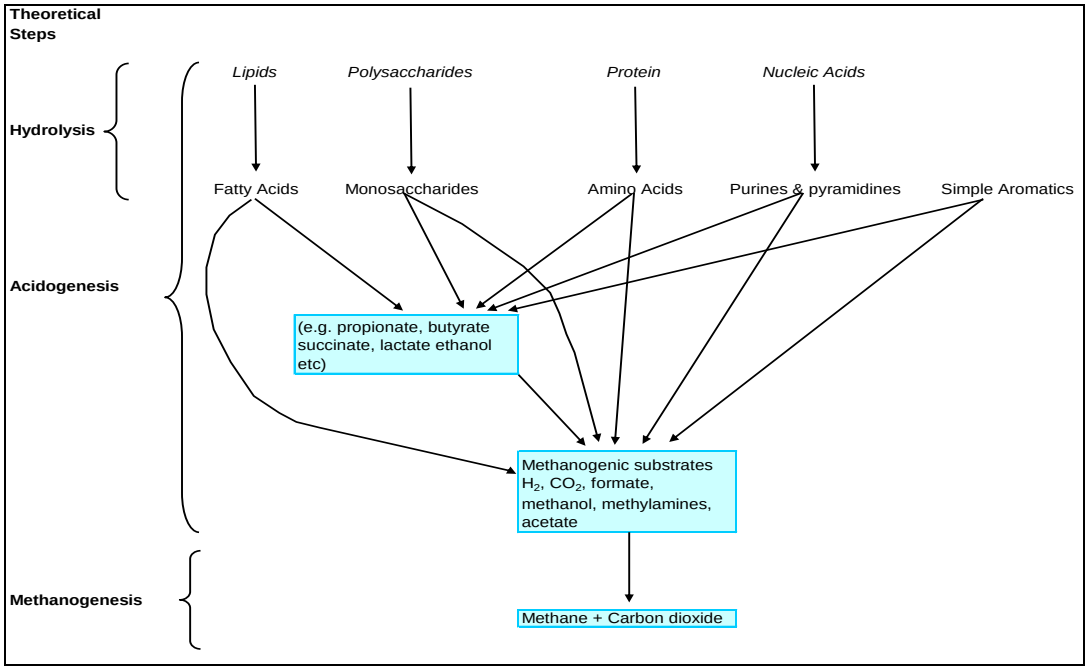


Figure 2-14: Schematic diagram of the patterns of carbon flow in anaerobic digestion (Source: Metcalf and Eddy, 1991)

This process is delicate and depends on a number of factors some of which are described under section 2.8.

2.8 Factors affecting reactions in pit latrines

There are several factors that affect the processes in pit latrines. Most of these factors affect the anaerobes in the pit which are responsible for the biodegradation reactions in the latrine. According to O'Flaherty (2006), factors affecting anaerobic reactions in pit latrines include temperature, pH, presence and absence of nutrients and presence of inhibitory and toxic substances.

2.8.1 Temperature

The processes of anaerobic digestion of organic matter are dependent on temperature (Adrianus et al., 1994). In general, the process can occur within a wide range of temperature which has been broadly divided into mesophilic and thermophilic. Mesophilic processes occur within a temperature range of 20 °C to 45 °C while thermophic processes occur within temperature ranges of 46 °C to 75 °C (Schiraldi and De Rosa, 2014).

According to Metcalf and Eddy (1991), most of the anaerobic digesters are designed to operate within the mesophilic range which they put as ranging between 30 °C to 38 °C. For processes occurring below 30 °C, Henze et al. (1997) indicate that the organic matter biodegradation rate decreases by about 11 percent for every Degree Celsius drop in temperature which shows the need for anaerobic digesters to always be operated above 30 °C.

In the study area, Lusaka, the average minimum ambient temperature is around 16 °C which is experienced in the month of July while the average maximum ambient temperature is around 24 °C experienced in the month of October (JICA, 2009). Considering that anaerobic processes are exothermic, it is expected that temperatures in the pit latrines will be mostly be in the mesophilic range in hotter periods.

2.8.2 pH

pH is an important parameter in anaerobic digestion. This is because microorganisms responsible for anaerobic digestion operate within specific pH ranges. Methanogens are sensitive to both high and low pH values and operate well

within a pH range of 6.5 and pH 8 (Sung and Tao, 2003). Outside this range, methanogenic bacteria usually get inhibited leading to accumulation of fatty acids in the reactor. pH also influences the conversion of NH_4^+ to NH_3. Ammonia (NH_3) is an inhibitor (Strande et al., 2014). Gerardi (2003) states that the most efficient and satisfactory pH range is 7.0 to 7.2 while the pH range of 6 to 8 is also acceptable but is somewhat restrictive and slow. Henze et al. (1997) puts the suitable pH range for anaerobic process at 6.5 to 8 which is similar to that stated by Sung and Tao (2003).

2.8.3 Nutrients

Processes predominant in pit latrines are anaerobic processes (Section 2.7.2). These processes use a consortium of microorganisms which require essential elements for their growth. Nitrogen, phosphorus, sulphur, iron and other micro-nutrients are essential for the growth of microorganisms (Todar, 2008). If these nutrients are not sufficient, they will serve as limiting factors to the anaerobic processes. This is because the growth of bacteria responsible for the processes will slow down or completely cease when nutrients are completely absent. This could in turn result in inhibition of the methane production during the methanogenic stage (Schanbacher et al., 2005). It is therefore imperative that these nutrients are readily available to the microorganisms for complete digestion of the faecal sludge (Buckley et al., 2008).

2.8.4 Inhibitory substances

The process of anaerobic digestion is very sensitive and is affected by several compounds such as heavy metals and chloro-organic compounds even at low concentrations (Adrianus et al., 1994). In biogas generation, inhibitory substances are the lead causes of anaerobic processes upsets and failures (Chen et al., 2008). This problem normally arises when the inhibitor is present in concentrations beyond critical values. Any inhibitory effect on methanogens during anaerobic digestion will result in the accumulation of acids in the reactor and will consequently lead to the failure of the digestion process (Henze et al., 1997). Some of the chemical substances known to inhibit the anaerobic digestion process are discussed below.

2.8.4.1 Ammonia

Ammonia stems from biodegradation of organic matter which is in form of proteins and urea (Strande et al., 2014; Chen et al., 2008). Ammonia (NH_3) has been

identified as the major inhibitor in comparison to ammonium and this is attributed to its property of "freely membrane- permeability" (de Baere et al., 1984). Gallert et al. (1998) indicate that the hydrophobic ammonia molecule can passively diffuse into the cell of a microorganism resulting in proton imbalance thereby impairing the bacteria's reproduction process. Ammonia inhibition is a factor that is affected by a number of parameters including pH, temperature and its concentration (Chen et al., 2008). Generally, a high concentration of ammonia in biogas production process inhibits the process. Sibiya et al. (2015) postulate that ammonia concentration of around 600 mg/L is good for the growth of microorganisms. However, in higher concentration, ammonia is inhibitory. Yenigün and Demirel (2013) submit that for sludge, ammonia inhibition sets in at concentrations greater than 5,000 mg/L. However, other researchers suggest that total ammonia in concentrations of around 1,700–1,800 mg/L result in process failure (Albertson, 1961; Melbinger and Donnellon, 1971).

For facilities that are receptors of both faeces and urine, ammonia would be expected to be present in high quantities arising from the biodegradation of constituents of urine especially urea which in the presence of urease, gets quickly converted to ammonium (Jönsson et al., 2004; Esrey et al., 1998). It should be noted that ammonia is not only an inhibitory substance but also an important source of nitrogen for plant growth.

2.8.4.2 Light Metals ions

Light metals ions are associated with compounds of salts. High salty content is known to be toxic to microbiological processes which are attributed to dehydration which is due to osmotic pressure that results (Yerkes et al., 1997). Although salts dissociate in water into cations and anions, the effect of toxicity is attributed to the light metal ions or the cations as opposed to the anions (Chen et al., 2008). However, it should be noted that these ions are also necessary nutrients for microbial growth. Therefore, their presence in lower concentrations is vital to anaerobic digestion but they become detrimental in higher concentrations (Soto et al., 1993).

2.8.4.3 Heavy Metals

By definition, heavy metals are metals and metalloids having densities greater than 5g/cm^3. They are usually associated with pollution and toxicity. However, some of these elements (essential metals) are required by microorganisms at low concentrations (Mudhoo and Kumar, 2013). Of concern in sewage and faecal sludge are chromium, lead, iron, cobalt, copper, zinc, cadmium and nickel which have been reported to be inhibitory and toxic depending on their concentration (Mudhoo and Kumar, 2013; Chen et al., 2008; Jin et al., 1998). In the anaerobic digestion, the most sensitive consortia of microorganisms to heavy metal inhibitory and toxic effects are the methanogens (Yin et al., 2011; Chen et al., 2008). Kouzeli-Katsiri et al. (1988) assessed the toxicity of heavy metals on the anaerobic digestion of sewage sludge. They reported toxicity of selected metals as presented in Table 2-3.

Table 2-3: Toxicity limits in anaerobic digesters

Metal	**Inhibition Starts**		**Failure**	
	mg/L	**% of dry solids**	**mg/L**	**% of dry solids**
Cu	40 – 450	0.30-2.00	170 - 300	0.83-4.70
Cd			20 - 600	1.10-4.00
Zn	150 - 400	1.00 – 3.20	250 - 600	1.00-3.00
CrIII	120 - 300	<2.25	200 - 500	1.15-4.00
CrVI	100 - 110		200 - 420	
Ni	10 - 300	<2.25	30 - 100	>1.0
Pb	300 - 340	<2.25	>340	

Source: (Kouzeli-Katsiri et al., 1988)

The presence of heavy metals in soils intended for crop production in excess of permissible limits also pose public health risk (Naveedullah et al., 2013). High content of heavy metals in treated faecal sludge may therefore impact on its usefulness as a soil conditioner. Generally, the concentration of heavy metals need to be below Guideline Values (Table 2-4).

Table 2-4: Regional and International Guidelines for the maximum permissible heavy metals concentration in agricultural soils (mg/kg)

Parameter	South Africa	Europe	USA	Australia and New Zealand
Cd	2	1-3	20	3
Cr	80	-	1,500	50
Ni	50	30-75	210	60
Pb	6.6	50-300	150	300
Zn	46.5	150-300	1,400	200
Cu	6.6	50-140	750	60
Co	20	-	-	-

Source: (Herselman et al., 2005).

According to Strande et al. (2014), heavy metals in domestic faecal sludge are usually below guideline values if at all present.

2.8.5 Moisture Content

Moisture content affects both the type and rate of processes that occur in a pit latrine. Low moisture content will limit the rate and extent of stabilisation of the sludge (Bhagwan et al., 2008). On the other hand, a pit latrine with high moisture content will promote anaerobic processes. In their study on soils, Ugolini and Edmonds (1983) indicated that most aerobic micro-organisms cease to function when the moisture content increases beyond 30 percent by volume. They attributed this phenomenon to the fact that at high soil-moisture contents, oxygen is occluded hence only facultative and obligate anaerobic bacteria can function. From these assertions, it can be concluded that moisture enhances the anaerobic biodegradation processes. Christensen et al. (1989) indentified four areas that moisture affects to result in the enhancement of the anaerobic biodegradation process as follows:

- It facilitates the exchange of substrate nutrients;
- It acts as a buffer and also dilutes inhibitory substances;
- It helps in the spreading of microorganisms to cover all areas in the pit; and
- It helps in the exclusion of oxygen from the pit contents thereby promoting anaerobic conditions.

Buckley et al. (2008) observed that beyond a moisture baseline level of 76 percent, gas production rate increased by a rate of between 0.006 and 0.02 mL gas/g total

solids per one percent increase in moisture content. Related studies conducted on solid waste also revealed an increase in methanogenic activity with the increase of moisture content (Le Hyaric et al., 2012; Jiunn et al., 1996).

2.8.6 Residence time

The natural biochemical reactions associated with faecal sludge in pit latrines are slow processes that require time to attain completion. The longer the residence time, the more stabilised the faecal sludge in the pit (Strande et al., 2014). Biodegradation processes in pit latrines in some cases can take years before the faecal sludge attains full stabilisation. Still (2002) reported faecal sludge in pit latrine that had not reached full stabilisation after five years of abandonment. With respect to microbiological characteristics, Franceys et al. (1992) observed that residence time in the pit has an effect on the sanitary quality of the sludge. They attributed this sanitisation effect to the fact that microorganisms are not able to survive because of high temperatures associated with the decomposition process over time. According to Feachem et al. (1983), pit latrine contents that have been left undisturbed for one year would virtually be pathogen free except for a few *Ascaris* eggs.

On their investigation into the long term risks associated with deep row entrenchment of pit latrine and wastewater treatment works sludge for forestry and land rehabilitation purposes, Still et al. (2015) concluded that over time, sludge buried in the soil dewaters and decomposes and turns to a material similar to background soil. With respect to some critical parameters, they observed that after a period of 48 months:

- COD decreased from 0.25 g COD/g dry sample to 0.05 g COD/g dry sample;
- The volatile solids decreased from 60 to 3 percent;
- The moisture content reduced from 75 to 13 percent; and
- *Ascaris* levels were the same as in background soil samples.

The above results indicate that the longer the residence time, the more stabilized and sanitized the faecal sludge becomes which underscores the importance of residence time in faecal sludge treatment.

2.8.7 Hydrogeological and soil characteristics of the surrounding environment

The nature of geology and soil surrounding a pit latrine has a huge influence on the reactions occurring in the pit. This is because geology and soil determines the permeability of the surrounding environment which in turn affects the movement of moisture in and out of the pit latrine (Buckley et al., 2008). Where pit latrines are unlined or only partially lined and located in a permeable geology, the level of the water table with respect to the faecal sludge level in the latrine will greatly affect the quality of the sludge. The effects are attributed to the processes of leaching and infiltration (Strande et al., 2014). It would therefore be expected that for latrines within project sites sited on dolomite, infiltration and leaching would greatly impact on the quality.

2.9 Faecal sludge Characterisation

It has generally been acknowledged that there is currently a lack of detailed information on the characteristics of faecal sludge (Bassan et al., 2013). From the available quality data, it has been observed that there is high variability (Strande et al., 2014). The high variability is attributed to a number of factors including the geology, climate, customs, user habits, design of facilities and the method of sludge collection (Bassan, et al., 2015). In addition to the highlighted factors, the lack of standardised methods for the characterisation of faecal sludge is also cited as one major reason (Schoebitz et al., 2014). In most cases, methods used for faecal sludge characterisation are adopted from wastewater and some may not be well adapted (Strande et al., 2014).

2.10 Resource Potential of Faecal Sludge

Faecal sludge is a resource that can be used for several purposes (Fanyin-Martin et al., 2017). It can be used for biogas production and also as a source of organic matter which can be used as a soil conditioner and plant nutrients (Singh et al. 2017; Daniel and Reed, 2010). Where subjected to treatment, treatment processes result in end products that have the potential for resource recovery and value creation (Strande et al., 2014). Table 2-5 summarises some of the identified potential uses of faecal sludge both in its raw and treated states.

Table 2-5: Summary of potential resource recovery options from faecal sludge

Produced Product	**Treatment or Processing Technology**
Soil conditioner	Untreated Faecal Sludge Sludge from drying beds Compost Pelletising process Digestate from anaerobic digestion Residual from Black Soldier fly
Reclaimed water	Untreated liquid faecal sludge Treated plant effluent
Protein	Black Soldier fly process
Folder and plants	Planted drying beds
Fish and plants	Stabilisation ponds or effluent for aquaculture
Building Materials	Incorporation of dried sludge
Biofuels	Biogas from anaerobic digestion Incineration/co-combustion of dried sludge Pyrolysis of faecal sludge Biodiesel from faecal sludge

Source: Strande et al., (2014)

When considering reuse of faecal sludge, it is always important to recognise its hazardous nature. Strande et al. (2014) indicate that there are many specific health and safety concerns that are associated with the emptying, transport, and discharge of faecal sludge which they categorised into physical, chemical and biological hazards (refer to section 2.10.3). As such, it is imperative that adequate appropriate measures are instituted to enhance safety and health of both the people who may come into contact with the sludge and those consuming faecal sludge derived products (e.g. crops). Faecal sludge for use in agricultural activities therefore needs to be sanitized before use or reuse (Fidjeland et al., 2013). Singh et al. (2017) identifies composting, vermicomposting, shallow trenching, anaerobic digestion and solar drying as some of the technologies that can transform faecal sludge into a useful sanitized resource. The sections below discuss faecal sludge reuse options with a bias towards biogas generation and application in agricultural activities which are currently the commonest faecal sludge applications in Zambia. It should be noted that reusing faecal sludge does not only yield the immediate benefits associated with the derived products but also has the potential to enhance the sanitation value chain with respect to FSM. It can improve the operations and

maintenance at the point of generation and can also impact positively on public health and environmental sustainability (Bates, 2007).

2.10.1 Biogas generation using faecal sludge

Biogas is a product that is realized from the anaerobic digestion of faecal sludge (Murray-Muspratt et al., 2014). As stated in section 2.7.2.1, it stems from the organic matter. Therefore, the more unstabilised the sludge, the more biogas that can be generated per unit mass of the sludge (Elmitwalli et al., 2011). Theoretically, a gram of COD produces a maximum of 0.35 liters of methane under Standard Temperature and Pressure (STP) (Araujo et al., 2008). This follows from the stoichiometry on the oxidation of organic matter which is presented in equations 5 and 6.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ ---------- ***Equation 5***

$C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2$ ---------- ***Equation 6***

By computing the amount of oxygen required to biodegrade organic matter and the quantity of methane anticipated from the same organic matter, a relationship between organic matter and methane production can be established. From equation (5), 192g of oxygen is required to biodegrade one mole of organic matter. But then, one mole of organic matter produces three moles of methane (equation 6). Since one mole of a gas occupies 22.4 liters volume under STP, three moles will occupy a volume of 67.2 liters. It therefore follows that 192g of COD will produce 67.2 liters of methane which implies that a gram of COD will yield 0.35 liters of methane.

In terms of mass, by relating equations 5 and 6, 192g of COD will yield 54g of methane. This translates into a methane production potential of 0.28g of methane for every gram of COD digested. Hamilton (nd) approximates the theoretical methane production at 0.25g and 0.4 liters per gram of COD while Kirk and Bickert (2004) report a theoretical conversion rate of 0.395 liters of methane per gram of COD. However, it should be noted that it is only the biodegradable component of the COD that results in the generation of biogas.

It should be realised that faecal sludge usage as feedstock in biogas generation will not only help to stabilize it but will also contribute to reducing the problem of global warming. The use of biogas would lead to less reliance on fossil fuels (Yogita et al., 2012) which generate huge amounts of Green House Gases (GHG). A further advantage is that when captured and reused, biogas which is predominantly methane is converted to carbon dioxide and water. Gupta and Singh (2012) compared the Global Warming Potentials (GWP) of the three gases associated with wastewater treatment namely carbon dioxide, methane and nitrous oxide. Their findings were that ton for ton, methane has a GWP that is 25 times more than that of carbon dioxide. This therefore means that carbon dioxide is a friendlier GHG than methane implying that biogas usage would help reduce greenhouse effects by a factor of 25 (Table 2-6).

Table 2-6: The GWP of GHGs produced in WWTPs

Gas	**Chemical Name**	**GWP (Factor)**
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298

Source: IPCC Fourth Assessment Report, 2007 in Gupta and Singh (2012)

2.10.2 Faecal sludge usage in agriculture

Reuse of treated faecal sludge for agricultural purposes has benefits in that it makes available the organic matter and nutrients contained in human excreta for beneficial purposes (Singh et al., 2017; Strande et al., 2014; Winblad, 1997). Utilisation of excreta (treated or/and untreated) for agricultural purposes emanates from the fact that both urine and faeces are rich in nutrients and are comparable to chemical fertilisers (Drangert, 1998). Because of this, there is a general shift on perception of faecal sludge from being a waste to a resource (Otterpohl, 2000). However, effective and efficient use of faecal sludge requires development of management and treatment strategies and technological options for faecal sludge to foster optimum recycling of nutrients and organic matter while at the same time being adaptable to the local situations and needs (IWMI, 2003). This is an aspect that currently needs strengthening in most countries. In Zambia, although initiatives for reuse are being implemented, the platform for reuse in most cases is not optimized (Nyambe et al., 2010). To address this gap, the National Urban Sanitation Strategy, under

Component 4 advocates for *"strengthened Commercial Utilities for sanitation service chains including faecal sludge management"* with one of the objectives being to *"increase the proportion of wastewater and faecal sludge treatment as per national standards and promote reuse".* The strategy directs Commercial Utilities to (GRZ, 2015):

i) investigate demand for treated wastewater and sludge;
ii) promote recycling of sludge;
iii) promote wastewater reuse; and
iv) increase resource recovery of nutrients and energy contained in wastewater and sludge.

The fertigative properties of faecal sludge stems from the nutrients it contains which originate from food consumption (Strande et al., 2014). The composition of the nutrients in the components of excreta, which are urine and faeces vary.

2.10.2.1 Composition and plant availability of nutrients in urine

Urine has high content of nitrogen of which between 75 and 90 percent is excreted as urea. The remainder is excreted as ammonium, creatinine, amino and uric acid (Rafie et al., 2012; Jönsson et al., 2004). The urea, in the presence of urease, is quickly converted to ammonium and carbon dioxide and the hydroxide ions produced normally increase the pH to 9-9.3 (Jönsson et al., 2004; Esrey et al., 1998). The plant availability of urine nitrogen is the same as that of chemical urea or ammonium fertilizers. This is because 90 to 100 percent of urine nitrogen is found as urea and ammonium (Pradhan, 2010; Kirchmann and Pettersson, 1995).

Almost all the phosphorus present in the urine is inorganic and is excreted in the form of phosphate ions (Jönsson et al., 2004; Esrey et al., 1998). These ions are directly plant-available hence the comparatively good fertigative properties of urine to artificial fertilizers or vice versa. Both phosphorus and potassium in urine are also in forms which are directly plant-available (Jönsson et al., 2004).

2.10.2.2 Composition and plant availability of nutrients in faeces

Whereas urine mostly has water-soluble nutrients, faeces contain both water-soluble and combined nutrients. About 50 percent of the nitrogen and the majority of the

potassium in faeces are water soluble. Phosphorus is mainly found as calcium phosphate particles which are slowly soluble in water. However, potassium is present as dissolved ions (Jönsson et al., 2004).

Since major proportions of the phosphorus and nitrogen in faeces stem from undigested matter which needs to be degraded in the soil to become available to plants, plant availability of the nutrients in the faeces is lower and slower than that of the urine. However, upon biodegradation of the organic matter, the 'trapped' nutrients then become available to plants (Jönsson et al., 2004).

The high concentrations of phosphorus, potassium and organic matter in faeces can give substantial yield increases, especially on poor soils. The presence of organic matter in the faeces makes it a potential soil conditioner. Its potential for soil conditioning stems from its ability to (IWMI, 2003):

- improve the soil structure;
- increase the water-holding capacity of the soil;
- increase the buffering capacity of the soil; and
- support the soil microorganisms by serving as an energy source.

2.10.3 Health and safety considerations in Faecal Sludge Reuse

Reuse of faecal sludge may pose health and safety risks to people who would directly or indirectly come in contact with it (Strande et al., 2014; Fidjeland et al., 2013). The risks may be attributed to the presence pathogenic microorganisms in the sludge (pathogenic health risks) or to the physical and chemical parameters (non-pathogenic related risks) (Strande et al., 2014).

2.10.3.1 Pathogenic health risks

Sanitation systems aim at forming a barrier against the spread of diseases caused by pathogens in the human excreta. Caincross and Feachem (1990), postulates that in fresh faeces, there are four main groups of organisms of concern to humans which are:

- bacteria;
- protozoa;

- viruses; and
- helminths.

These microorganisms are expected to be found in pit latrine contents and depending on the extent of the treatment, may also be present in treated sludge. Sanitation related diseases are therefore of specific importance in waste reuse schemes (IWMI, 2003). Reuse of untreated or inadequately treated faecal sludge for agricultural purposes can cause significant excessive infection with intestinal nematodes in both field workers and consumers of the produced crops. However, adequate treatment reduces or completely eliminates the risk of transmission (Fidjeland et al., 2013; Blum and Feachem 1985). Wherever sludge needs to be used for agricultural purposes, it needs to conform to specified standards and guidelines (Amoah et. al., 2017). In terms of helminths, the United States Environmental Protection Agency (US EPA, 1993) sets a standard of 0.25No. of eggs/g of faecal sludge while WHO, (2006) puts the guideline value at 1No. of eggs/g of faecal sludge.

The main factors influencing die-off rate of pathogens in faecal sludge include temperature, moisture content, nutrients and organic matter content, microorganisms, sunlight and pH (Strande et al., 2014; Carrington, 2001; Esrey et al., 1998). Table 2-7 summarises how each of the identified environmental factors need to be manipulated to speed up the die-off rate.

Table 2-7: Environmental conditions and how they need be manipulated to speed up the die-off rate of pathogens

Environmental Factor	**How**
Temperature	Increase in temperature
Moisture	Decrease in moisture
Nutrients (organic matter)	Decrease in nutrients
Microorganisms (including other pathogens)	Decrease in organisms
Sunlight	Increase in sunlight
pH	Increase in pH

(Source: Esrey et al., 1998)

2.10.3.2 Non-Pathogenic risks

Non-pathogenic risks result mostly from direct exposure of humans to physical, chemical and biological hazards associated with faecal sludge (Strande et al., 2014).

Non-biodegradable waste in faecal sludge in form of sharp objects like broken glass may pose health and safety risks especially to the workers. They might also promote the proliferation of vectors like rodents which may lead to disease outbreaks (IWMI, 2003).

Other forms of non-pathogenic risks may arise from chemical parameters especially heavy metals. The most hazardous ones to humans are cadmium, mercury, and lead. Copper, zinc, chromium, and nickel in high concentrations are particularly poisonous to plants. The concentration of metals in sludge cannot be decreased by sludge treatment (Strande et al., 2014). When the faecal matter is stabilised, the organic matter content decreases resulting in an increase in the metal concentration on a gram of heavy metals per gram of faecal sludge basis. High heavy metal concentrations in food meant for human consumption poses carcinogenic risks (Mishra et al., 2010).

2.11 Gap Analysis

In this chapter, data has been reviewed on a number of aspects linked to FSM including the availability of faecal sludge quality data which is the gist of this study. Several scholars have given views on faecal sludge quality data from the availability and variability perspectives. Strande et al. (2014) presents a world view of the FSM status. On the aspect of availability, they hold that faecal sludge quality data is generally lacking worldwide. This assertion is also echoed by Schoebitz et al. (2014) who further states that of the little data available, the majority is on septic tanks which they say also show high variability making predictions difficult.

It has been indicated that for the effective and adequate design of FSM systems, it is critical that faecal sludge quality data is generated which should be based on the local context (Strande et al., 2014; Schoebitz et al., 2014; Bassan et al., 2013). Bassan et al. (2013) gives an example of a plant designed based on imported faecal sludge quality data that ended up being overdesigned by a factor of two. This underscores the need to base the designs of faecal sludge treatment facilities on local faecal sludge quality data.

An analysis of the available local publications of faecal sludge quality data reveals a glaring gap as there has been no study that has been undertaken to generate this data. The closest research on the local context was a study by Phiri et al., (2014). However, this research did not look at pit latrine faecal sludge quality data. It instead concentrated on faecal sludge from wastewater facilities and that from UDDTs. Further, the focus of this research was on treated sludge and the analysis was restricted to microbiological parameters (Also refer to section 2.6). It is therefore clear that there is a gap on the availability of pit latrine faecal sludge quality data in terms of rheological, physical, chemical and microbiological parameters. This study therefore explored an area that had not been researched on before and was designed to address this identified knowledge gap.

2.12 Chapter summary

This chapter reviewed literature relating to the area of study. It revealed that a bigger proportion of the population in the study area resides in peri-urban areas and depend on onsite facilities for excreta disposal especially pit latrines. The chapter indicated that systems for the management of faecal sludge are not well established to accommodate the faecal sludge that is generated from the onsite facilities resulting in a large percent of the generated faecal sludge to accumulate in the residential environment. The review also showed that there are initiatives to reverse the situation in Zambia but that there is paucity of critical data necessary for effective implementation of responsive FSM system including faecal sludge quality data. The chapter further revealed that there has so far been no study to generate comprehensive faecal sludge quality data that can be used in the effective design of facilities and other initiatives to improve the current sanitation situation. This chapter therefore underlined the need for pit latrine faecal sludge quality determination to support efforts in designing treatment facilities and resource recovery initiatives aimed at fostering FSM in Zambia and hence improving sanitation. The ensuing chapter discusses the methodological approach that was designed to address the set objectives of the study.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 Introduction

This study aimed at answering several questions relating to faecal sludge quality in pit latrines with the aim of devising an operations framework for improving FSM service provision especially in peri-urban areas. To this effect, the research sought to answer the research questions and prove the hypotheses presented in sections 1.4 and 1.5, respectively. A critical analysis of the available literature on the research topic which is comprehensively presented in Chapter 2 resulted in the identification of knowledge gaps thereby providing support for the significance of this research. This section summarises the underpinning philosophical orientation of the study and the methodology that was employed in this research.

3.2 Philosophical orientation of the study

Philosophical orientation of any scientific study forms the backbone for the adopted research strategies including data collection and data analysis methods making it imperative that the researcher is aware of the orientation of his/her study well in advance (Crotty, 1998). According to Easterby-Smith et al. (2002), there are at least three reasons why it is important to understand the philosophical orientation of any study as follows:

- It helps researcher to better clarify the research design through consideration of the type of data required, the methods to employ in the collection of the data and how it is to be interpreted;
- It helps the researcher recognize which of the research designs can work and which ones cannot thereby enabling him/her to avoid wasting time on designs that are not workable and at the same time revealing the limitations of each of the identified approaches; and
- It can help researchers in the identification and creation of designs outside the confines of their past experience and may also serve as a stepping-stone for the adaptation of the research designs to better respond to the identified research constraints.

Easterby-Smith et al. (2002) also opine that a clear definition of the philosophical assumptions enhances the quality of the research and contributes to the

resourcefulness of the researcher. This assertion is echoed by Scotland (2012) who indicates that an understanding of the underpinning philosophical orientation will help to improve the researchers' ability with respect to: -

- comprehension of the research;
- application of theory;
- engagement in academic debate; and
- presentation of their own research findings.

Crotty (1998) contends that the methodology selected in any research should be guided by assumptions made about reality and on our perception of human knowledge. He further submits that in any research, a research process should fully address the objectives of the study. This therefore implies that the research process needs to be guided by the researcher's perception of the nature of reality and the process of acquiring the knowledge about this reality which are the main issues that underlie the philosophical debates. Easterby-Smith et al. (2002) categorises philosophical assumptions that underpin the different research paradigms into four categories which are summarised in Table 3-1 below.

Table 3-1: Summary of the categories of philosophical assumptions

Category	**Definition**
Ontology	Philosophical assumptions about the nature of reality
Epistemology	A general set of assumptions about ways of inquiring into the nature of the world
Methodology	A combination of techniques used to inquire into a specific situation
Methods and techniques	Individual techniques for data collection and analysis

Source: (Easterby-Smith et al., 2002)

The above assumptions are discussed in the ensuing sections after which a summary of the philosophical orientation of this study is presented.

3.2.1 Ontology

Ontology is a philosophical discipline, namely the branch of philosophy which deals with the nature and structure of "reality". It relates to the nature of reality and its characteristics (Easterby-Smith et. al. 2012; Guarino et al., 2009; Kuipers, 2007).

Ontology can better be understood through the following questions (Sarantakos, 2005; Cohen et al. 2000):

i) is reality of an objective nature or the result of individual cognition or subjective?

ii) is it a given 'out there' in the world, or is it created by one's own mind? and

iii) What does the research focus on?

Ontology therefore refers to whether a researcher's perception of the social world is as an entity that is external to social actors or is something that people are in the process of shaping (Bryman, 2012). In ontology, the interests are in discussions on what reality is and what kinds of phenomena are real. Easterby-Smith et al., (2012) submit that ontology can be distinguished into four categories (Table 3-2).

Table 3-2: Four different ontologies

Ontology	**Truth**	**Facts**
Realism	Single Truth	Facts exist and can be revealed
Internal Realism	Truth exists but is obscure	Facts are concrete but cannot be accessed directly
Relativism	There are many truths	Facts depend on the view point of the observer
Nominalism	There is no truth	Facts are all human creations

Source: (Easterby-Smith et al., 2002)

In realism, the social world is perceived as an entity that exists externally and that, its properties can be assessed objectively. On the other hand, relativism and nominalism, which have contradictory perceptions to those of realism, contend that reality is determined by people and that the researcher needs to focus on what people, either individually or collectively feel and think. In this case, the researcher needs to provide explanations on why people have different experiences (Bryman, 2012; Easterby-Smith et al., 2002).

3.2.2 Epistemology

Epistemology simply refers to how researchers know what they know. Easterby-Smith et al. (2002) assert that epistemology is about different ways of inquiring into the nature of the physical and social worlds. Epistemology is therefore, literally, the theory of knowledge which should dictate the principles and rules to employ for the exploration of the social phenomena and how knowledge can be demonstrated

(Mason, 2002). According to Sarantakos (2005), epistemology poses the following questions:

- How do we know what we know?
- What is the way in which reality is known to us? and
- What kind of knowledge is the research looking for?

Easterby-Smith et al. (2002) present two traditional approaches on how research may be conducted namely positivism and social constructivism which may be considered as the two research paradigms. The overarching principle assumption in the positivist paradigm is that *"the social world exists externally, and that its properties should be measured through objective methods, than being inferred subjectively through sensation"* (Easterby-Smith et al., 2002). From the ontological standpoint, positivism goes with realism which contends that the social world is an entity that exists externally whose properties can be assessed objectively. Hence the task of the researcher in this context is to gather facts and carry out measurements.

Social constructivism on the other hand is literary the opposite of positivism. Its viewpoint is that reality is not objective and exterior, but is socially constructed and given meaning by people (Easterby-Smith et al., 2002). In other words, Social Constructivism concentrates on how people make sense of the world especially through sharing of experiences with others through the medium of language. In this context, the researcher's role is to appreciate the different constructions and meanings people place upon their experience. Cardinal differences between the two paradigms are presented in Table 3-3.

Table 3-3: Contrasts between positivism and social constructivism paradigms

Item	**Positivism**	**Social Constructivism**
The observer	Must be independent	Is part of what is being observed
Human interests	Should be irrelevant	Are the main drivers of science
Explanations	Must demonstrate causality	Aim to increase the general understanding of the situation
Research progresses through	Hypothesis and deductions	Gathering rich data from which ideas are induced
Concepts	Need to be defined so that they can be measured	Should incorporate stakeholder perspectives

Table 3-3: Continued

Item	Positivism	Social Constructivism
Units of analysis	Should be reduced to simplest terms	May include the complexity of 'whole' situations
Generalisation through	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

Source: (Ramanathan, 2008; Easterby-Smith et al., 2002)

3.2.3 Methodology

Ghosh (1992) refers to methodology as *"the correct arrangement of thoughts either for the discovery or for the exposition of truth"* and emphasises on the need to have a correctly designed methodology to enable a researcher realise a correct or exact knowledge which needs to be established. Sarantakos (2005) defines methodology as the nature of research design and methods seeking to answer the questions:

- How do we gain knowledge about the world? and
- How is research constructed and conducted?

Research methodology therefore does not only talk of the research methods but also gives consideration to the logic behind the methods adopted in the context of the research study and explains why a particular method or technique is being used and why other methods are rejected. All this is done so that research results are capable of being replicated and/or evaluated either by the researcher himself or by others (Kothari, 2004).

Methodological assumptions focus on analysis of the methods used to collect the data (Cohen et al., 2000). In the positivist paradigm, quantitative methodologies are usually employed in the collection of data. It uses mathematics to compute results and draw generalizations of the findings. In other words, it relies on empirical data and is therefore also referred to as an empiricist paradigm. In contrast, in the social constructivism paradigm, qualitative methodologies are usually exploited. In this paradigm, the collected data is subjected to rigorous analysis aimed at interpreting the collected views to arrive at a conclusion. It is therefore also referred to as the interpretive paradigm. Major differences between the quantitative and qualitative approaches are summarised in Table 3-4 below.

Table 3-4: Comparisons between quantitative and qualitative approaches

Question	Quantitative approach	Qualitative approach
What is the purpose of the research?	• To explain and predict • To confirm and validate • To test (or verify) theory	• To describe and explain • To explore and interpret • To build (or generate) theory
What is the nature of the research process?	• Focused • Known variables • Established guidelines • Static design • Context free • Detached view	• Holistic • Unknown variables • Flexible guidelines • Emergent design • Context bound • Personal view

Source: (Sarantakos, 2005)

3.2.4 Summary of the research

The need to identify the ontological inclination of the research at the onset of the research was explained in Section 3.2. Sarantakos (2005) postulates that ontology, epistemology, and methodology dictate the paradigms that are adopted for any particular research. Figure 3-1 below summarises how the chosen ontology influences research methods, epistemology, research approach, research strategy and data collection and analysis methods.

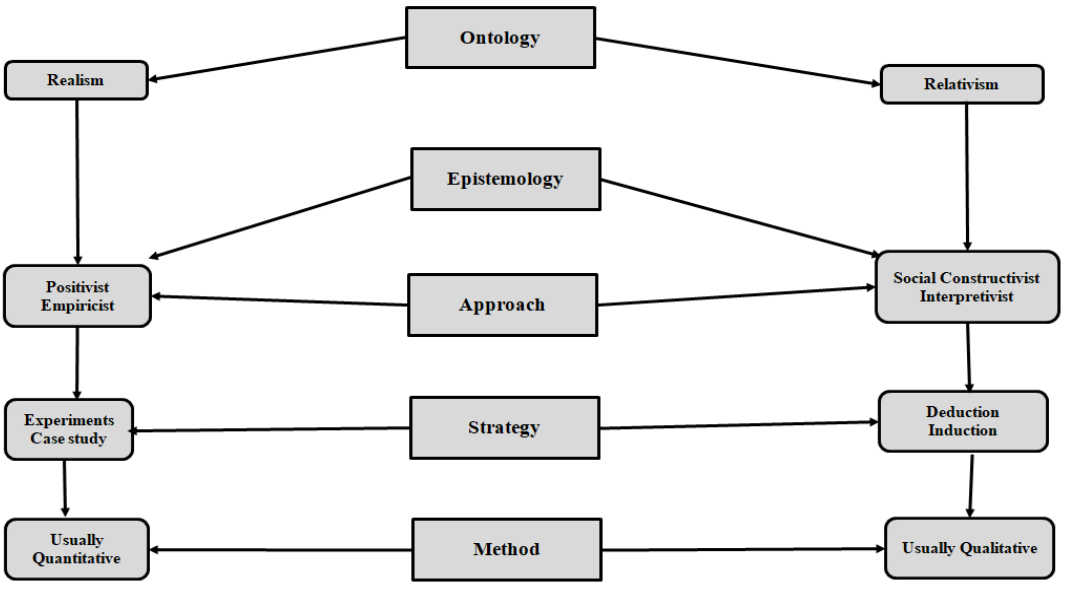


Figure 3-1: Illustration on how the choice of ontology influences methods, epistemology, approach, strategy and data collection and analysis methods (Source: Adapted from Easterby-Smith et. al. 2012; Sarantakos, 2005; and Crotty; 1998)

This study sought to characterise pit latrine faecal sludge within peri-urban areas in order to generate comprehensive faecal sludge quality data which could aid the design of effective FSM systems in peri-urban areas. The researcher's ontological view point was therefore Realism which contends that facts exist and can be revealed. The epistemological perspective was positivist (empiricist) paradigm which assumes that the social world exists externally, and that its properties should be measured through objective methods, than being inferred subjectively through sensation. With a realist ontology and a positivist epistemology, the research was therefore generally guided by the quantitative methodology which requires the use of fixed designs and quantitative methods which Sarantakos (2005) summarises in 13 points as presented in Table 3-5.

Table 3-5: Central criteria of quantitative research

S/N	Criteria
1	It uses empirical methods
2	It observes objectivity
3	It adopts value neutrality
4	It is clear in design and procedure
5	Ensures that the researcher is detached from subjects of research
6	It relies on measurements and quantification
7	It requires accuracy and precision
8	Results can be replicated
9	It uses representative samples and results can be generalised
10	It strictly relies on methods and their results
11	It employs rigorous, disciplined, systematic and reality bound procedures
12	It requires a strict research design that is constructed before commencement of the research
13	It should have ethical considerations

Source: Sarantakos, (2005)

It should however be pointed out that qualitative approaches were also utilised on some aspects of the study although this was on a very limited scale and was limited to understanding the general sanitation situation in the project sites in the initial stages of the research. Section 3.3 presents the research design for this study.

3.3 Research Design

Yin (2003) defines research design as *"the logical sequence that connects the empirical data to a study's initial research questions/ and ultimately, to its conclusions"*. Yin also states that research design can be thought of as the plan of research dealing with at least four problems which may be summarised as in Figure 3-2.

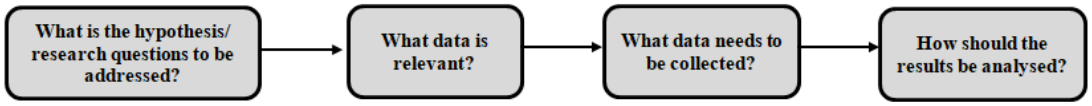


Figure 3-2: Presentation of the main questions to consider in coming up with a research design. (Source: Based on data from (Yin, 2003)).

In the formulation of the research design, it is critical that under the question *"What data needs to be collected"*, the researcher also needs to answer the following questions:

- Where the data needs to be collected from; and
- How it should be collected.

These two questions where critical in this research as the research required identification of appropriate research sites representative of the city-wide situation. There was also need to design appropriate means of sample collection.

Based on the developed hypotheses and research questions of this study, the research design was formulated and is presented in Figure 3-3.

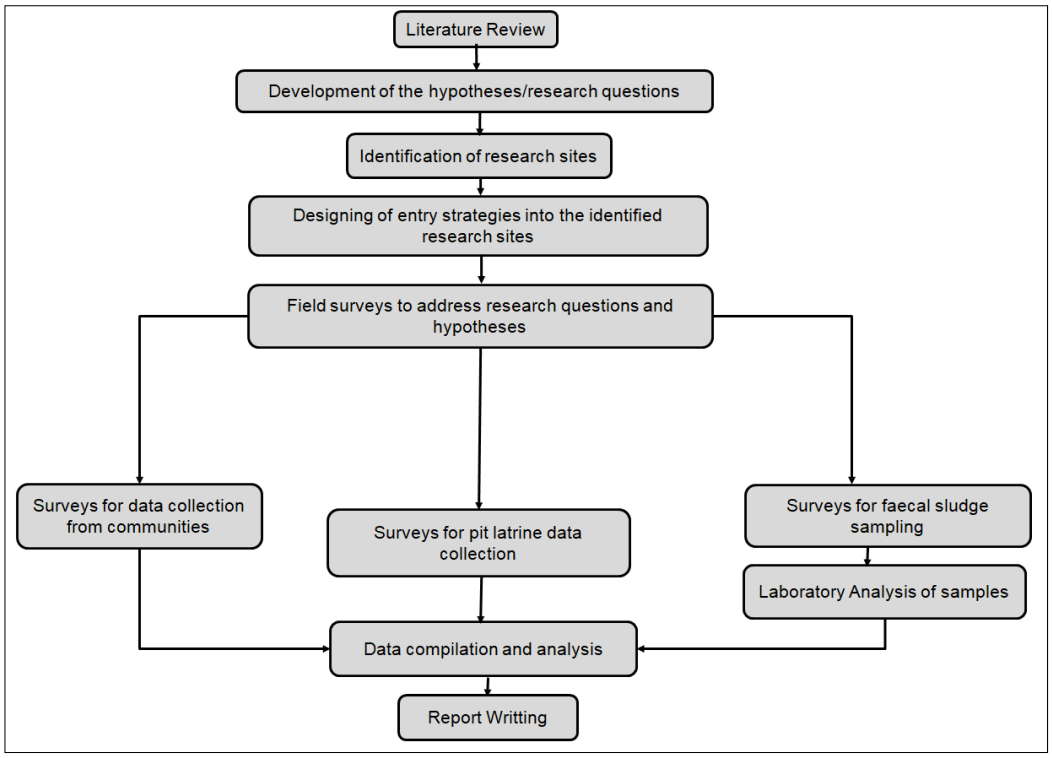


Figure 3-3: Graphical presentation of the research design for the study

An elaboration of each of the stages presented in the above figure is given in the ensuing sections.

3.4 Study area selection

The study area selected for this research was Lusaka, the capital city of Zambia. Four peri-urban areas were selected as study areas which included Chaisa, George, Kanyama and Madimba settlements (Figure 3-4).

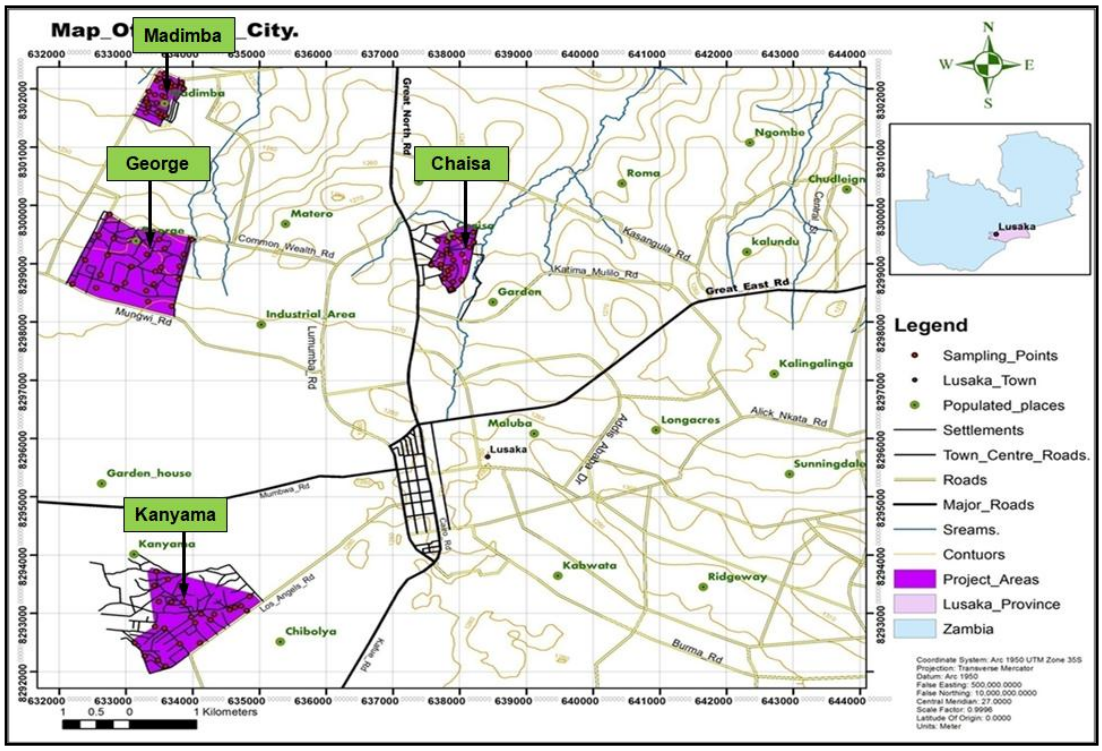


Figure 3-4: Location of the study areas in relation to the City Centre (Modified from GIS Maps)

The main criteria used for the selection of these areas included the following:

- **Availability of an active Ward Development Committee (WDC):** The research was sensitive as apart from just collecting data about usage of on-site sanitation facilities and faecal sludge from residents, it involved collection of faecal sludge samples from private pit latrines. This therefore required the involvement of the WDCs to facilitate this process.

- **Coverage of the geo-physical characteristics in Lusaka:** The selected study areas were chosen to cover the major different geological characteristics prevalent in the city. This implies that the selection of the study areas covered both areas sited on limestone/dolomite and Schists which are the major underlying geological features in the city.

Kanyama, George and Madimba compounds are predominantly on dolomite while Chaisa is exclusively on schist geology. Within the compounds, areas are affected differently in terms of inundation and differ from season to season according to the amount of precipitation received in each respective rain season. The degree to which the research areas get inundated is dependent on several factors including the

topography and hydrogeological characteristics of the area. Kanyama, mainly due to the flatness of the terrain and poor drainage systems sometimes gets completely inundated in the rain season. Madimba, especially the southern part is mostly waterlogged for a bigger part of the year because this portion of the area is located on a swampy area. On the other hand, Chaisa does not get inundated to the same level as the other areas because it is sited on an area that is on a naturally well drained area.

3.5 Entry strategy into research sites

In order to respond to the objectives of the research, data needed to be collected from a number of sources but mostly from the selected study areas. This required the researcher to get familiarised with the project sites as well as the institutional arrangements with respect to FSM in the study areas. It was therefore imperative that rapport between the researcher and the relevant stakeholders in the study areas was established in advance to avoid unforeseen challenges later during the research. According to Johl and Renganathan (2010), failure to obtain access to the study area is one of the greatest drawbacks a researcher can face when conducting research. They also indicate that access can be even more difficult to gain if the research topic is sensitive. This research was sensitive and as such, matters of access were of paramount importance. Okumus et al. (2007) observed that in research, there will always be issues with gaining access to the research site which may even be beyond the researcher's control. To avoid this possible snag in this study, a strategy was therefore devised which involved:

- Publicising the research at a city level; and
- Publicising the research in the selected study areas.

These activities were conducted through workshops as explained in the sections below.

3.5.1 Inaugural workshop with stakeholders at a city level

A workshop was organised with stakeholders at the city level as a way of introducing the research. Stakeholders for this workshop were personnel from various institutions and organisations including:

- The Local Authority;

- The water utility;
- Water Trusts;
- Research and learning institutions;
- Government ministries especially those involved with issues of sanitation in peri-urban areas like the MLGH and MoH;
- All WDC senior representatives from selected sites;
- NGOs involved in sanitation at the local level like the Network for Environmental Concerns and Solutions (NECOS), the Water and Sanitation Association of Zambia (WASAZA), the Bremen Overseas Research Agency (BORDA), Water Supply and Sanitation for the Urban Poor (WSUP) and NGO-WASH.

Figure 3-5 presents some of the stakeholders that were present at the workshop.

Figure 3-5: Part of the stakeholders who attended the inaugural workshop.

The purpose of this workshop was to introduce the research to relevant stakeholders with the ultimate aim to have the research appreciated by the various relevant stakeholders. Among the major issues discussed at this workshop were:

- The sanitation status of the city;
- The sanitation initiatives by several stakeholders including the water utility (LWSC); and
- Aims and objectives of this research.

3.5.2 Workshops with community members in the study areas

Riding on the inaugural workshop, follow-up workshops were conducted in the four identified study areas. In all the areas, the workshops were coordinated through the WDCs with the exception of Madimba Compound where NECOS spearheaded the organisation of the workshop. People invited to these workshops included members of the WDCs, all stakeholders within the project areas involved with issues of sanitation like the Neighbourhood Health Committees (NHC), Health workers and selected community members. The major objectives of these workshops were:

- to introduce the research to stakeholders at community level; and
- to formally request for WDC members to work with the research team during the various aspects of the research that required data collection from the study areas.

Figure 3-6: Community workshops in research sites. (LHS: The researcher facilitating at a workshop with residents of George study area; RHS: Part of the participants for the Madimba study area workshop)

These workshops together with the inaugural workshop helped to create an enabling environment for implementation of the other project activities in the study areas which are discussed in subsequent sections. Small teams from among the WDC members and residents were identified at these workshops to assist the researcher with establishing links to specific areas within the study areas where data was to be collected. This included liaison with households where samples from pit latrines were to be collected.

3.6 Field surveys

Most of the data required to address the objectives of this research was generated from the field surveys and laboratory analyses of samples collected from the field. Field surveys were therefore designed to aid the collection of data and information

necessary to address the research objectives. These surveys were divided into three categories as follows:

- Surveys for data collection from communities;
- Surveys for pit latrine data collection (assessment of the latrines selected as sampling points; and
- Surveys for faecal sludge sampling.

3.6.1 Surveys for data collection from communities

Data on sanitation from the four proposed study areas was partly collected using Focus Group Discussions (FGDs). Although the research was predominantly quantitative, this approach was justified in the early stages of the study to gather preliminary data on the research topic and to get people's perceptions on the sanitation situation in the project sites. Stewart et al. (2007) states that FGDs are exploratory and may therefore be helpful in the early stages of a research which may be followed up with other qualitative or quantitative surveys that would provide more precise data. They advance seven uses for FGDs as follows:

- To gather general background information on a topic of interest;
- For gathering participants' perceptions on the research topic which can assist with the design and construction of other research tools such as questionnaires;
- To establish research hypotheses that can be tested through larger quantitative methods;
- For the purposes of triggering new ideas and innovative concepts;
- For identifying potential challenges with a new programme or service;
- For creating impressions of services, programmes or products; and
- To aid with the analysis of previously obtained quantitative results.

In this study, the main objectives of the FGDs was to gather general background information on some aspects critical to the study including:

- General information on the type of facilities in the study areas;
- Construction aspects of the facilities and challenges associated with building of facilities in the study areas; and
- General operational aspects of the facilities.

The discussions were guided by a FGD Guide presented in Appendix A. Each of these FGDs constituted not more than 20 participants. According to Morgan (1998), the group should be limited to about 10 to 12 participants although in this case, it was not possible to stick to 12 as the maximum number due to the many relevant stakeholders in the study areas. Limiting the group size in a FGD is cardinal to enhance effective participation as smaller groups guarantee an interesting discussion and at the same time are easier to control. Morgan (1997) submits that managing deliberations of a larger group can be difficult, especially in situations where all participants are conversant and involved in the topic under discussion.

According to Stewart et al. (2007), soliciting data through FGDs is a good strategy for data collection as agreement between group members can build an elaborated and fuller picture of views on an issue whilst disagreement between group members may lead participants to defend or change their views thereby providing further explanations.

It should be noted that most of the participants in the FGDs were purposively selected to ensure they had knowledge and expertise on the subject under investigation. In terms of gender, the participants were mixed and in all cases, they were drawn from WDCs, Community Based Enterprises (CBEs) and community based NGOs with a stake in sanitation provision and community members resident in the project areas.

3.6.2 Surveys for pit latrine data collection

This research required advance identification of pit latrines to be used as sampling points for the faecal sludge sample collection. In addition, it was imperative that for each latrine selected, data on the physical characteristics of the latrine were collected together with the household demographical data. It was also critical that the general geological characteristics of the location were assessed. Therefore, two main activities were undertaken as follows:

- Identification of latrines to be used as sampling points; and

- Collection of the demographical data of the respective households, collection of latrine physical characteristics and assessment of the hydrogeological characteristics of the area.

A total of 100 latrines, 25 from each study area were selected to serve as sampling points. The number of latrines adopted for the surveys in each area was not based on statistical considerations as this would have resulted in a huge number of samples that could not have been manageable with the resources that were available. For example, using statistical tables, the smallest study area, Madimba, which had about 600 households, would have required a sample size of 234 for a confidence level of 95 percent and an error of margin of 5 percent (Krejcie and Morgan, 1970). For all the study areas, the sample size would have been over 1,000 which would not have been manageable. However, the adopted numbers were still sufficient to provide data upon which objective generalisation of the results could be made.

The selection of the 25 pit latrines from each area was done through stratified purposive sampling of households. Each of the study areas was first zoned to ensure that the whole area of interest was covered. Pits from households were then purposively selected. This was necessary to ensure that selected pits had enough sludge in them to allow for the collection of two samples at different depths. It should be noted that the sampling adopted in this study was in situ sampling where two sets of samples were collected from each pit; one from the top and the other from the bottom of the pit, respectively (refer to section 3.6.3.2). Stratifying of the study areas ensured an even distribution of the sampling points to ensure that the selected sampling points were representative of the areas under survey. The selection criteria of the pit latrines included:

- **Accessibility:** It was important that all latrines selected for sampling were accessible. Therefore, unless unavoidable, only latrines that were accessible by vehicle were selected;
- **Amount of sludge in the latrine:** Only latrines with enough faecal sludge to allow for collection of samples at two vertical profiles (Top and Bottom) were adopted;

- **Permanency of the structure:** Pits selected were those that were permanent (at least those that were not visibly makeshift). This was to ensure availability of the structure throughout the study period; and
- **Usage of the facility:** Pits used exclusively for excreta disposal as well as those that combined excreta and sullage disposal were selected.

In each of the study areas, hydrogeological and socioeconomic conditions were more or less the same and therefore these factors were not used as part of the criteria for selecting sampling points. The selected sampling points were mapped in Google Maps to ensure traceability of the points throughout the duration of the study. The Google Maps for all the four study areas together with the identified sampling points are presented in Appendix B.

In order to collect demographical data and other important characteristics for each of the latrines selected for sampling, a simple structured household survey questionnaire was used (Appendix C1). The questionnaire was designed to aid the collection of data on number of users, hydrogeological information, physical dimensions of the latrines and aspects related to usage and operations of the facilities. Respondents were household heads or spouses and the mode of questionnaire administration was personal face-to-face (Figure 3-7). A summary of the data collected from this exercise is presented in Table C2-1 Appendix C2.

Figure 3-7: Collection of household demographic data and aspects of latrine operations and maintenance (Source: This study)

Data on latrines critical to faecal sludge quality, which could not be collected from interviews, was assessed through observations and measurements. Data collected through observations included the geo-physical characteristics of the locations and some aspects of the latrine construction details which were used to triangulate responses from household interviews. Data collected through measurements was

mostly on dimensions of the latrines including the height of the faecal sludge in the pit. The length and width of the pits were estimated by measuring the outside dimensions of the latrine and then subtracting the wall thickness. The depth of the pit and that of the accumulated sludge was estimated through probing with a dipping rod (Figure 3-8).

Figure 3-8: Latrine data collection (LHS: Measuring the dimensions of the pit latrine; Middle and RHS: Determination of faecal sludge depth in a latrine using a dipping rod).

3.6.3 Surveys for Faecal sludge sampling

Three types of faecal sludge sampling were undertaken in this study as follows:

- Sampling for determination of grit and other forms of solid waste;
- Sampling for physical, chemical and microbiological parameters; and
- Sampling for rheological parameters.

3.6.3.1 Sampling for determination of grit and other forms of solid waste

In this study, solid waste in the faecal sludge was categorised as either grit or other forms of solid waste. Therefore, in this section and in the rest of the report, solid waste will refer to the inorganic constituents found in pit latrines excluding grit.

Samples for the quantification of grit and solid waste were collected from the desludged barrels. A total of eight pits were sampled for this purpose. These were not among the pre-selected 100 pits. It should be noted that the number of pits sampled for this purpose were low. However, the results obtained (section 4.2.2) still provided quantitative data to support the qualitative findings on the content of solid waste and grit in faecal sludge. This area will obviously require further exploration.

In this particular survey, samples were collected as pit latrines were being emptied by the desludging team (Kanyama Water Trust). The choice of the latrines to sample in this case was therefore dictated by the latrines earmarked for desludging by the Trust which were all not among the 100 latrines that had been identified for

sampling at the start of the study (see section 3.6.2 and also refer to Appendix B). However, it should be noted that although these latrines were not from the ones that were preselected for sampling, their characteristics in terms of construction and usage where generally aligned with the latrines that had been identified for sampling for which interviews were conducted. The sampling was designed based on the number of barrels that were to be desludged. The Trust offers three options for desludging as follows (Holm et al., 2015):

- 12 barrels of 60l capacity;
- 24 barrels of 60l capacity; and
- 32 barrels of 60l capacity.

Depending on the number of barrels being desludged, a sampling criterion was devised for the selection of barrels to be collected for analysis as presented in Table 3-6.

Table 3-6: Barrels to be collected for analysis depending on the number of barrels being desludged from a pit

Number of barrels desludged	**Number of barrels collected from pit**	**Sequencing of barrels collected for analysis**
12	3	4^{th}, 8^{th} and 12^{th}
24	3	4^{th}, 14^{th} and 24^{th}
32	3	4^{th}, 18^{th} and 32^{nd}

The selected barrels were properly labelled and were later transported to the Kanyama Faecal Sludge Treatment Plant where separation of the grit, solid waste and excreta components of the faecal sludge was done. From each of the three barrels earmarked for quantification and characterization, three smaller samples were collected for analysis of moisture content. This moisture content analysis was intended to help in the approximation of the dry excreta component of the faecal sludge. The collection of these samples was therefore done in a way that avoided collection of solid waste and grit as far as it was possible. The laboratory analysis of moisture content for all the collected samples was carried out at University of Zambia Environmental Engineering Laboratory. The analysis was done in accordance with the standard protocols specified in the American Public Health

Association/American Water Works Association Standard for Water and Wastewater Examination (APHA, 1998).

i) **Quantification Procedure for the solid waste and grit**

The quantification started with the weighing of the faecal sludge contained in the barrels (Figure 3-9). This was done by weighing the total mass of barrel filled with sludge, which was recorded as mass (A). The mass of the dry barrel was also recorded after all the contents had been removed, which was recorded as (B).

Figure 3-9: Weighing of the barrel together with the faecal sludge before separation (Source: This study)

1. Separation of the Excreta Component of the Faecal Sludge from the Grit and Solid Waste

Separation of the excreta component of the faecal sludge from the rest of the contents (i.e. grit and solid waste) was done using water. In order to reduce on chances of washing out the solid waste and grit due to agitations as the water was flowing out, the contents of the barrel were first divided into two portions to create enough room for expansion of the FS bed during washing. Each portion was then washed separately and gently using a hosepipe in each respective barrel. The washing continued until all the excreta component was washed off from the sand/grit and the solid waste. This separation was facilitated by the differences in densities, the agitation and continued injection of water into the barrels. The overflowing water, which carried with it the excreta component of the faecal sludge, was channelled into the anaerobic digester (Figure 3-10).

Figure 3-10: Washing of faecal sludge to separate the sludge from grit and solid waste (Source: This study)

2. Quantification of the solid waste and grit

During the washing of the faecal sludge, the solid waste was manually separated from the contents. After all the excreta had been washed off, the remaining solid waste that could not be separated during washing was manually sorted out from the grit. The solid waste was then thoroughly air dried for two days. The dried waste was then weighed and the mass was recorded (Mass C).

Total Mass of Sludge = A – B

Total Mass of Dry Solid Waste = C

Solid Waste Content (D as % of wet sludge) = (C/(A-B)) x 100 ----- ***Equation 7***

After the thorough washing and removal of all the solid waste, the grit that remained was also air dried for two days as was the case for the solid waste. The air dried grit was then weighed in the field and the mass was recorded (Mass E). As the drying of grit was not thorough, samples were then collected from the air dried grit for moisture content analysis in the laboratory. The mass of the dried grit was then computed as in the equation 8.

Mass or air dried grit = E

Moisture content of air dried grit = X%

Mass of dried grit (F) = (E x (1-X/100)) ---------- ***Equation 8***

The grit content in the wet sludge expressed as a percent was then computed using equation 9.

Grit content (G as % of wet sludge) = (F/(A-B)) x 100 ---------- ***Equation 9***

Both solid waste and grit content in the dry faecal sludge were computed by expressing the masses of the computed dry solid waste and grit as a percentage of the total mass of dry faecal sludge. The total dry mass was computed by summing up the masses of the dried solid waste, the dried grit and the dry mass of excreta, which was approximated by multiplying the mass of the excreta component of the faecal sludge by the solids content percentage. Thus, the excreta component of the dry faecal sludge was computed as per equation 10.

Mass of dry excreta component of FS = ((A-B)-(C+F))x (1-MC/100) --***Eqn 10***

Where MC is the moisture content of the faecal sludge. Results for both grit and solid waste contents are presented in section 4.2.2.

3. Characterisation of the Solid Waste

After the solid waste was quantified as explained in section (2) above, it was sorted into the following categories: plastics, glass, textiles, paper, metals, organic waste and others (Figure 3-11). The sorting was done manually. The separated fractions were then weighed and their masses were computed as percentages of the total dry mass of the solid waste. Detailed results are presented in section 4.2.2.

Figure 3-11: Examples of some constituents from the fractionated solid waste (LHS: Plastics; Middle: organic waste; RHS: Textiles)(Source: This study).

3.6.3.2 Sampling for physical, chemical and microbiological parameters

According to Bassan et al. (2014), faecal sludge sampling and analysis is a field that is not yet standardised which normally results in high variability of analytical results. Strande et al. (2014) submit that faecal sludge quality results are strongly influenced by the way samples are collected and the laboratory methods and practices used in the analyses of the samples. In order to reduce on this variability, this study adopted procedures and methods proposed by Reddy (2013) which have been used extensively in the analyses of faecal sludge in South Africa and the SADC Region. These methods are based on APHA (1998).

In the collection of samples for the determination of physical, chemical and microbiological parameters, it was imperative that undisturbed samples from the latrines at the desired depth profiles were collected. Sampling was therefore aided by a modified sampling tool specifically engineered to collect relatively uncontaminated samples at different depths of interest in the pit. The tool or sampler was designed with a mechanism to facilitate opening and closing at a required depth. This facilitated collection of samples at the desired depth after which the sampler could be closed so that the sample was not contaminated as the sampler was being pushed in or pulled out of the pit (Figure 3-12).

Figure 3-12: Faecal sludge sampling with the modified sampling tool (Source: This study)

From each latrine, two sets of samples were collected: one set comprising three samples at the top and the other set also comprising three samples from the bottom of the latrine. Three equal portions of the sample were collected from each horizontal level (i.e. top and bottom). These were put in a 2.5-liter container where they were then thoroughly mixed until a homogeneous sample was obtained. From

this homogenised composite sample, three aliquots were collected in 250 mL sampling containers (Figure 3-13). These samples were immediately put in cooler boxes containing ice packs in readiness for transportation to the laboratory for analysis.

Figure 3-13: Faecal sludge sampling (LHS: Homogenisation of the sample in a 2.5 litre container; Middle: Transferring a homogenized sample into a labeled sampling container; LHS: Collected samples ready for transportation). (Source: This study)

It should be noted that sampling for the physical, chemical and Microbiological parameters was undertaken in two campaigns as follows:

- Samples for physical and chemical parameters were collected in the dry season of 2016 in the months of September and October. In this campaign, only 58 of the 100 identified latrines were sampled; and
- Samples for microbiological parameters were collected in the dry season of 2016 in the months of July to August 2016. In this campaign, samples were collected from all the 100 identified pit latrines.

3.6.3.3 Sampling for rheological parameters

Sampling for rheological parameters was conducted on samples from 11 of the 100 selected pit latrines from the study areas. Four latrines were from Chaisa, two from Madimba, two from George and three from Kanyama. From each latrine, several samples were collected at different depths as presented in Table 3-7. The idea behind collecting several samples was to establish the variability of rheological properties over the depth profile of the pit latrine. The samples were collected using the modified sampling tool as presented in section 3.6.3.2. After collection of the samples, all the solid waste was manually removed. The sample was then put in sampling container without disturbing it before transferring it to the cooler box. This process was repeated for the various depths. Samples were only collected for the dry season (July, 2017) and the number of samples collected from each pit was guided

by the depth of the pit with more samples being collected from pits where the depth of the faecal sludge was large enough.

Table 3-7: Sampling points and depths for rheological samples

Study Area	Pit ID	Source (Depth in cm)	Bottle Number
Chaisa Compound	**C008**	0	1
		50	2
		100	3
		150	4
		200	5
	C005	0	6
		30	7
		60	8
		90	9
	C003	0	10
		30	11
		62	12
		88	13
	C014	0	14
		30	15
		60	16
Madimba Compound	**M009**	0	17
		40	18
		74	19
		107	20
	M006	0	21
		25	22
		40	23
George Compound	**G021**	0	24
		40	25
		80	26
		110	27
	G015	0	28
		35	29
Kanyama Compound	**K009**	0	30
		30	31
		45	32
		75	33

Table 3-7: Continued

Study Area	Pit ID	Source (Depth in cm)	Bottle Number
Kanyama Compound	**K010**	0	34
		25	35
		56	36
		70	37
	K017	0	38
		25	39
		65	40
		80	41

The samples were then properly packaged into cooler boxes before exportation to KwaZulu Natal University (UKNZ), Durban, South Africa for analysis.

The sample size of 11 pits may be on the lower side to generalise the results to the city of Lusaka. The limitation on the sample size was due to logistical consideration. As explained in the preceding paragraph, samples had to be exported. This is because there was no local capacity to undertake this type of analysis. However, the data obtained from this analysis was still adequate to provide insight on faecal sludge arrangement in latrines hence aiding in the discussion on variability of some parameters that were analysed.

3.7 Laboratory analysis of faecal sludge samples

Apart from the analysis of samples for the quantification of grit and solid waste that has been presented in section 3.6.3.1, laboratory analysis of faecal sludge samples in this study included:

- Laboratory analyses for physical, chemical and microbiological parameters; and
- Laboratory analyses for rheological parameters.

3.7.1 Laboratory analyses for physical, chemical and microbiological parameters

On each of the collected samples, physical, chemical, and microbiological parameters were analysed. For all physical and rheological parameters and selected microbiological parameters (*Ascaris* and *Cryptosporidium*), the analyses were carried out on the undiluted faecal sludge samples. For chemical parameters, direct

analysis was not possible. In this case, the faecal sludge was first diluted (Figure 3-14). The tests were then conducted on the diluted sample.

Figure 3-14 : Faecal sludge dilution (LHS: Faecal sludge in sampling containers before dilution; RHS: Diluted faecal sludge in 1 litre glass bottles) (Source: This study)

To formulate diluted samples from faecal sludge samples, 25 mL of faecal sludge was carefully measured out from the faecal sludge sample. The mass of this sample was weighed before it was transferred into a 250 mLbeaker where it was blended with about 200 mL of distilled water for about 30 seconds by vigorous mixing. The distilled water used in diluting the faecal sludge was normal distilled water whose conductivity and pH averaged 4.5 mMhos/cm and 6.5, respectively. The blended mixture was then transferred into a one litre volumetric flask which was then made up to one litre with distilled water. The resulting mixture was again vigorously shaken to obtain a homogeneous solution. The resulting solution was then transferred to a one litre glass bottle and this was the sample on which parameters that required dilution of the faecal sludge were conducted.

Moisture content was analysed on the undiluted sample. This was important as moisture content is an important input parameter in the transformation of analytical results from units of “mass/unit volume” to “mass/unit mass of dry sample”. Since the initial volume of sample used was 25 mL which was finally topped up to 1,000 mL, it means that all tests done on the diluted sample were done on a sample with a dilution factor of 40. Where other dilutions had to be done, then the results were diluted by a factor of 40 multiplied by the other subsequent dilution factors.

All the analyses were conducted in accordance with standard analytical protocols adapted from APHA (1998). The majority of the methods, especially for the analysis of chemical parameters yield results in mass per unit volume. For parameters where

it was desired to have results in ‘mass per unit mass of dry sample’, the conversion was done using equation 11.

*Mass/Unit Mass = ((Conc. in mass/unit volume) x (Volume used in formulation of Wastewater))/(Mass of wet Sample x (1- (Moisture content (in g/g)) ----------**Equation 11***

Table 3-8 presents physical, chemical and microbiological parameters that were analysed in the sludge together with the method of analysis and the methods detection limits. It should be noted that during sampling, for each composite sample, three aliquots were collected. This implies that for all samples, analyses were done in triplicates. This was important to allow for statistical analysis of the results in order to establish the degree of variability of the results.

3.7.2 Laboratory analyses for rheological parameters

Rheological analyses of the faecal sludge were conducted by the laboratory at UKZN using an Anton Parr MCR51 Rheometer. A cone-cup setup was adopted for this analysis. Before commencing the analysis, all equipment and apparatus were first cleaned and cleared of any obstructions which was followed by running the associated Anton PaarRheometer Software as a way of initialising the Rheometer. An appropriate cup attachment was installed ensuring that the corresponding cone measuring instrument was inserted and then the rheometer software was allowed to load to ensure calibration for the attached instrument. A desired test worksheet from the list of available worksheets within the software was selected and a temperature of 25 °C was set. The equipment was then allowed self calibrate at the set temperature. After the calibration, the measuring device was raised and the sample loaded to the specified volume marker in the cup. The measuring instrument was then lowered and the sample was allowed to ‘relax’ for 30 minutes, to negate the effects of structural deformation. The test was initialised for the selected program which was allowed to run up to completion. The measuring device was then detached from the machine head and raise above the cup before the sample was unloaded from the cup. Both the cup and measuring instrument were immediately cleaned in readiness for another test which followed the same procedure. Results for the analyses were downloaded from the computer and the full set tables are

presented in Appendix F1. The Standard Operating Procedures (SOPs) for this analysis are detailed in Reddy (2013).

3.7.3 Summary of parameters analysed together with adopted method of analysis

Physical, chemical, microbiological and rheological parameters were analysed in this study as elaborated in sections 3.7.1 and 3.7.2. Table 3-8 summarizes the method of analysis that was adopted.

Table 3-8: Parameters analysed in raw sludge and methods of analysis used.

Category	**Parameter**	**Method and Equipment**	**Method Detection Limit**
Physical	Physical composition: Grit/Solid waste (%)	Gravimetric	-
	Density (kg/m^3)	Gravimetric	-
	Total Solids (%)	Gravimetric; Oven- 105 °C	-
	Total Volatile Solids (%)	Gravimetric; Oven- 105 °C; Muffle Furnace – 550 °C	-
	Moisture Content (%)	Gravimetric; Oven 105 °C	-
Chemical	pH	Electrometric	-
	Ammonia ($mgNH_3$-N/L)	Spectrophotometric; Spectrophotometer- for use at 640 nm with a light path of 1 cm or greater	<0.01
	Sulphates (mg/L)	Turbidimetric; Spectrophotometer- for use at 420 nm with a light path of 1 cm or greater	<0.01
	Phosphates (mg PO_4^{3-} P/L)	Ammonium Molybdate Method; Spectrophotometer- for use at 400 nm with a light path of 1 cm or greater	<0.01
	Total and Soluble COD (mg O_2/L)	Titrimetric; Closed Reflux Method; Block digester with digestion tubes (16 x 100 mm).	2.0
	Light Metals: K, Mg, Na and Ca (mg/L)	Atomic Absorption Spectrophotometric method	<0.003for K
			<0.0002for Na
			<0.001for Ca
			<0.0003for K

Table 3-8: Continued

Category	Parameter	Method and Equipment	Method Detection Limit
Chemical	Heavy Metals: Co, Pb, Cr, Zn, Cd, Cu and Fe (mg/L)	Atomic Absorption Spectrophotometric method	<0.01for Co, Pb, Cr and Fe
			<0.005 for Zn
			<0.003 for Cu
			<0.002 for Cd
Microbiological	Faecal Coliforms (No.100mL)	Membrane Filtration Method	≤0
	Ascaris Lumbricoides (quantitative) (No./g)	AMBIC floatation and sedimentation method	≤0
	Ascaris Lumbricoides (Viability test) (No./g)	Crystal violet stain	≤0
	Cryptosporidium (No./g)	Modified Ziehl-Neelsen Stain Method	≤0
	Total BOD (mg O_2/L)	Winkler Method	2.0
Rheological	Viscosity (Pa-s)	Rheometer	-
	Shear Stress (Pa)	Rheometer	-
	Moisture Content (%)	Gravimetric; Oven-105 °C	-

3.8 Analyses and Interpretation of the field and laboratory analytical data

This study was predominantly quantitative involving laboratory analysis of various parameters (Table 3-8). However a bit of qualitative data was also collected in the early stages of the study to gather general background information on some aspects as elaborated in section 3.6.1. Various analyses were conducted on the collected data. The sections below presented some of the critical analysis that were performed on the data.

3.8.1 Analysis of qualitative data

The analysis of the small quantity of qualitative data collected in the study was through the process of synthesis, coding and interpretation and most of this data was used to triangulate the quantitative data collected through household questionnaires (section 3.6.2).

3.8.2 Analysis of quantitative data

All quantitative data collected through questionnaires was entered in Statistical Package for Social Sciences (SPSS) and transposed into excel data formats. Excel

was used to analyse all responses from the questionnaires to bring out statistical representation of data in graphs. Descriptive and inferential statistics were calculated to describe the responses.

For laboratory results, for each parameter and for all sampling points, data was compiled in tabular form (Appendices E, F1, G, H, I and J). For some parameters, the data was plotted into graphs using Microsoft Excel. Some of the generated graphs are presented within the main body of the thesis under respective sub headings while others are presented in Appendices F2 and K. It should be noted that for heavy metals, the values appearing as 0 simply indicate results below the methods detection limit for each respective parameter. Method Detection Limits for the adopted methods of analyses for all parameters are presented in Table 3-8.

3.8.3 Determination of distribution of the datasets

For all analytical data for faecal sludge quality parameters, the generated datasets were first subjected to the skewness and kurtosis analyses to determine whether the data sets were parametric or non parametric. In addition, means, medians and quartile parameters were also computed for all the parameters and the results of these analyses are presented in Appendix D. This analysis aided in the selection of appropriate statistical tools to use in the analyses of parameters where the significance of associations among and between data sets was required like in the determination of how significant the differences in the means were between the top and bottom sludge for parameters linked to biodegradable (section 4.5) and also in the determination of whether geological conditions have significant impacts on the faecal sludge quality (section 4.6).

3.8.4 Determination of outliers

Where determination of outliers in the data sets was required, the 1.5xIQR statistical rule was used. This rule specifies that in a data set all values outside the ranges given by the expression $(Q_1\text{-}(1.5\text{xIQR}))\leq X\geq (Q_3\text{+}(1.5\text{xIQR}))$ are outliers. In this expression, the definitions of the variables are as follows:

Q_1 = Lower Quartile: the data at the 25^{th} percentile of the data.

Q_3 =Upper Quartile: the data at the 75^{th} percentile of the data.

IQR = Inter Quartile Range: a measure of statistical dispersion, being equal to the difference between the upper quartile (Q_3) and lower quartile (Q_1), that is, IQR = Q_3 - Q_1.

3.8.5 Statistical determination of levels of association among and between datasets

To determine the significance of associations between and among datasets from the study areas, an algorithm was developed which was used in determining the appropriate statistical tools to employ (Figure 3-15). The first step in the algorithm was to decide on whether the tests was required to analyse significance of differences between or among data sets. The second step was to test whether the data was parametric or not after which an appropriate statistical tool could then be selected.

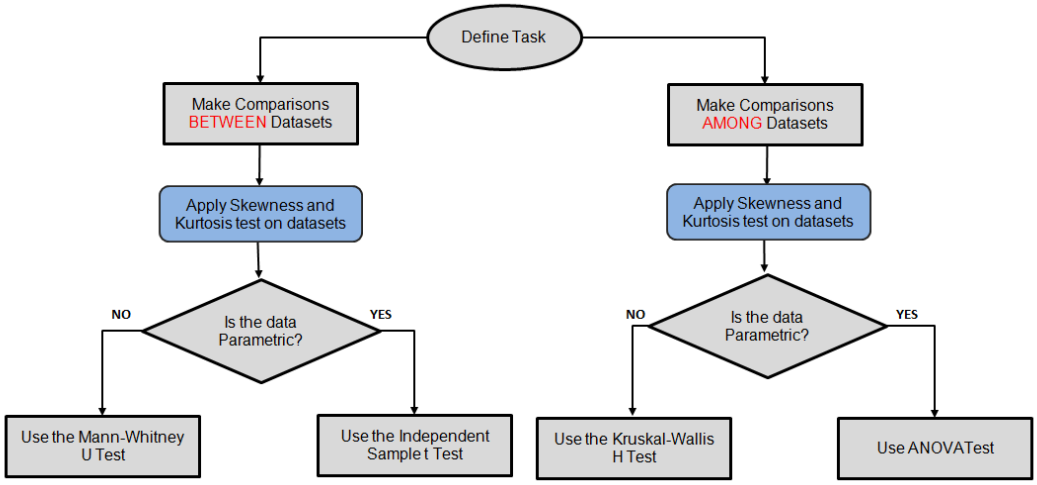


Figure 3-15 : Designed algorithm for determining suitable statistical tools to use in analysis of data

For analyses where there was need to identify the source of statistically significant differences among datasets, the sequence of the analysis was to first identify whether there were statistically significant differences among datasets. For whichever parameters yielded statistically significantly different results, the follow-up test would then be one between datasets (pair-wise comparisons) to establish which combinations from among the data sets were responsible for the observed statistically significantly different results.

3.9 Summary of the methods with reference to specific objectives

The methodology was designed to respond to the objectives of the study. The details of the methodology have been presented in detail in the preceding sections. This section now summaries the methods adopted for each respective objective. The main research tools that were employed are also highlighted (Table 3-9).

Table 3-9: Summary of the methods and tools employed for each specific objective

Objective	**Method (s) employed**	**Research tools/instruments**
To establish sanitation practices in peri-urban areas that impact on faecal sludge quality	• Household Interviews • FGDs • Observations	• Household questionnaires • FGD Guide
To determine the faecal sludge quality characteristics in pit latrines from a valorisation perspective at different depth profiles;	• Field Faecal Sludge Sampling • Laboratory Faecal Sludge Analysis	• Sampling protocols • Analytical protocols • Statistical packages
To determine whether faecal sludge quality is affected by geological characteristics of the area; and	• Field Faecal Sludge Sampling • Laboratory Faecal Sludge Analysis	• Sampling protocols • Analytical protocols • Statistical packages
To design an operations framework for enhanced FSM in peri-urban areas taking into account the quality and reuse potential of the sludge.	• Analysis of laboratory results • Analysis of reviewed literature	• N/A

3.10 Chapter Summary

This chapter evaluated and contrasted the various philosophical standpoints and identified the 'realism' ontology as the most appropriate study inclination embracing a positivist (empiricist) epistemology and accordingly, a quantitative methodology. It summarized the criteria used in the selection of the study areas and the entry strategy that was devised to access these areas. The chapter also highlighted the methods used in coming up with the sampling points that were used in the study. The methods for sample collection for the various parameters of interest namely physical, rheological, chemical and microbiological parameters have been highlighted. The analytical methods for these parameters have been highlighted and the methods employed in the analysis of the collected data have been presented. The next chapter presents results obtained from the various data collection methods presented in this chapter.

CHAPTER 4 : RESULTS

4.1 Introduction

A detailed description of the methodology employed in this study was elaborated in the previous chapter. This chapter presents the findings of the study. It is important to recall that the main focus of this study was to characterise pit latrine faecal sludge from peri-urban areas with the view that the generated data would aid the design of measures for effective FSM systems. To this effect, based on the faecal sludge quality data, the study aimed to design an operations framework for improved FSM provision in peri-urban areas and consequently contribute to improved sanitation provision in these areas. In order to address this objective, the study sought to address the research questions and hypotheses which were set forth in this study. The ensuing sections therefore present results according to the research questions/hypotheses. The results are discussed in Chapter Five.

4.2 Sanitation Practices

Sanitation practices have a profound effect on faecal sludge quality. The study therefore investigated practices in peri-urban areas in order to establish some aspects that may impact on the quality of the faecal sludge (refer to section 3.6.2 and Appendix C). These included:

- Latrine design and construction; and
- Latrine usage and operational aspects.

The sections below give details on each of the above aspects.

4.2.1 Latrine design and construction

Several different types of latrines exist in the study areas. From the latrine survey data, 63 percent of the latrines (n=100) were found to be in rocky geology with only 37 percent being located in pickable material. For the Kanyama study area, all the latrines were sited in a rocky geology. Although Madimba and George study areas are sited on a dolomite/limestone geology, some of the latrines were located in pickable material which happened to be isolated patches within the dolomite/limestone geology. For Chaisa study area which is predominantly sited on schist, 88 percent of the latrines surveyed (n=25) were in pickable material. Details on location of latrines with respect to study areas are presented in Figure 4-1 below.

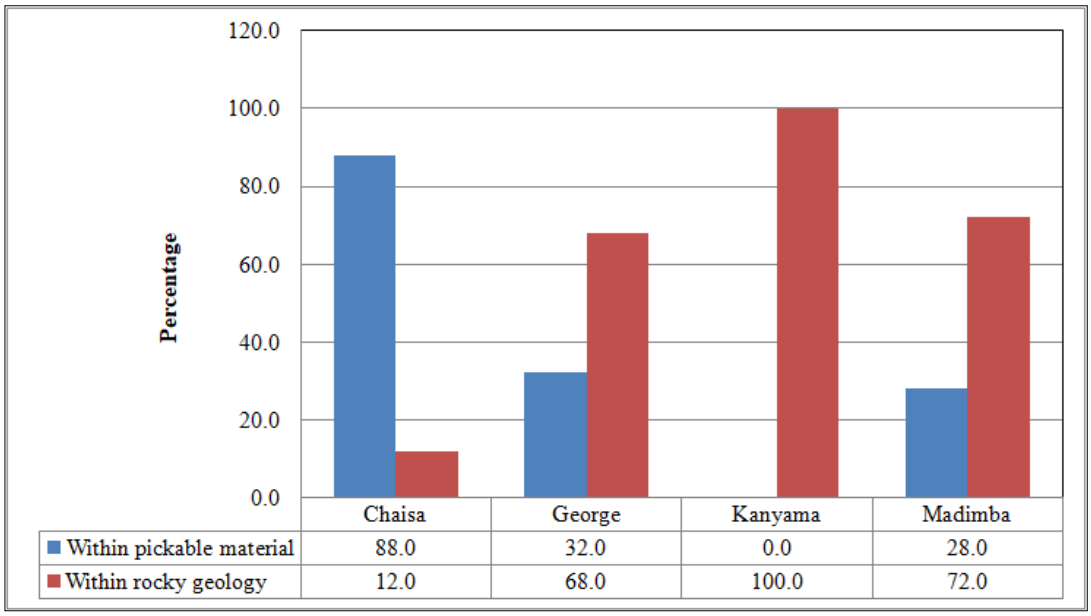


Figure 4-1: Geology type where selected latrines are located according to study areas (Source: Compiled by Author)

No standards existed to guide the design and construction of pit latrines in these areas. As such, latrine dimensions varied significantly between latrines. In terms of depth, the majority of the latrines in the study areas (30 percent; n=100) had overall depths falling in the range between 151 to 200cm (Figure 4-2).

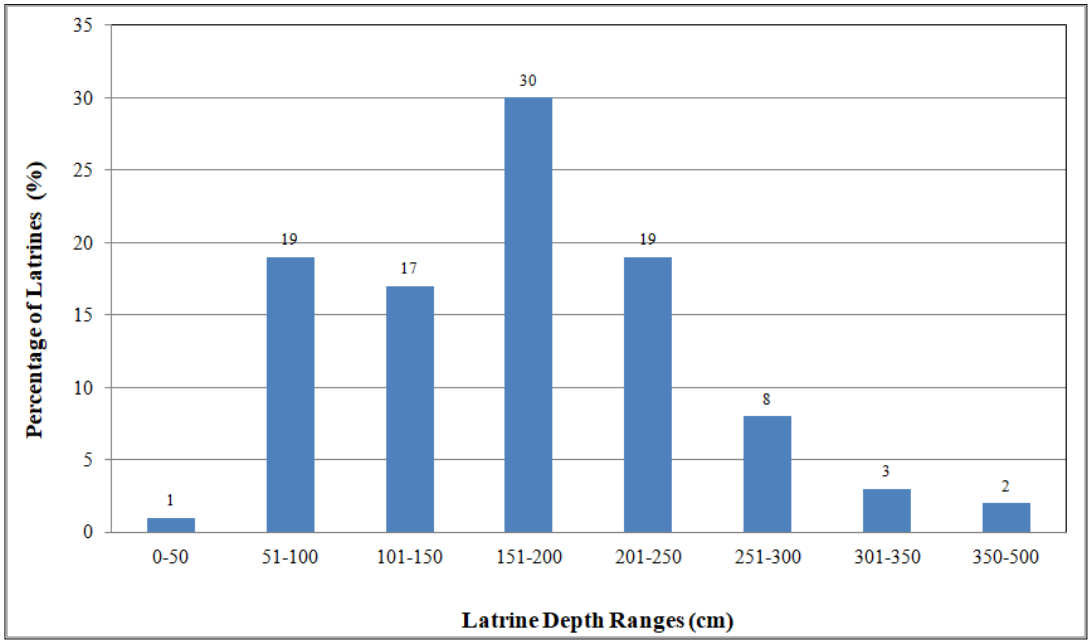


Figure 4-2: Latrine depth ranges in the study areas

In most cases, it was observed that pit latrines constructed on rocky geology could not be dug to satisfactory depths due to the underlying rocks. In such cases, the latrines were constructed with elevated vaults. Elevated vaults help to increase

storage capacity by providing space above ground level (Figure 4-3). For latrines with elevated vaults, the vault elevation was mostly around 0.6 to 0.8m above ground level.

Figure 4-3: Examples of pit latrines with elevated latrine vaults (Source: This study)

In some cases, latrine depths were in excess of 2m. For the three areas sited on dolomite, such cases were mainly in situations where the pits followed the caverns within the dolomite/limestone (Figure 4-4).

Figure 4-4: Example of latrine construction where the pit follows the profile of the caverns (Source: This study).

In terms of lining, 98 percent of the latrines were said to be lined. However, where it was possible to conduct physical observations, it was revealed that the lining was partial in most cases. The bottom in most cases was not fully sealed. In other cases as presented in Figure 4-4 above, although block work was provided on sides without rock outcrops, it was still evident that the lining did not result in 100 percent water tightness of the containment facility making it probable that the majority of the sampled latrines were only partially lined.

4.2.2 Latrine usage and operational aspects

Identified latrine usage and operational aspects with possible impacts on faecal sludge quality included the use of the latrines as receptors of excreta and sullage,

disposal of solid waste in the latrines, addition of chemicals to latrine contents and desludging. Results on these aspects are presented in the subsequent sections.

4.2.2.1 Use of the latrines as receptors of excreta and sullage

Latrines in the study areas were constructed to either exclusively serve as excreta disposal facilities (52 percent; n=100) or to serve both as excreta disposal facilities as well as bathing rooms (48 percent; n=100). In the later case, two scenarios existed: the first one where the same room served both as latrine and bathroom; and the second one where the latrine was separated from the bathroom. To determine whether this practice had significant impacts on the faecal sludge quality, results for phosphate and moisture content between latrines used for the dual purpose and those used specifically for excreta disposal were compared. Results for phosphates presented obvious differences (Figure 4-5).

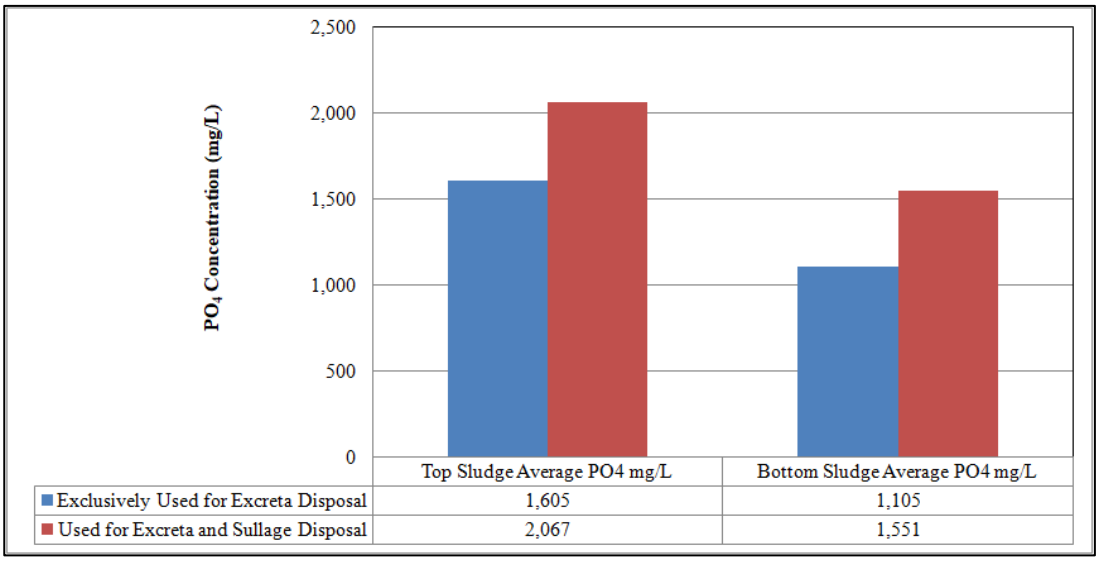


Figure 4-5: Comparative analysis of phosphates in latrines used for excreta disposal only and those used for both excreta and sullage disposal. (Source: Based on phosphate results in section 4.4.3.7 and latrine survey data presented in Appendix C2)

The differences in the phosphates results between the two types of latrines were not only noticeable but were also statistically significantly different. A Mann-Whitney U Test indicated significant differences in the results between the latrines exclusively used for excreta disposal and those serving the dual purpose of excreta and sullage disposal for top sludge (U=228.5, Z=-2.0413, n_1=41, n_2=17, p=0.0414 two tailed) and for bottom sludge (U=231, Z=-1.9986, n_1=41, n_2=17, p=0.0455 two tailed).

It was also hypothesized that latrines with ingress of sullage would be more diluted. However, an assessment of the moisture content in pit latrines exclusively used as excreta disposal facilities and those that were used for disposal of both excreta and sullage did not show this expected correlation (Figure 4-6).

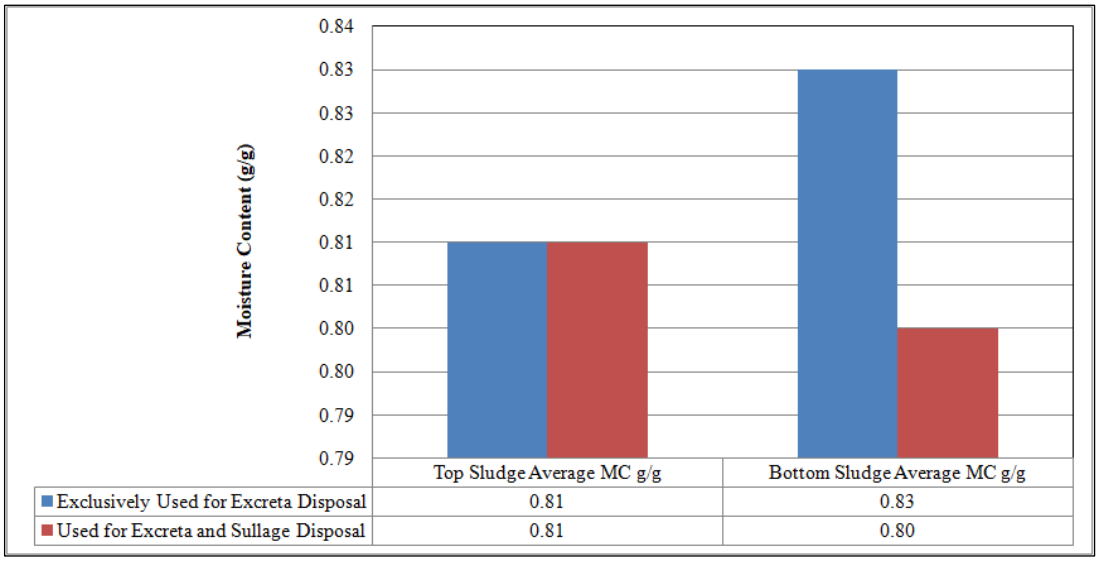


Figure 4-6: Comparative analysis of moisture content in latrines used for excreta disposal only and those used for both excreta and sullage disposal. (Based on moisture content results in section 4.4.1.2) and latrine survey data in Appendix C2)

The Mann-Whitney U Test indicated statistically insignificant differences in the means of the moisture content for facilities used exclusively for excreta disposal and those reported to serve the dual purpose (U=334, Z=-0.2392, n_1=41, n_2=17, p=0.8030 two tailed) for top sludge and (U=283, Z=1.1104, n_1=41, n_2=17, p=0.2670 two tailed) for bottom sludge.

4.2.2.2 Use of the latrines as receptors of solid waste

A physical qualitative survey of latrines revealed high content of solid waste of different types including plastics, textiles and so on (Figure 4-7).

Figure 4-7: Pit latrine contents showing presence of solid waste (Source: This study)

Analysis of solid waste on the desludged faecal sludge revealed high prevalence ranging from 3.5±2.2 to 34.6±8.5 percent of wet sludge and 10.1±4.7 to 51.6±4.2 percent of dry solids. Grit was also present in high concentrations ranging from 12.6±3.2 to 22.6±4.8 percent for wet sludge and 14.9±3.6 to 55.6±3.9 percent for dry sludge (Table 4-1). Pit latrine No. 5 (Table 4-1) had extreme values indicative of a pit latrine that was used almost as a waste dumping pit.

Table 4-1: Solid waste content in pit latrine faecal sludge (Mean±Sample Standard Deviation)

PIT No.	No. of samples analysed	SW* Content (% Wet Sludge)	SW Content (% Dry Sludge)	Grit Content (% Wet Sludge)	Grit Content (% Dry Sludge)	Total SW (% wet sludge)	Total SW % dry solids)
1	3	14.4±1.6	27.6±1.3	22.6±4.8	41.2±3.9	37	58.5
2	3	18.9±6.3	39.8±3.1	18.7±6.7	37.6±6.0	37.6	68.0
3	3	15.0±4.6	36.6±3.7	16.3±14.0	33.7±16.9	31.3	71.4
4	3	3.5±2.2	10.1±4.7	17.5±2.9	55.6±3.9	20.9	70
5	3	34.6±8.5	51.6±4.2	19.6±6.4	29.0±5.5	54.2	84.6
6	3	25.1±11.0	30.8±13.9	12.6±3.2	14.9±3.6	37.7	67.9
7	3	10.4±9.4	25.0±16.8	12.7±2.9	35.2±5.4	23.1	60.2
8	3	17.6±10.4	31.1±13.5	18.7±7.3	40.9±11.6	32	70.8
Mean	24	18.6±10.6	32.8±13.9	17.3±6.7	33.9±13.3	34.2±10.3	68.9±8.0

SW = Solid Waste

Due to the small sample size, the results on solid waste and grit content were also manipulated to generate quartile parameters (Table 4-2).

Table 4-2: Quartile values for the grit and solid waste content results

Quartile Parameter	SW Content (% Wet Sludge)	SW Content (% Dry Sludge)	Grit Content (% Wet Sludge)	Grit Content (% Dry Sludge)	Total SW (% wet sludge)	Total SW (% dry solids
Minimum	3.5	10.1	12.6	14.9	20.9	58.5
Lower Quartile	13.4	27.0	15.4	32.5	29.3	66.0
Q2 (Median)	16.3	31.0	18.1	36.4	34.5	69.0
Upper Quartile	20.5	37.4	18.9	41.0	37.6	71.0
Maximum	34.6	51.6	22.6	55.6	54.2	84.6
IQR*	7.1	10.5	3.5	8.5	8.4	5.0

IQR = Inter Quartile Range

A comparison between the means presented in Table 4-1 and the medians presented in table 4-2 shows marginal differences between the two parameters (Figure 4-8) which is indicative of data that is symmetrically distributed.

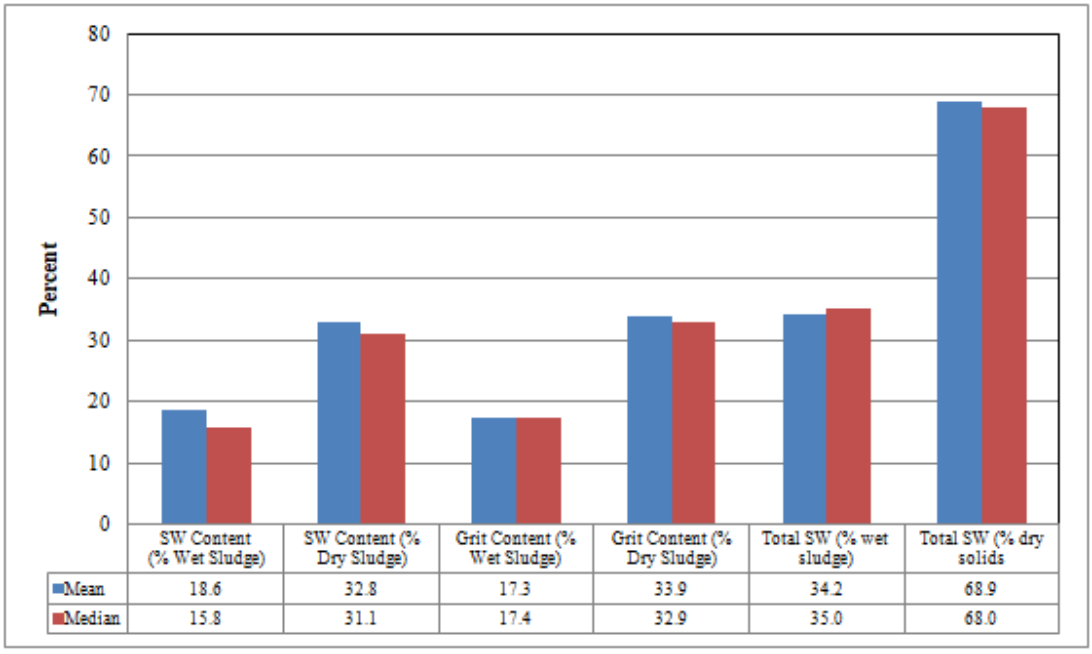


Figure 4-8: A comparison between the mean and median values for solid waste and grit

For the solid waste, the major constituent was textiles which included rugs, diapers, sanitary pads, sacks and so on (Figure 4-9).

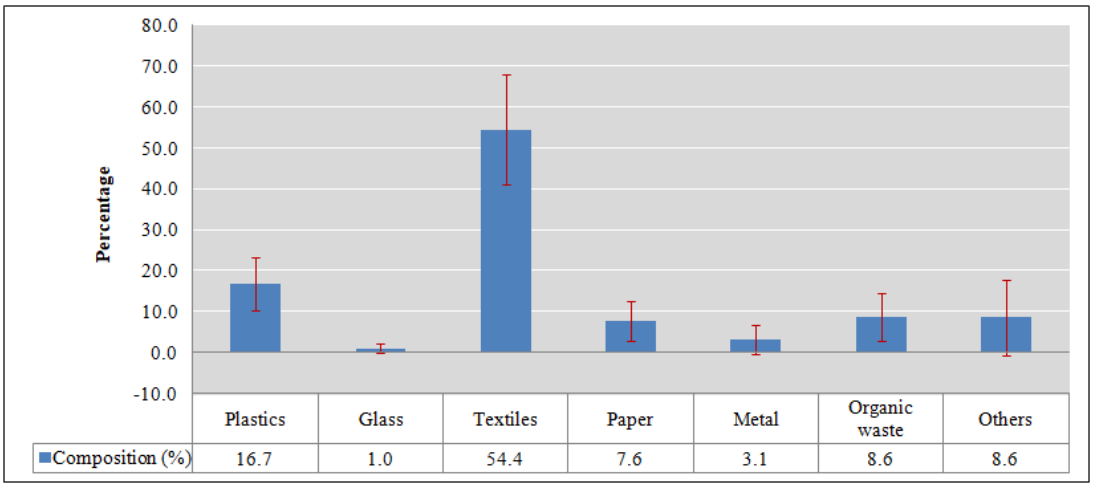


Figure 4-9: Composition of the pit latrine faecal sludge based on the eight sampled pits.

4.2.2.3 Addition of Chemicals to pit latrine contents

It was established that about 62 percent of residents (n=100) added chemicals to their latrines. According to the results from FGDs, chemicals were added to pit latrines for various reasons including:

- Addressing the problem of fly nuisance;
- Addressing the problem of smell;
- inactivation of pathogens in the pit latrines; and
- Enhancing digestion of faecal sludge to create more room when the latrines filled up.

Various chemicals were used among which the most common were reported to be chlorine and lime. However, the quantities added were not possible to quantify as addition was not guided by any standards. The wide spread usage of chemicals in pit latrines was reportedly due to the health and hygiene awareness campaigns in these areas which encouraged usage of chemicals.

To establish whether the practice of adding chemicals to pit latrines resulted in statistically significantly different results, the Mann-Whitney U test analysis was performed on pit latrines that reportedly got treated with chemicals and those that did not. Parameters chosen in the analysis included pH, Faecal Coliforms, Total COD and Total BOD which are likely to be affected by the chemicals that were reported to be used in study areas (i.e. chlorine and lime). The faecal sludge quality results for the parameters of interest were therefore analysed together with the latrine survey data on addition of chemicals (Appendix C2).

Results indicated marginal differences. The observed means for pH for both types of sludge were almost the same with results for samples where chemicals were reportedly added being only slightly higher (Table L-1 in Appendix L). Similarly, the metrics of organic matter biodegradation between samples from latrines where chemicals were dosed and those that reported no dosing of chemicals were also not statistically significantly different. No significant differences in microbiological quality were observed either despite the reported use of chlorine (Table 4-3).

Table 4-3: Results of the Mann-Whitney U Test on samples from latrines treated with chemicals and those where there was no addition of chemicals

Parameter	P	Conclusion
pH (-)		
Mann-Whitney U test between top sludge samples	0.1676	Not Significantly different
Mann-Whitney U test between bottom sludge samples	0.7642	Not Significantly different
Faecal Coliforms (No. CFU/100 mL)		
Mann-Whitney U test between top sludge samples	0.8026	Not Significantly different
Mann-Whitney U test between bottom sludge samples	0.9522	Not Significantly different
COD (mg O_2/L)		
Mann-Whitney U test between top sludge samples	0.6599	Not Significantly different
Mann-Whitney U test between bottom sludge samples	0.4654	Not Significantly different
BOD (mg O_2/L)		
Mann-Whitney U test between top sludge samples	0.5961	Not Significantly different
Mann-Whitney U test between bottom sludge samples	0.7263	Not Significantly different

Note: Refer to Table L-1 in Appendix L for comprehensive Mann-Whitney U Test results.

4.2.2.4 Desludging frequency of the latrines

Another activity investigated on operational aspects was the desludging frequency of the latrines. Of the total surveyed latrines (n=100), only 17 percent reported to have had their latrines desludged within a year prior to the time of the survey and the majority of the pits reported to have been desludged were from Kanyama. The majority of the respondents (51 percent; n=100) indicated that their latrines had never been emptied before with the majority in this category coming from Chaisa and George study areas (Table 4-4).

Table 4-4: Status on desludging for the sampled pits

Study Area	When the latrine was last desludged							Number of samples(n)
	Never	No Idea	1 Year	2 Years	3 Years	4 Years	Over 5 Years	
Chaisa	20	2	2	1	0	0	0	25
George	20	3	2	0	0	0	0	25
Kanyama	10	0	8	1	0	1	5	25
Madimba	2	1	5	2	1	3	11	25

To investigate the impacts of desludging on faecal sludge quality, the Mann-Whitney U Test was conducted on pit latrines reportedly desludge within a year prior to the sampling activity and those that were not desludged. Parameters used in the analysis included Total COD, Total BOD and Faecal Coliforms which yielded results presented in Table 4-5.

Table 4-5: Results of the Mann-Whitney U Test on samples from latrines never desludged and those reportedly desludged within not more than a year prior to sampling

Parameter	P	Conclusion
Faecal Coliforms (No. CFU/100 mL)	-	-
Mann-Whitney U Test between top sludge samples	0.4654	Not Significantly different
Mann-Whitney U Test between bottom sludge samples	0.0076	Significantly different
COD (mg O_2/L)	-	-
Mann-Whitney U Test between top sludge samples	0.4839	Not Significantly different
Mann-Whitney U Test between bottom sludge samples	0.5485	Not Significantly different
BOD (mg O_2/L)	-	-
Mann-Whitney U Test between top sludge samples	0.2380	Not Significantly different
Mann-Whitney U Test between bottom sludge samples	0.3843	Not Significantly different

The results for the mean Total COD and Total BOD results presented marginal differences with the means for the latrines reported to have been desludged within a year prior to sampling registering higher values (see Table M-1 in Appendix M). However, the Mann-Whitney U Test results indicated statistically insignificant differences in the results for all the parameters except for faecal coliform results for bottom sludge.

4.3 Sludge depth in the sampled latrines

Sludge depth in the latrines is an important parameter to consider especially when comparisons are also being made on how the quality varies with depth. In this study, the difference in height between the top and bottom sludge was measured using a probing rod as indicated in section 3.6.2. The faecal sludge depths in the latrines at the time of sampling for the physical and chemical analyses for the latrines that were sampled are presented in Table 4-6. For faecal sludge net height differences for samples for microbiological parameters, refer to section 4.4.6.

Table 4-6: Faecal sludge depths in the sampled pit latrines

Pit code	**Faecal sludge depth (cm)**	**Net height difference (cm)***	**Pit code**	**Faecal sludge depth (cm)**	**Net height difference (cm)***
C001	108	83	GO23	58	33
C002	95	70	K004	102	77
C003	147	122	K005	92	67
C004	93	68	K009	99	74
C005	67	42	K010	78	53
C007	93	68	K011	105	80
C008	217	192	K014	120	95
C011	290	265	K013	87	62
C012	95	70	K016	88	63
C014	87	62	K017	124	99
C015	95	70	K019	80	55
C017	93	68	K020	67	42
C019	54	29	K021	82	57
C020	64	39	K022	82	57
C024	54	29	K023	98	73
G001	98	73	K025	76	51
G002	65	40	M001	114	89
G003	159	134	M004	81	56
G004	102	77	M005	110	85
G013	70	45	M006	87	62
G014	58	33	M007	118	93
G015	79	54	M008	58	33
G016	87	62	M009	97	72
G024	68	43	M010	95	70
G012	81	56	M011	74	49
G013	84	59	M013	54	29

Table 4-6: Continued

Pit code	Faecal sludge depth (cm)	Net height difference (cm)*	Pit code	Faecal sludge depth (cm)	Net height difference (cm)*
G017	77	52	M014	84	59
G018	56	31	M020	75	50
G021	108	83	M021	80	55

Distance between the top and bottom samples computed by subtracting 25cm which was the "Dead height" of the sampler from the depth of the sludge in the pit.

The difference in the depths for the sampled latrines (n=58) averaged 93±38cm with the range being 54 - 290cm. The depth differences varied significantly among pit latrines. However, about 76 percent of the latrines had faecal sludge height lying between 50 and 100 cm (Table 4-7).

Table 4-7: Summary of sludge depth in sampled latrines used in the analyses of the physical and chemical parameters

Faecal sludge depth range (cm)	Percentage of pit latrines with faecal sludge height within the range (n=58)
0 - 50	0.0
51 - 100	75.9
101 - 150	20.0
151 - 200	1.7
201 - 250	1.7
251 - 300	1.7

In terms of means by study areas, Chaisa recorded the highest value for faecal sludge depth at 110±64cm with the lowest being 83±26cm obtained for the latrines from George Compound (Table 4-8).

Table 4-8: Mean faecal sludge depths in sampled pit latrines

Study Area	Mean Depth (cm)	Number of Samples (n)
Chaisa	110±64	15
George	83±26	15
Kanyama	92±16	15
Madimba	87±20	13

However, the high mean value for samples from Chaisa can be attributed to three pits latrines, C003, C008 and C011 which were clear outliers based on statistical analysis of the pit latrine faecal sludge depth data (Table 4-9). For determination of outlier latrines, refer to section 3.8.4.

Table 4-9: Outlier pit latrines in terms of faecal sludge depth

Statistical Parameter	Overall Sludge Depth	Net Sludge Depth
Minimum	54.0	29.0
Lower Quartile (Q1)	75.3	50.3
Median (Q2)	87.0	62.0
Upper Quartile (Q3)	98.8	73.8
Maximum (Q4)	290.0	265.0
Inter Quartile Range (IQR)	23.5	23.5
Upper Bound (=Q3+(1.5xIQR	134.0	109.0
Lower Bound (=Q1-(1.5xIQR)	40.0	15.0
Outliers	C003, C008, C011, G003	C003, C008, C011, G003

In the analysis presented in Table 4-9, it is clear that C003, C008, C011 and G003 are the only latrines with values above the upper bound limit hence falling in the outlier category.

4.4 Results on valorisation potential of the faecal sludge

This section presents findings to assist in answering the research question set out in section 1.4 that stated: *"What is the concentration of parameters critical to valorisation in the pit latrine faecal sludge"*. In order to answer this question, faecal sludge characterisation was imperative and was the gist of this study. The setup of the characterisation was therefore designed to generate faecal sludge quality data that impacts on the sanitation value chain and valorisation prospects with a bias on reuse in energy generation and agricultural activities. The results are presented in categories as follows:

- Physical;
- Rheological;
- Chemical; and
- Microbiological.

Details on how the parameters relate to valorisation and how they would consequently link to improving sanitation provision in peri-urban areas are presented in the Discussion Chapter (i.e. Chapter Five). Save for rheological results, all other categories looked at the concentration of the parameters of interest in the top and bottom samples (Refer to Section 3.6.3.2). It should also be noted that rheology is not an indicator of resource recovery potential. However, it was investigated to

providing an understanding on why some parameters varied in an odd manner, especially with respect to depth.

Based on the results from the analyses on the distribution of the datasets, it was observed that only 11 percent of the results exhibited normal distribution (i.e., skewness of between -0.5 and 0.5 and a kurtosis of between -3.0 and 3.0) (Appendix D). Therefore, the statistical analysis for the significance of associations between the various relevant variables presented in this section were analysed using either the Man-Whitney U Test or the Kruskal-Wallis H Test depending on whether the statistical analyses was between two or more data sets, respectively (See section 3.8.5). These statistical tools were adopted as they are appropriate where data being analysed is not normally distributed or is non parametric. In all the statistical analysis, the adopted significance level was 0.05 and the hypothesis adopted was a 2-tail hypothesis. Comprehensive results of the Mann-Whitney U Test and the Kruskal-Wallis H Test are presented in Appendix D in Tables D2 and D3, respectively.

4.4.1 Results for physical characteristics of faecal sludge

Results for the selected physical characteristics of the faecal sludge are presented in the sections below. Tables for results of the analysed physical parameters are presented in Appendix E. Graphical results are presented in Appendix K.

4.4.1.1 Density

The density of the sludge averaged 1,098±119kg/m^3 and 1,096±121kg/m^3 for top and bottom sludge, respectively, indicating a marginal difference of only 2kg/m^3. The range was 898±53 kg/m^3 to 1,469±43 kg/m^3 and 897±23 kg/m^3 to 1,387±129 kg/m^3 for the top and bottom sludge, respectively (Figure K1 in Appendix K). Results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U= 1,653; p =0.873).

With respect to the different study areas, the mean averages were marginally different. Samples from George registered the highest while Madimba recorded the lowest for both the top and bottom sludge, respectively (Table 4-10).

Table 4-10: Variability of faecal sludge density with study areas

Study area	Samples from the top layer (kg/m^3)	Samples from the bottom layer (kg/m^3)	Number of samples (n)
Chaisa	1,071±110	1,091±114	15
George	1,132±154	1,129±125	15
Kanyama	1,124±105	1,099±117	15
Madimba	1,061±92	1,065±133	13

4.4.1.2 Moisture Content

Moisture content for the analysed samples averaged 0.81±0.064g/g and 0.82.0±0.079g/g for the top and bottom sludge, respectively. This shows a very marginal difference of just about 0.01g/g between the two sets of samples. About 55 percent of the samples analysed (n = 58) had a higher moisture content in the bottom sludge. The moisture content range was 0.58±0.02 g/g to 0.92±0.005 g/g and 0.58±0.081 g/g to 0.97±0.057 g/g for the top and bottom sludge, respectively (Figure K-2 in Appendix K) which are almost the same. Results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference in the results (U= 1,536; p = -0.424).

With respect to the different study areas, Chaisa posted the highest mean values for both top and bottom sludge at 0.85±0.049 g/g and 0.86±0.07g/g of sample, respectively, while the lowest values were registered for samples from George at 0.78±0.073 g/g and 0.78±0.082g/g of sample, respectively (Table 4-11).

Table 4-11: Mean moisture content for samples from the four study areas

Study area	Top mean moisture content (g/g of sample)	Bottom mean moisture content (g/g of sample)	Number of samples (n)
Chaisa	0.85 ± 0.049	0.86 ± 0.070	15
George	0.78 ± 0.073	0.78 ± 0.082	15
Kanyama	0.80 ± 0.065	0.81 ± 0.076	15
Madimba	0.81 ± 0.048	0.84 ± 0.073	13

4.4.1.3 Total Solids

Total Solids (TS) in a sample are complementary to moisture content. TS averaged 0.19±0.063 g/g and 0.18±0.075g/g of wet sample for the top and bottom sludge samples respectively, indicating marginally higher solids content in top sludge.

About 55 percent of the samples had a higher TS content in top sludge. The range was 0.08±0.005g/g to 0.42±0.020g/g and 0.05±0.032 g/g to 0.42±0.081g/g of sample for the top and bottom sludge, respectively (Figure K-3 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,536; p =0.424).

On a comparative basis for the study areas, TS content was least for samples from Chaisa at 0.15±0.049g/g and 0.14±0.070g/g of the sample for the top and bottom sludge, respectively. Highest mean values were recorded for samples from George at 0.22±0.073g/g and 0.22±0.082g/g for the top and bottom sludge, respectively (Table 4-12). These results present maximum differences of about 0.07 g/g and 0.08g/g of sample between the mean values for the top and bottom sludge from the different study areas.

Table 4-12: Mean Total Solids content for samples from the four study areas

Study area	Top mean Total Solids (g/g of wet sample)	Bottom mean Total Solids (g/g of wet sample)	Number of samples (n)
Chaisa	0.15 ± 0.049	0.14 ± 0.070	15
George	0.22 ± 0.073	0.22 ± 0.082	15
Kanyama	0.20 ± 0.065	0.19 ± 0.076	15
Madimba	0.81 ± 0.048	0.16± 0.073	13

4.4.1.4 Total Volatile Solids

Total Volatile Solids (TVS) presented a higher average value for top sludge as compared to bottom sludge. The average for the top samples was 0.63±0.145g/g dry solids while that for the bottom sludge was 0.55±0.107g/g dry solids. This shows a decrease of TVS with depth. Slightly over 79 percent of the samples analysed (n = 58) registered higher TVS in top samples compared to only about 21 percent of bottom samples that registered higher values. The TVS range for the top and bottom sludge was 0.26±0.106g/g dry solids to 0.91±0.208g/g dry solids and 0.28±0.013g/g dry solids to 0.81±0.162g/g dry solids, respectively (Figure K-4 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was significant difference (U=1,057; p =0.0006).

With respect to study areas, significant differences were observed especially with top faecal sludge where Chaisa recorded the highest mean value at 0.72±0.091g/g

dry solids compared to George which only posted 0.54±0.132g/g dry solids giving a difference in volatility of 0.18g/g dry sample between the two study areas (Table 4-13).

Table 4-13: Mean Total Volatile Solids for samples from the four study areas

Study area	Top mean TVS (g/g dry solids)	Bottom mean TVS (g/g dry solids)	Number of samples (n)
Chaisa	0.72 ± 0.091	0.58 ± 0.091	15
George	0.54 ± 0.132	0.52 ± 0.095	15
Kanyama	0.62 ± 0.155	0.50 ± 0.130	15
Madimba	0.63 ± 0.148	0.58± 0.089	13

4.4.2 Results for rheological characteristics of faecal sludge

Rheological characteristics of sludge are critical in the design of suitable means of emptying although other factors like solid waste and grit content may also have an influence. The results presented in this report may not fully reflect the impact of solid waste and grit as the method used to measure the rheological properties required the removal of all solid waste before analysis.

As elaborated in section 3.6.3.3, samples were collected from a total of 11 pits at different depths. For each sample moisture content was also determined in addition to parameters that were read off from the Rheometer which are presented in Appendix F (Tables F1-1 to F1-41). Based on the results presented in these Tables, several faecal sludge rheological characteristics were established including:

- Viscosity – shear rate relationship;
- Variability of shear stress with moisture content;
- Variability of viscosity with moisture content; and
- Variability of faecal sludge shear resistance with depth.

These aspects are presented in the ensuing sections. It is worth noting that the analysis was done using a shear rate ranging from $0.1s^{-1}$ to $100s^{-1}$.

4.4.2.1 Viscosity – Shear rate relationship

The results of viscosity were plotted against shear rate for all the faecal sludge samples. All results exhibited pseudo-plastic behaviour or shear thinning as can be

observed from Figure 4-10. A full set of graphs for the analysed samples is presented in Appendix F2.

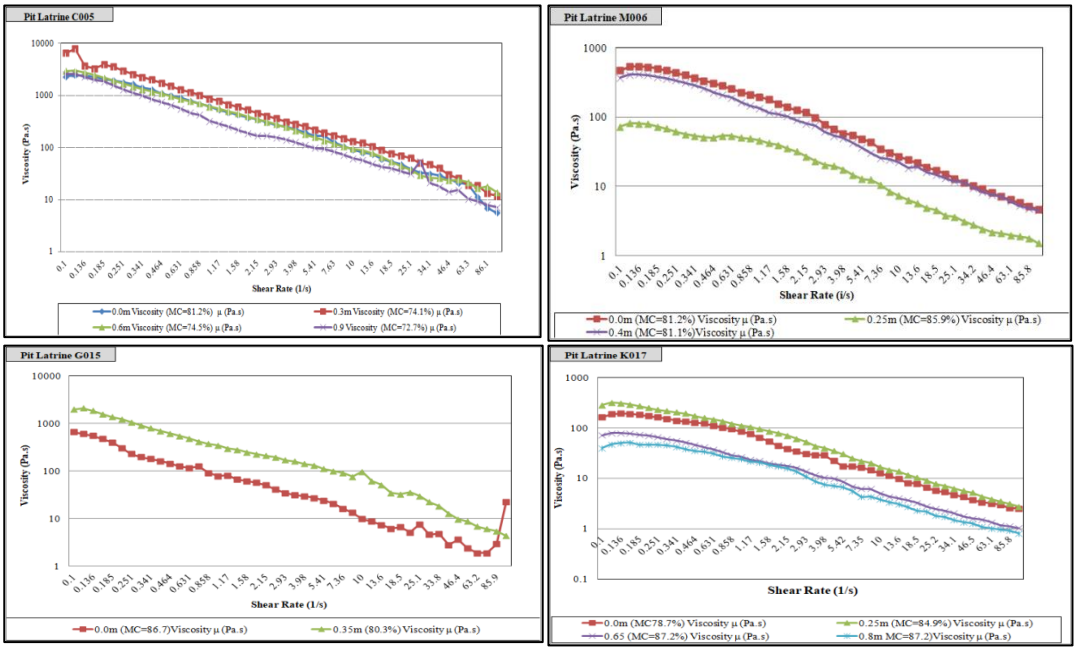


Figure 4-10: Behaviour of faecal sludge in terms of viscosity under increasing shear rate.

The tendency of shear thinning was also observed on results for the plot of shear stress against shear rate. In the majority of case, the graphs presented a reduced gradient with increasing shear rate which is indicative of shear thinning (Figure 4-11. Also refer to graphs in Appendix F3).

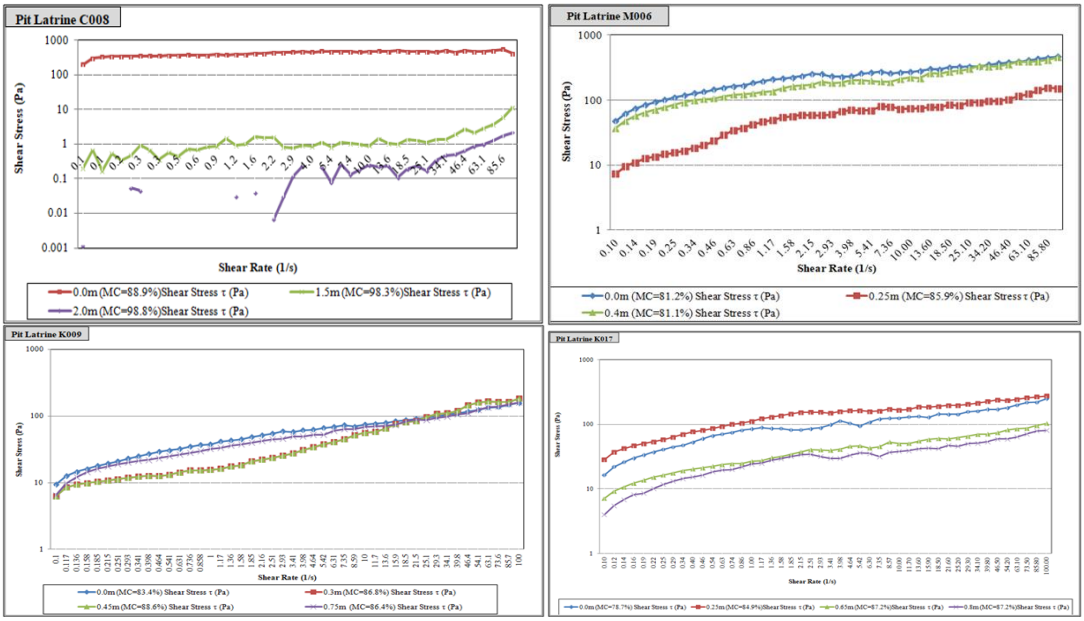


Figure 4-11: A plot of Shear stress against shear rate exhibiting shear thinning.

4.4.2.2 Variability of shear stress with moisture content

Shear stress at minimum and maximum shear rate which was at around $0.1s^{-1}$ and $100s^{-1}$, respectively, excluding all points for which the test failed, were plotted against moisture content. The results indicated an inverse relationship between the two parameters. At minimum shear rate, the majority of samples yielded at a shear stress of less than 200 Pa. Almost all samples with moisture content above 82 percent registered a yield shear stress of less than 100Pa. At maximum shear rate, the relationship between shear stress and moisture content was also an inverse relationship with the majority of samples recording a shear stress of less than 400Pa at a moisture content of more than 82 percent (Figure 4-12).

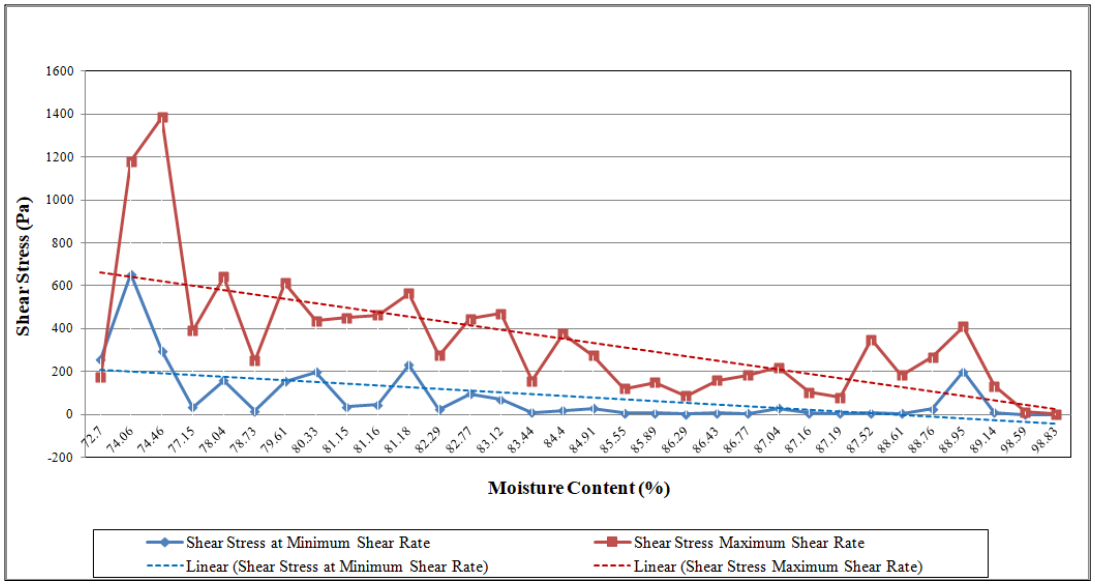


Figure 4-12: Relationship between shear stress and moisture content at minimum and maximum shear rates

4.4.2.3 Variability of viscosity with moisture content

Viscosity generally reduced with increasing moisture content (Refer to figures in Appendix F2 and F3). At very high moisture content (>98 percent), the faecal sludge registered very low viscosities (Figure 4-13) tending towards the viscosity of water which is $8.90x10^{-4}$ Pa.s at Standard Temperature and Pressure (STP). Low viscosity resulted in negative shear stress readings for certain values of shear rate resulting in discontinuity in the graph as the case was with the graph for results for the sample collected at 2.0m (Figure 4-13).

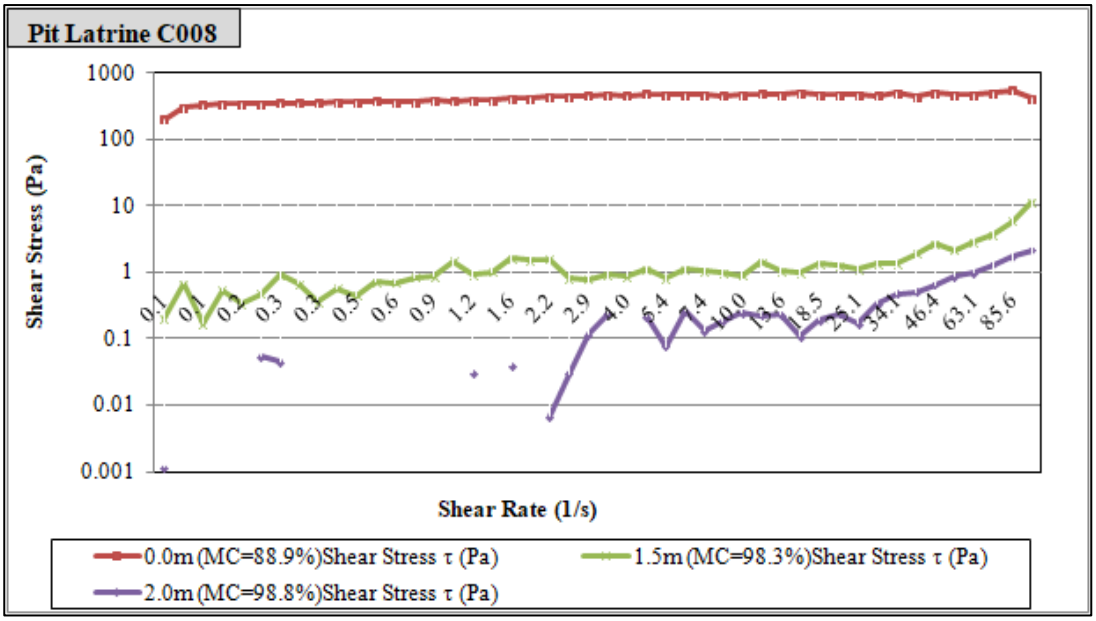


Figure 4-13: Variability of viscosity with moisture content for pit C008 (Note the very low viscosity for samples with moisture content above 98 percent)

In a few cases, it was observed that faecal sludge with higher moisture content had a comparatively higher viscosity contrary to expectations (Figure 4-14. Also refer to graphs in Appendices F2 and F3).

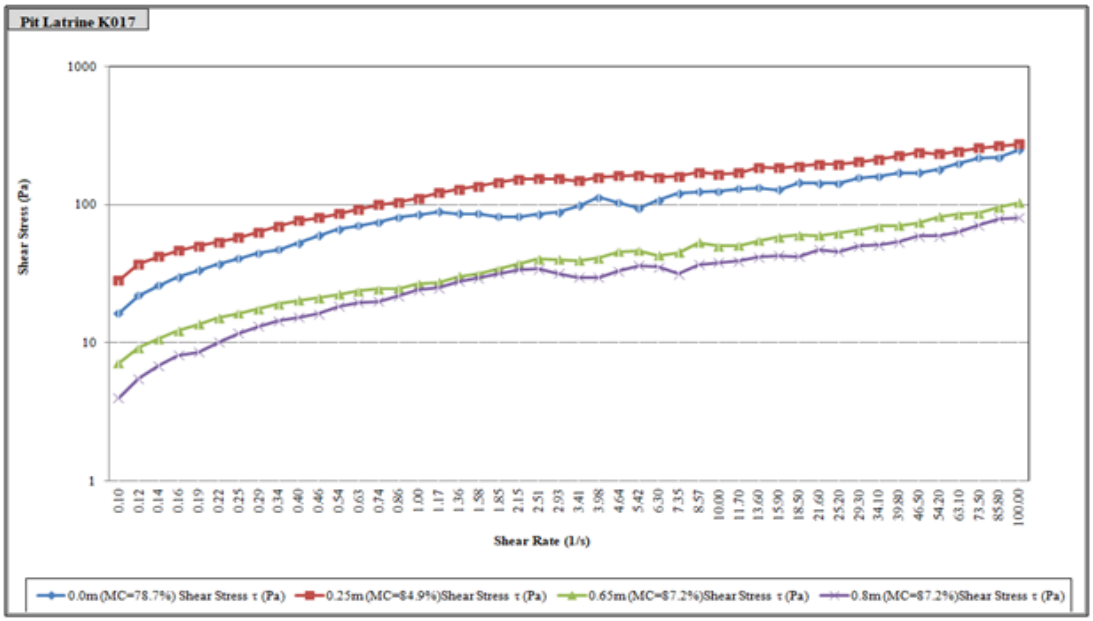


Figure 4-14: Graph presenting a case where a sample with higher moisture content had a comparatively higher viscosity (Compare top sample with a moisture content of 78.7% and the sample from a depth of 25cm with a moisture content of 84.9%)

4.4.2.4 Variability of viscosity with depth

Results on how viscosity varied with depth did not produce a consistent correlation. For some pits, the viscosity was higher for top sludge and reduced with depth as the

case was for Pit C008 (Figure 4-13 above). In other cases, higher viscosity was observed for either the top or bottom layers with the least viscosity being observed in the middle layers (Figure 4-15).

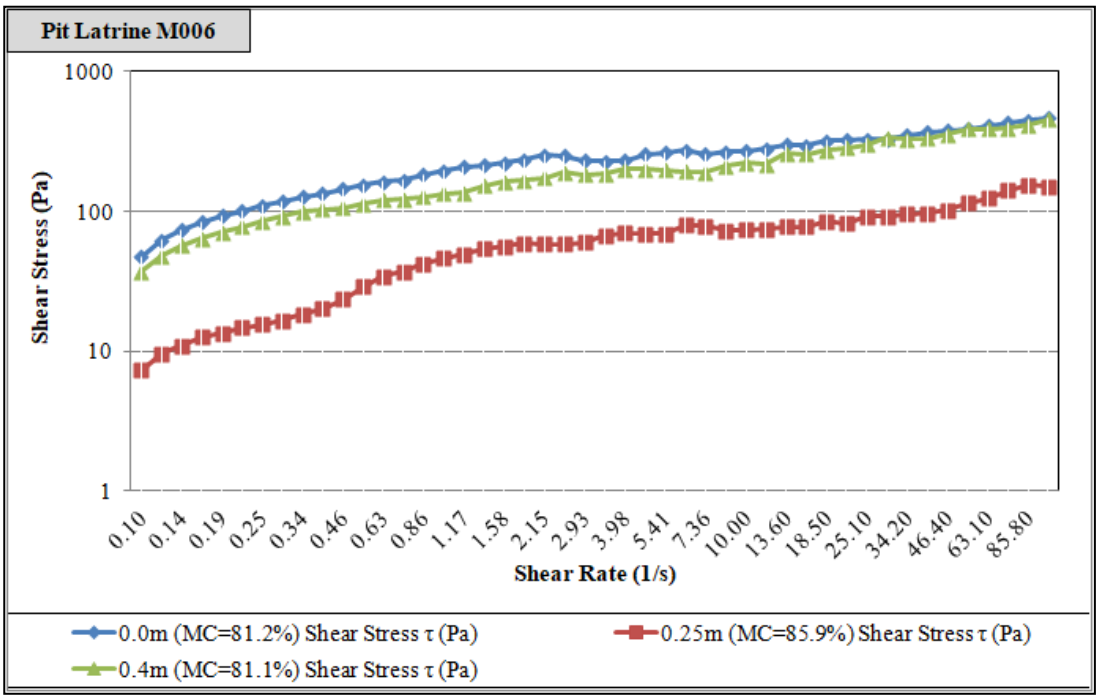


Figure 4-15: Viscosity results for pit M006 where the highest viscosity was recorded in the top layer and the least in the middle layer.

Cases, opposite to what was observed for pit M006 were also encountered. For example, Pit Latrine G015 registered lower viscosity for top sludge compared to that of the bottom sludge (Figure 4-16).

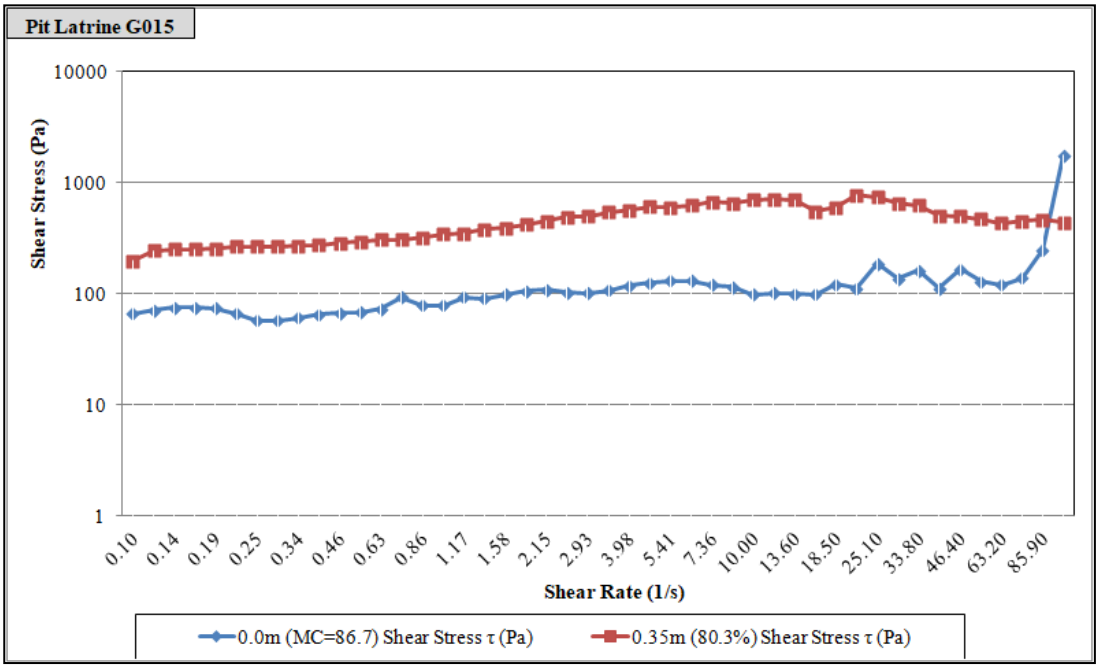


Figure 4-16: Viscosity results for pit G015 showing top layer with lower viscosity.

4.4.3 Results for chemical characteristics of faecal sludge

Various chemical parameters relevant to the determination of the valorisation potential of the faecal sludge were assessed. Also assessed under this category were parameters that would inhibit the usage of faecal sludge for beneficiation prospects so as to provide information upon which intervention measures for enhancing valorisation could be identified. The results for these selected parameters are presented in the subsequent sections. Tables for results of the analysed chemical parameters are presented in Appendix G. Graphical results are presented in Appendix K.

4.4.3.1 pH

The pH results indicated average values of 7.1±0.46 and 7.4±0.40 for top and bottom sludge, respectively. This shows an increase of pH with depth. It was found that 86 percent of the samples analysed (n = 58) had a higher pH for bottom sludge. For the samples where top sludge registered higher pH, the differences in most cases were very marginal. The pH range for the top and bottom sludge was 6.2±0.07 to 8.3±0.27 and 6.5±0.72 to 8.1±0.03, respectively (Figure K-5 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was significant difference (U=993; p =0.0001).

With respect to study areas, significant differences were observed with Chaisa and George registering relatively lower results compared to Kanyama and Madimba. The maximum differences were observed between the average results for Kanyama and Chaisa where the top and bottom sludge both differed by 0.5 (Table 4-14).

Table 4-14: Mean pH values for samples from the four study areas

Study area	Top samples mean pH (-)	Bottom samples mean pH (-)	Number of samples (n)
Chaisa	6.9 ± 0.39	7.2 ± 0.36	15
George	6.9 ± 0.42	7.3 ± 0.34	15
Kanyama	7.4 ± 0.47	7.7 ± 0.33	15
Madimba	7.2 ± 0.42	7.6± 0.33	13

4.4.3.2 Total Chemical Oxygen Demand

The average total COD results for the top and bottom samples computed by averaging results from all the study areas were 129,407±55,088 mg O_2/L and

112,052±51,467 mg O_2/L for the top and bottom sludge samples, respectively. This represents a decrease in organic matter content with increasing depth in the pits. About 69 percent of the samples analysed (n=58) registered higher COD concentrations in top samples. The COD range was 22,613±8,229 mg O_2/L to 314,667±67,006 mg O_2/L and 26,453±14,557 mg O_2/L to 246,400±84,867 mg O_2/L for the top and bottom sludge, respectively (Figure K-6 in Appendix K). This shows a wider range for top sludge compared to bottom sludge. However, the results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,334; p =0.0549).

With respect to study areas, significant differences were observed, with Kanyama recording the highest values for both top and bottom sludge while Madimba registered the lowest for both (Table 4-15).

Table 4-15: Mean COD concentration for samples from the four study areas

Study area	Top mean total COD concentration (mg O_2/L)	Bottom mean total COD Concentration (mg O_2/L)	Number of samples (n)
Chaisa	125,952 ± 48,438	121,771 ± 60,430	15
George	118,926 ± 37,902	104,875 ± 31,626	15
Kanyama	164,267 ± 67,017	134,343 ± 62,672	15
Madimba	105,262 ± 49,586	83,397± 29.651	13

4.4.3.3 Soluble Chemical Oxygen Demand

Soluble COD results for the top and bottom samples from the study areas averaged 66,659±40,223 mg O_2/L and 54,667±38,143 mg O_2/L, respectively. This represents a decrease in soluble organic matter content in the sludge with increasing depth. The majority of the analysed samples (76 percent; n=54) registered higher Soluble COD in top samples with only 24 percent of bottom samples registering higher values. The Soluble COD range was very wide spanning from a few thousands to hundreds of thousands. The top sludge registered a range of 17,280±11,853 mg O_2/L to 165,653±47,482 mg O_2/L while the range for bottom sludge was 5,333±2587 mg O_2/L to139,947±32,542 mg O_2/L (Figure K-7 in Appendix K). However, the results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=5,716; p =0.8026).

With respect to study areas, significant differences in terms of the mean COD concentrations were observed among samples from the different study areas with George registering the highest while Madimba registered the least mean for both the top and bottom sludge, respectively (Table 4-16).

Table 4-16: Mean Soluble COD concentration for samples from the four study areas

Study area	Top mean soluble COD concentration (mg O_2/L)	Bottom mean soluble COD concentration (mg O_2/L)	Number of samples (n)
Chaisa	58,112 ± 41,338	47,205 ± 39,150	15
George	85,799 ± 41,833	80,213 ± 40,607	11
Kanyama	78,606 ± 43525	60,089 ± 40105	15
Madimba	46,539 ± 20,880	35,446± 16,802	13

4.4.3.4 Total Biochemical Oxygen Demand

The mean BOD results for the top and bottom samples were 1,045±527 mg O_2/L and 1,006±470 mg O_2/L, respectively. This represents a marginal decrease in organic matter concentration with increasing depth in the pits on average. Only 54.5 percent of the samples analysed (n = 56) registered higher BOD values in top samples. The BOD range was 373±284 mg O_2/L to 3,573±711 mg O_2/L and 355±180 mg O_2/L to 3,107±711 mg O_2/L for the top and bottom sludge, respectively (Figure K-8 in Appendix K). This presents a slightly wider range for top sludge compared to bottom sludge. The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,527; p =0.8103).

With respect to study areas, Chaisa recorded the highest mean Total BOD concentration for both top and bottom sludge while George registered the lowest for both (Table 4-17).

Table 4-17: Mean Total BOD concentration for samples from the four study areas

Study area	Top mean total BOD concentration (mg O_2/L)	Bottom mean total BOD concentration (mg O_2/L)	Number of samples (n)
Chaisa	1,360 ± 892	1,249± 785	13
George	799 ± 223	820 ± 257	15
Kanyama	904 ± 255	826 ± 215	15
Madimba	1,178 ± 329	1,175± 245	13

4.4.3.5 Ammonia

Ammonia concentration in the sludge varied widely for the individual pit latrines as evidenced by the huge sample standard deviation values for the computed means. Overall, the results for the top and bottom samples for the study areas averaged 1,996±1,615mg NH_3-N/L and 2,231±1,749mg NH_3-N /L. Therefore, on average, there was an increase in ammonia content with increasing depth. Slightly over 60 percent of the samples analysed (n = 58) registered higher ammonia concentration in bottom sludge samples compared to top sludge samples. The range also varied widely with top sludge results ranging from 137±110 to 6,943±631mg NH_3-N /L while that for bottom sludge ranged from 50±30 mg/L to 7,577±2,100 NH_3-N mg/L (Figure K-9 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,510; p =0.3421).

For the study areas, huge variation were also observed for the mean ammonia concentration with Kanyama registering the highest values for both top and bottom sludge while Chaisa registered the lowest for both (Table 4-18).

Table 4-18: Mean ammonia concentrations for samples from the four study areas

Study area	Top mean ammonia conc. (mg NH_3-N /l)	Bottom mean ammonia conc. (mg NH_3-N /l)	Number of samples (n)
Chaisa	1,389 ± 794	1,360 ± 659	15
George	1,890 ± 1,431	2,376 ± 1,965	15
Kanyama	2,896 ± 1,892	3,268 ± 2,145	15
Madimba	1,781 ± 1,882	1,872± 1,300	13

4.4.3.6 Sulphates

Sulphate concentration in the sludge varied widely for the individual pit latrines as evidenced by the huge sample standard deviations for the computed means. The mean value for the top sludge was 8,669±4,300 mg/L while that for the bottom sludge was 6,344±4,443 mg/L. These results indicate a decrease in sulphate concentration with increasing depth. Slightly over 74 percent of the samples analysed (n = 58) registered higher sulphate concentration in top sludge samples compared to only 26 percent of the bottom sludge samples that registered higher concentrations. The range varied widely with top sludge recording 302±46 mg/L to

19,349±3,437 mg/L while bottom sludge recorded 969±411 mg/L to 19,057±581 mg/L (Figure K-10 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was significant difference (U=1,099; p =0.0012).

For the study areas, huge variation were also observed with Madimba registering the highest values for top sludge while the highest in bottom sludge was registered for samples from Chaisa (Table 4-19).

Table 4-19: Mean sulphate concentration for samples from the four study areas

Study area	Top mean sulphate conc. (mg/L)	Bottom mean sulphate conc. (mg/L)	Number of samples (n)
Chaisa	9,169 ± 5,009	7,881 ± 4,379	15
George	7,012 ± 3,573	5,696 ± 3,183	15
Kanyama	6,912 ± 3,371	4,398 ± 3,021	15
Madimba	12,031 ± 3,479	7,563± 6,386	13

4.4.3.7 Phosphates

Phosphates in the study areas averaged 1,740±964 mg/L and 1,235±812 mg/L for the top and bottom sludge, respectively, indicating a reduction in concentration with depth. Slightly over 79 percent of the samples analysed (n = 58) registered higher phosphate concentration in top sludge samples compared to bottom sludge samples. The range for top sludge was 61±8 mg/L to 4,049±432 mg/L while that for bottom sludge was 170±101 mg/L to 4,241±1,710 mg/L (Figure K-11 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was significant difference (U=1,131; p =0.0024).

With respect to study areas, Kanyama registered the highest concentrations while Madimba recorded the lowest for both top and bottom sludge, respectively (Table 4-20).

Table 4-20: Mean phosphate concentration for samples from the four study areas

Study area	Top mean phosphate conc. (mg/L)	Bottom mean phosphate conc. (mg/L)	Number of samples (n)
Chaisa	1,479 ± 672	1,120 ± 710	15
George	1,662 ± 984	1,342 ± 690	15
Kanyama	2,194 ± 1,057	1,637 ± 1,066	15
Madimba	1,610 ± 1,044	780± 453	13

4.4.4 Light metals

Light metals analysed included Calcium (Ca), Sodium (Na), Potassium (K) and Magnesium (mg) (section 3.7.3). The results for each respective element are presented in the subsequent sections. Tables for results of the analysed light metals are presented in Appendix H. Graphical results are presented in Appendix K.

4.4.4.1 Potassium

Potassium was present in all the samples analysed and averaged 23,249±33,057 mg/kg dry solids and 20,072±24,450 mg/kg dry solids for the top and bottom sludge, respectively. The majority of the latrines (55 percent; n=53) registered higher concentrations of potassium in top sludge as compared to bottom sludge. The range was 1,166±96 mg/kg to 195,179±132,232 mg/kg of dry solids for top sludge and 46±3 mg/kg to 35,692±2,068 mg/kg of dry solids for bottom sludge. However, the majority of the samples recorded concentrations of less than 40,000 mg/kg (Figure K-12 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=5,556; p =0.9840).

With respect to study areas, Madimba registered the highest mean concentrations for both the top and bottom sludge while the least concentrations were recorded for samples from Kanyama (Table 4-21).

Table 4-21: Mean potassium concentration for samples from the four study areas

Study area	Top mean potassium conc. (mg/kg dry solids)	Bottom mean potassium conc. (mg/kg dry solids)	Number of samples (n)
Chaisa	21,535 ± 31,020	19,444 ± 29,350	13
George	17,311 ± 14,052	18,624 ± 15,886	13
Kanyama	14,391 ± 14,522	10,205 ± 5,314	14
Madimba	40,443 ± 53,795	32,984± 33,984	13

4.4.4.2 Sodium

Sodium was present in all the samples analysed and averaged 17,520±28,316 mg/kg and 17,933±33,117 mg/kg of dry solids for the top and bottom sludge, respectively. The majority of the latrines (62 percent; n=53) registered higher concentrations of sodium in top sludge as compared to bottom sludge. The range was 2,375±305

mg/kg to 164,275±98,267 mg/kg of dry solids for top sludge while that for bottom sludge was 691±196 mg/kg to 182,368±143,297 mg/kg of dry solids. However, the majority of the samples recorded concentrations of less than 20,000m g/kg dry solids (Figure K-13 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=5,208; p =0.4237).

With respect to study areas, Madimba registered the highest mean concentrations for both the top and bottom sludge. The least results were recorded for samples from Kanyama (Table 4-22).

Table 4-22: Mean Sodium concentrations for samples from the four study areas

Study area	Top mean sodium conc. (mg/kg dry solids)	Bottom mean sodium conc. (mg/kg dry solids)	Number of samples (n)
Chaisa	15,922 ± 25,957	12,359 ± 24,505	13
George	10,540 ± 10,241	10,687 ± 10,921	13
Kanyama	8,235 ± 4,500	6,455 ± 3,600	14
Madimba	36, 097 ± 46,305	43,196± 55,526	13

4.4.4.3 Calcium

Calcium was prevalent in all the samples analysed and averaged 16,003±28,150 mg/kg and 15,999±30,017 mg/kg of dry solids for the top and bottom sludge, respectively. The majority of the latrines (62 percent; n=53) registered higher concentrations of calcium in top sludge as compared to bottom sludge. The range was 1,370±804 mg/kg to 160,884±37,881 mg/kg of dry solids for top sludge and 1,508±117 mg/kg to 135,729±1,0371 mg/kg of dry solids for bottom sludge. Higher concentrations were recorded by samples from a few sampling points especially from Madimba. Sampling points C012, M008 and M010 had results in excess of 60,000 mg/kg. However, the majority of the samples recorded concentrations of less than 20,000 mg/kg (Figure K-14 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=5,445; p =0.4237).

With respect to study areas, Madimba registered the highest mean concentration for both the top and bottom sludge at 30,200±33,483 mg/kg and 35,090±44,127 mg/kg of dry solids, respectively. The least result for top sludge was recorded by samples

from Kanyama while the least result for bottom sludge was recorded by samples from George (Table 4-23).

Table 4-23: Mean calcium concentration for samples from the four study areas

Study area	Top mean calcium conc. (mg/kg dry solids)	Bottom mean calcium conc. (mg/kg dry solids)	Number of samples (n)
Chaisa	19,855 ± 42962	16,909 ± 36,382	13
George	7,609 ± 5,198	6,205 ± 3,059	13
Kanyama	7,008 ± 5,644	6,520 ± 4,284	14
Madimba	30,200 ± 33,483	35,090± 44,127	13

4.4.4.4 Magnesium

Magnesium, like all the other analysed light metals was prevalent in all the samples and averaged 13,482±18,478 mg/kg and 11,202±13,821 mg/kg of dry solids for the top and bottom sludge, respectively. The majority of the latrines (64 percent; n=53) registered higher concentrations of magnesium in top sludge. The range was 2,632±1,869 mg/kg to 117,394±63,585 mg/kg of dry solids for top sludge while that for bottom sludge was 274±279 mg/kg to 70,065±30,735 mg/kg of dry solids. Higher concentrations were recorded by samples from a few sampling points from Madimba while the majority of the other sampling points recorded concentrations of less than 20,000 mg/kg (Figure K-15 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=5,497; p =0.8808).

With respect to study areas, Madimba registered the highest mean concentrations for both the top and bottom sludge at 27,490±32,403 mg/kg and 22,161±23,597 mg/kg of dry solids, respectively. The least result for top sludge was recorded by samples from George while the least result for bottom sludge was recorded for samples from Chaisa (Table 4-24).

Table 4-24: Mean magnesium concentrations for samples from the four study areas

Study area	Top mean magnesium conc. (mg/kg dry solids)	Bottom mean magnesium conc. (mg/kg dry solids)	Number of samples (n)
Chaisa	9,923 ± 8133	7,163 ± 5,,890	13
George	7,266 ± 4,992	7,349 ± 4,799	13
Kanyama	9,551 ± 6,950	8,354 ± 6,069	14
Madimba	27,490 ± 32,403	22,161± 23,597	13

4.4.5 Heavy metals

Heavy metals analysed included Zinc (Zn), Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Chromium (Cr) and Lead (Pb) (section 3.7.3). The results for each respective element are presentment in the subsequent sections. Tables for results of the analysed heavy metals are presented in Appendix I. Graphical results are presented in Appendix K.

4.4.5.1 Zinc

Zinc was detected in 58.5 percent (n=53) of the analysed samples. The element was detected in 49.1 percent and 50.9 percent of the top and bottom sludge samples, respectively. For samples where the element was detectable (n=31), slightly more latrines (51.6 percent) had higher concentrations of Zinc in the top sludge as compared to bottom sludge. In terms of concentration, all the points registered very low concentrations with the range for top sludge being 0.0±0.00 to 134.4±93.28 mg/kg of dry solids and that for bottom sludge being 0.0±0.00 to 95.9±110.79 mg/kg of dry solids. The majority of the samples recorded concentrations of less than 40 mg/kg of dry solids (Figure K-16 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,373; p =0.8415).

The majority of samples that recorded the presence of zinc were from Madimba (84.6 percent; n=13) while Kanyama recorded the least at only 42.9 percent (n=14). Table 4-25 summarises prevalence of zinc in the four study areas.

Table 4-25: Prevalence of zinc in the four study areas

Study area	Latrines with positive Zn results (%)	Number of samples (n)
Chaisa	53.8	13
George	46.2	13
Kanyama	42.9	14
Madimba	84.6	13

4.4.5.2 Cadmium

Cadmium was detected in 66 percent of the analysed samples (n=53). With respect to source of sludge, the element was detected in 47.2 percent and 52.8 percent of the top and bottom sludge samples, respectively. For the samples where the element was

detectable (n=35), a slightly bigger proportion of the samples registered higher concentrations in the bottom sludge (54.3 percent) with only 45.7 percent registering higher concentrations in top sludge. However, the concentrations were low with top sludge recording a range of 0.0±0.00 mg/kg to 24.3±16.56 mg/kg of dry solids and bottom sludge recording a range of 0.0±0.00 mg/kg to 121.6±67.56 mg/kg of dry solids. In the majority of samples where cadmium was detectable, the concentration was less than 30 mg/kg of dry solids except for sampling points M008 and M010 which recorded values in excess of 50 mg/kg (Figure K-17 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,288; p =0.4654).

The majority of samples that recorded presence of cadmium were from Madimba (84.6 percent; n=13) while Kanyama registered the least at only 42.9 percent (n=14). Table 4-26 summarises prevalence of cadmium in study areas.

Table 4-26: Prevalence of cadmium in the four study areas

Study area	Latrines with positive Cd results (%)	Number of samples (n)
Chaisa	69.2	13
George	61.5	13
Kanyama	42.9	14
Madimba	84.6	13

4.4.5.3 Cobalt

Cobalt was detected in 43.4 percent (n=53) of the analysed samples. The element was detected in only 37.8 percent and 39.6 percent of the top and bottom sludge samples, respectively. For the samples where the element was detectable, higher concentrations were registered for top sludge samples (65.2 percent) compared to bottom sludge. However, the concentrations were very low with top sludge recording a range of only 0±0.0 mg/kg to 124±102 mg/kg of dry solids and bottom sludge recording 0±0.0 mg/kg to 240±184 mg/kg of dry sample. The two highest figures in each range which were 124±102 mg/kg and 240±334 mg/kg for the top and bottom sludge were observed at sampling points C012 and K021. For all other samples, the concentrations were well below 50 mg/kg (Figure K-18 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,381; p =0.8808).

The majority of samples that recorded presence of cobalt were from Chaisa (61.5 percent; n=13) while only 7.7 percent (n=13) of samples from Madimba had detectable cobalt concentrations. Table 4-27 summarises prevalence of cobalt with study areas.

Table 4-27: Prevalence of cobalt in the four study areas

Study area	Latrines with positive Co results (%)	Number of samples (n)
Chaisa	61.5	13
George	38.5	13
Kanyama	57.1	14
Madimba	7.7	13

4.4.5.4 Copper

Copper was detected in 30.2 percent (n=53) of the analysed samples from the study areas. With respect to source of sludge, the element was detected in only 28.3 percent and 22.6 percent of the top and bottom sludge samples, respectively. For the samples where the element was detectable, it was evenly distributed in terms of samples registering higher concentrations between the top and bottom sludge (50 percent). The concentrations ranged from 0±0.0 mg/kg to 300±12.4 mg/kg and 0±0.0 mg/kg to 345±25.5 mg/kg of dry solids for the top and bottom samples, respectively. For the majority of samples, the concentrations were below 10 mg/kg except for a few samples including those from K008, K009, K010 and K016 which registered concentrations in excess of 100 mg/kg (Figure K-19 in Appendix K). The results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was no significant difference (U=1,344; p =0.7039).

The majority of samples that recorded presence of copper were from Kanyama (35.7 percent; n=14) while only 15.4 percent (n=13) of samples from George had detectable copper concentrations. Table 4-28 summarises prevalence of copper with study areas.

Table 4-28: Prevalence of copper in the four study areas

Study area	Latrines with positive Cu results (%)	Number of samples (n)
Chaisa	30.8	13
George	15.4	13
Kanyama	35.7	14
Madimba	30.8	13

4.4.5.5 Iron

Iron was detected in 85 percent (n=53) of the analysed samples. The element was detected in 84.9 and 81.1 percent of the top and bottom sludge samples, respectively. For the samples where the element was detectable, just over 53 percent registered higher concentrations in the top sludge samples. The concentrations ranged from 0±0.0 mg/kg to 1,634±637 mg/kg and 0±0.0 mg/kg to 2,711±393 mg/kg of dry solids for the top and bottom samples, respectively. A considerable number of samples that recorded positive results for iron registered concentrations below 150 mg/kg of the dry solids. Higher concentrations were recorded by samples from Madimba some of which recorded results in excess of 1,000 mg/kg followed by samples from Kanyama where a few samples registered concentrations in excess of 500 mg/kg (Figure K-20 in Appendix K). Results of the Mann-Whitney U Test between the top and bottom sludge indicated that there was significant difference ($U=685$; $p < 0.00001$).

George had all samples registering the presence of iron while the least prevalence was recorded by samples from Kanyama at 71.4 percent (n=14). Table 4-29 summarises prevalence of iron with study areas.

Table 4-29: Prevalence of iron in the four study areas

Study area	Latrines with positive Fe results (%)	Number of samples (n)
Chaisa	76.9	13
George	100	13
Kanyama	71.4	14
Madimba	92.3	13

4.4.5.6 Chromium

Chromium was not detectable in all the samples analysed (n=53) indicating a complete absence of this element in the faecal sludge from the study areas.

4.4.5.7 Lead

From the 53 samples analysed, lead was only detectable in one sample from Kanyama (K011 top sludge). However, the recorded result was very low at only 0.01±0.008 mg/kg of dry solids.

4.4.6 Results for microbiological characteristics of faecal sludge

Microbiological quality of the faecal sludge was assessed using Faecal Coliforms, *Ascaris* and *Cryptosporidium*. As indicated in section 3.6.3.2, sampling for microbiological analysis was done earlier. All the 100 pits were sampled in this case unlike in the case of physical and chemical parameters. However, for faecal coliforms, results were obtained only for 95 pits out of the 100 that were sampled. Tables for results of the analysed microbiological parameters are presented in Appendix J.

The sludge height in the latrines at the time of sampling for this campaign was as presented in Table C2-1 in Appendix C. The mean net height difference between the top and bottom samples was only 51.2±43cm when the dead height of the sampling tool which was 25cm was taken into account.

4.4.6.1 Faecal Coliforms

Results for faecal coliforms are presented from the perspectives of prevalence, variability with study areas and variability with depth.

i. Prevalence

Faecal Coliforms were prevalent in almost all samples analysed. Interesting results were however obtained for two sampling points, K023 and M011, which registered counts of 0 CFU/100 mL for both the top and bottom samples. This made no scientific sense especially when compared to other samples, the majority of which had mean counts in excess of $1x10^{10}$ CFU/100 mL.

ii. Variability with study areas

Results on variability with study sites showed some differences in average faecal coliform counts among the study areas. Samples from Kanyama recorded the least values compared to the other three study areas. While the mean counts computed using data for all study areas were (134±226) $x10^9$ and (73±8) $x10^9$ (n=95), that for Kanyama was only (55±181) $x10^9$ and (25±49) $x10^9$ (n=24) for the top and bottom sludge, respectively. The high sample standard deviations for the means are indicative of the high variability of results among the different sampling points. Figure 4-17 summarises the average faecal coliform counts for the study areas.

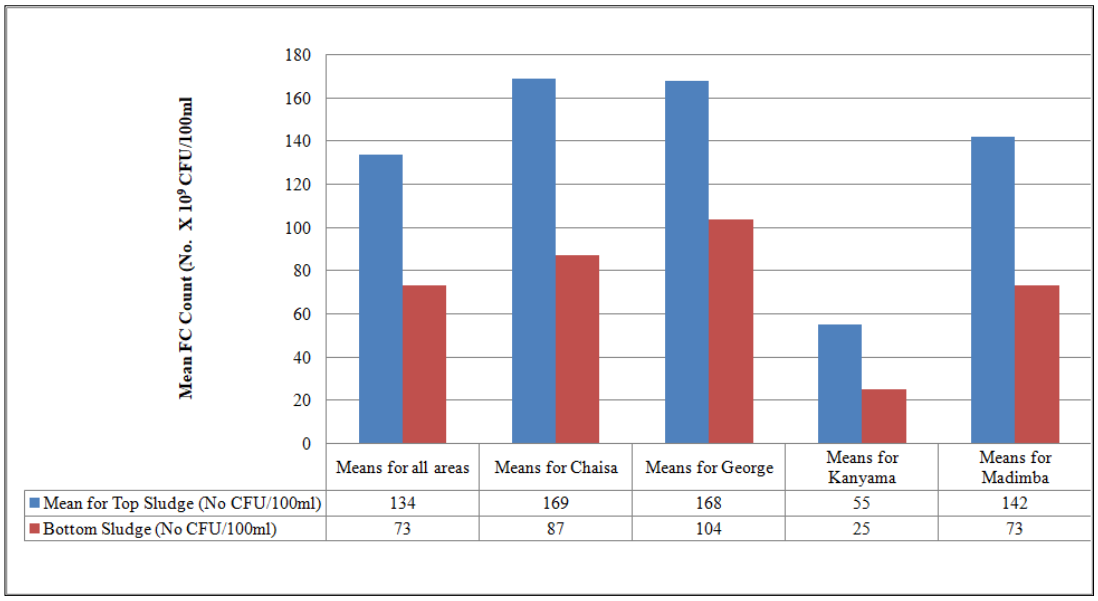


Figure 4-17: Mean faecal coliform counts for study areas

iii. Variability with depth

An assessment of variability of faecal coliforms with depth, in most cases, had top sludge registering higher counts as compared to the bottom sludge. However, the opposite was observed for samples from George where 60 percent of the latrines (n=25) recorded higher counts in bottom sludge contrary to expectations. Table 4-30 summarises proportions by percentage of latrines that recorded higher counts of faecal coliforms in the top and bottom sludge for the respective study areas.

Table 4-30: Proportions by percentage of latrines that recorded higher counts of faecal coliforms in the top and bottom sludge for the respective study sites.

Study area	Latrines with higher counts in Top sludge (%)	Latrines with higher counts in Bottom sludge (%)	Number of Samples (n)
Chaisa	56	44	25
George	40	60	25
Kanyama	64	36	24
Madimba	60	40	21

A graphical presentation of how faecal coliforms varied between the top and bottom sludge for samples from all the four study areas is presented in Figure 4-18. Significant standard deviations were recorded for the samples (Refer to Table J-1 in Appendix J). The results of the Mann-Whitney U test between the top and bottom sludge indicated that there was no significant difference (U=4,289; p =0.5552).

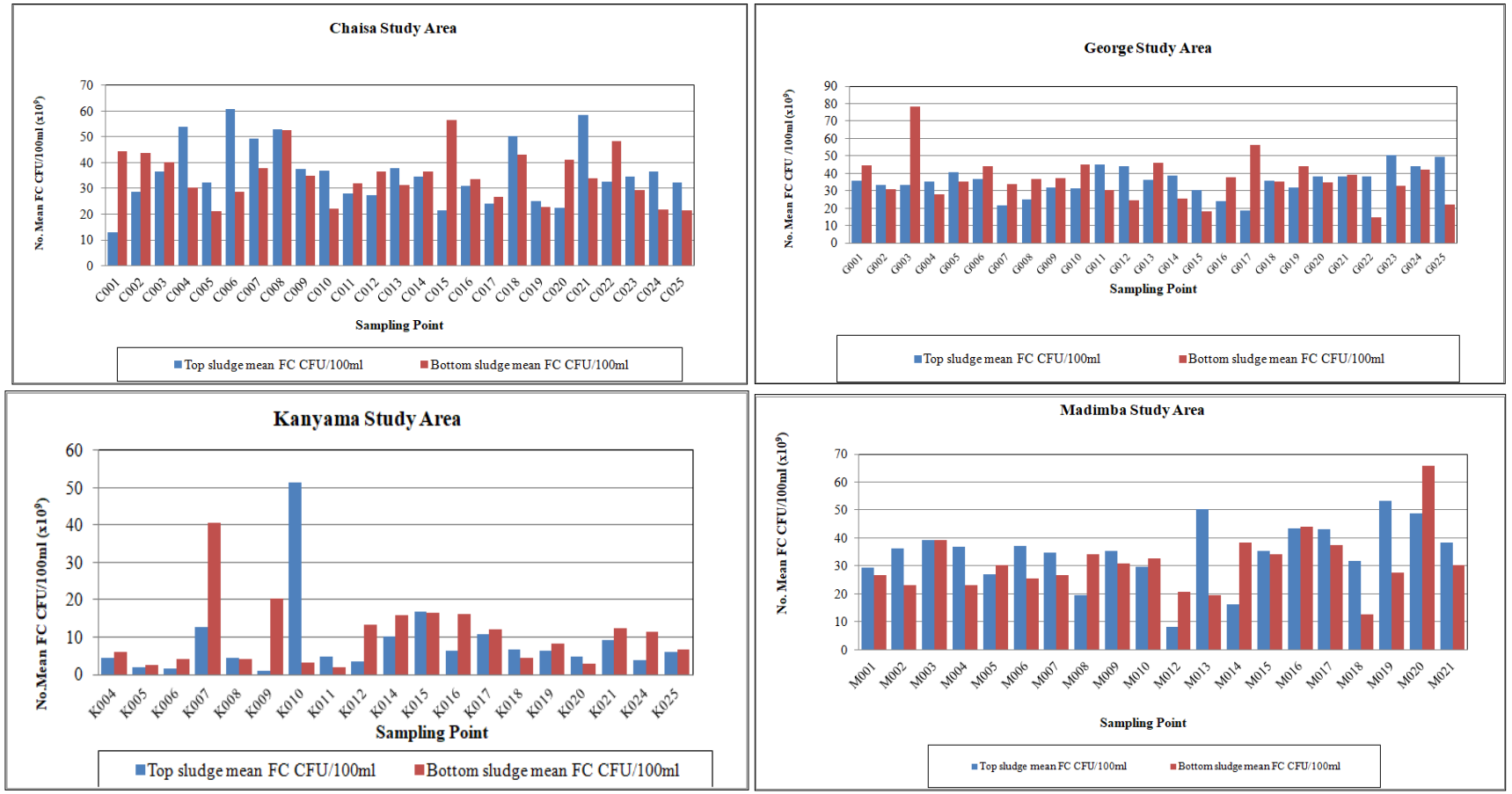


Figure 4-18: Prevalence of Faecal Coliforms in faecal sludge samples and its variability with depth in each of the four study areas

4.4.6.2 Ascaris

Analysis of *Ascaris* included the enumeration of both total and viable *Ascaris*. The results for each of these two forms of *Ascaris* are presented in the sections below. For Total *Ascaris*, results are presented from the perspectives of prevalence, variability with study areas and variability with depth.

i. Total *Ascaris*

Results for Total *Ascaris Lumbricoides* in the analysed samples presented very large variations as evident from the huge sample standard deviations which in most cases were in excess of the mean values (Appendix J Table J-2) .

a. Prevalence

Over half of the analysed samples (57 percent; n=100) were positive for the presence of *Ascaris*. Huge variations in the results were observed with the ranges being 0±0 to 471±137 and 0±0 to 683±104 (n=100) for the top and bottom sludge, respectively.

b. Variability with study areas

In terms of variability among the study areas, Kanyama and George had the highest numbers of the latrines registering positive counts for *Ascaris* at 64 percent each (n=25) while Madimba recorded the least at only 40 percent (n=25) (Table 4-31).

Table 4-31: Prevalence of Ascaris in the four study areas

Study area	Latrines with positive counts of *Ascaris* (%)	Number of samples (n)
Chaisa	56	25
George	64	25
Kanyama	64	25
Madimba	40	25

c. Variability with depth

For Total *Ascaris*, results showed no pronounced variations between the counts in the top and bottom sludge. However, slightly more latrines had higher *Ascaris* counts in top sludge as compared to bottom sludge in all the study areas except for Kanyama which registered higher counts in the bottom sludge (Figure 4-19). It

should be noted that the proportions being referred to here are with respect to latrines which registered positive *Ascaris* counts.

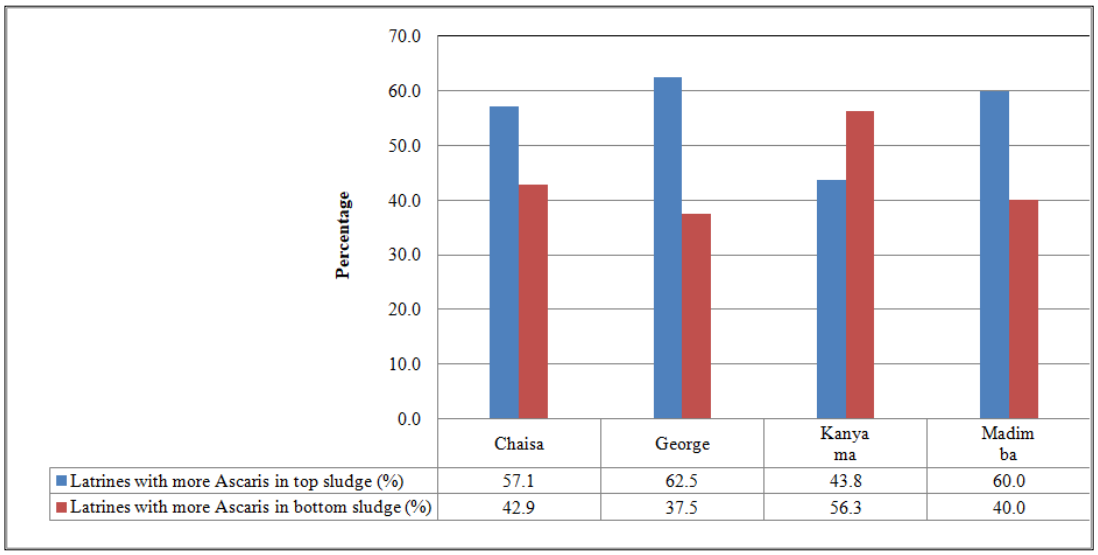


Figure 4-19: Variability of Ascaris counts in top and bottom sludge for latrines that registered positive counts

A graphical presentation of how Total *Ascaris* varied between the top and bottom sludge for samples from all the four study areas is presented in Figure 4-20 below. The results of the Mann-Whitney U test between the top and bottom sludge indicated that there was no significant difference (U=4,834; p =0.6892).

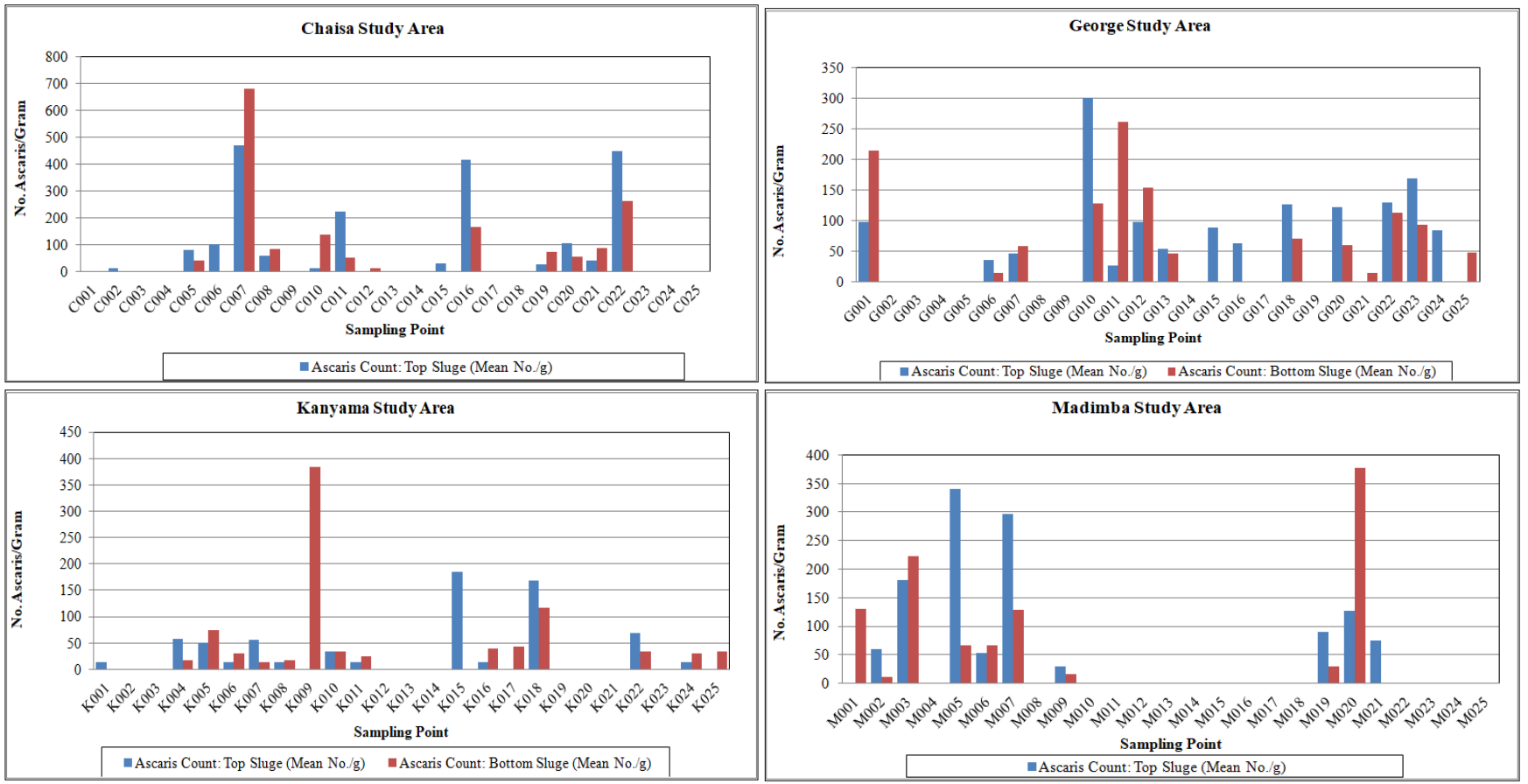


Figure 4-20: Prevalence of Ascaris in sludge samples and its variability with depth in each of the four study areas

ii. Viable *Ascaris*

Viable *Ascaris* was only recorded in 27 percent (n=100) of the latrines that were sampled. This translates to 47.4 percent of the latrines that registered positive counts for Total *Ascaris*. For all the samples where viable *Ascaris* was registered, it was recorded in top sludge except for samples from C008 and K022 where it was also present in bottom sludge (Figure 4-40). The range for the top sludge was 0±0 to 471±112 No./g of sludge while for the bottom sludge, the only samples that recorded positive counts, C008 and K022 registered 85±39No./g of sludge and 17±24No./g of sludge, respectively. The results are summarised in Figure 4-21. The results of the Mann-Whitney U test between the top and bottom sludge indicated that there was significant difference (3,738; p =0.0021).

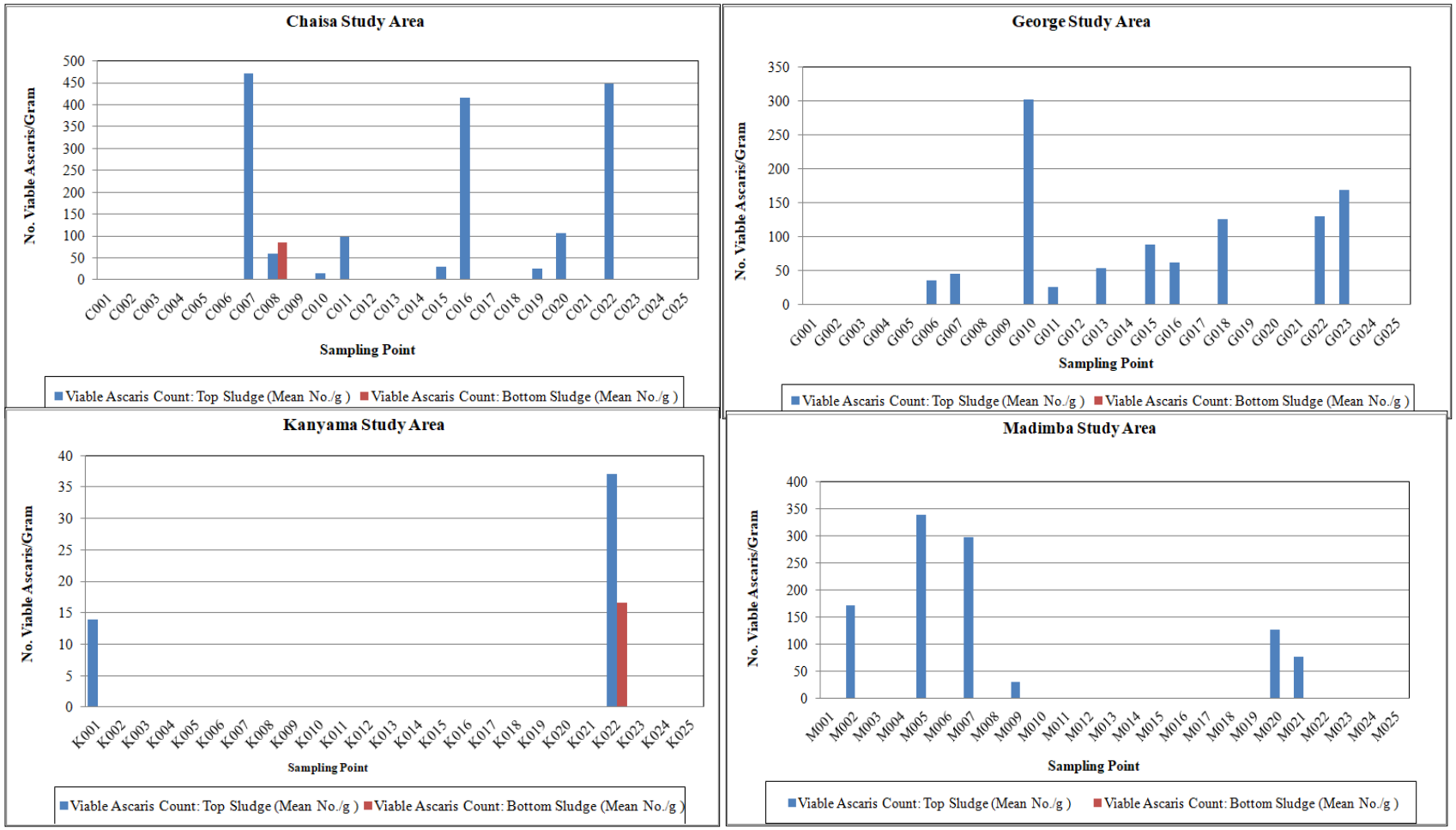


Figure 4-21: Prevalence of viable Ascaris in faecal sludge samples and its variability with depth in each of the four study areas

4.4.6.3 Cryptosporidium

Results for *Cryptosporidium*, like the case was for faecal coliforms and *Ascaris* results had large variations as evident from the large magnitude of the computed standard deviations though not to the extent observed for faecal coliforms and *Ascaris* (Table J-3 in Appendix J). The results are presented in the sections below.

i. Prevalence

Cryptosporidium was detected in 94 percent (n=100) of the latrines analysed. There were huge variations in counts with the range for top sludge being 0±0.0 to 11,987±1,459 No./g of sludge and that for bottom sludge being 0±0.0 to 10,000±14,142 No./g of sludge. While the minimum value of zero was registered by several sampling points, the maximum values were recorded from the same sampling point, K025.

ii. Variability with study sites

Prevalence in respective study sites was generally very high for all areas at 96 (n=25), 92 (n=25), 96 (n=25) and 92 (n=25) percent for Chaisa, George, Kanyama and Madimba study areas, respectively. Quantitatively, George registered the highest counts at 1,339±1,488 No./g of sludge and 777±1,034 No./g of sludge for the top and bottom sludge, respectively. The minimum mean count for top sludge was recorded for samples from Madimba at 739±1,090 No./g (n=25) while for bottom sludge, the least mean count was recorded for samples from Chaisa which was 524±960 No./g of sludge (n=25) (Table 4-32).

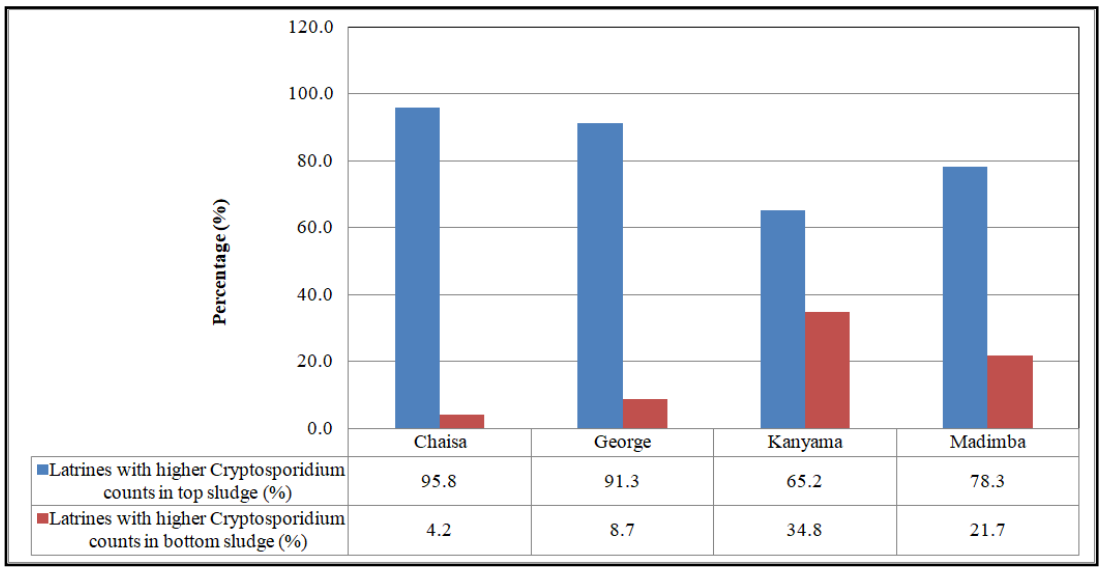
Table 4-32: Mean Cryptosporidium counts for the four study areas

Study area	Mean Crypto. counts in Top sludge (No./g)	Mean Crypto. counts in Top sludge (No./g)	Number of samples (n)
Chaisa	920±1,156	524±960	25
George	1,339±1,488	777±1,034	25
Kanyama	763±2,352	618±1,962	25
Madimba	739±1,090	549±776	25

iii. Variability with Depth

Variability of *Cryptosporidium* with depth was evident in all samples from the study areas. Sludge from top samples generally exhibited higher counts than bottom

sludge. Overall, 84 percent of the samples that had positive counts exhibited higher counts in the top sludge. With respect to the study areas, Chaisa had the highest number of samples registering higher counts in top sludge (95.8 percent) with Kanyama recording the least at only 65.2 (Figure 4-22).



	Chaisa	George	Kanyama	Madimba
Latrines with higher Cryptosporidium counts in top sludge (%)	95.8	91.3	65.2	78.3
Latrines with higher Cryptosporidium counts in bottom sludge (%)	4.2	8.7	34.8	21.7

Figure 4-22: Proportion of latrines with higher counts of Cryptosporidium in top and bottom sludge, respectively.

A graphical presentation of how *Cryptosporidium* varied between the top and bottom sludge for samples from all the four study areas is presented in Figure 4-23 below. The results of the Mann-Whitney U test between the top and bottom sludge indicated that there was significant difference (U=3,740; p =0.0021).

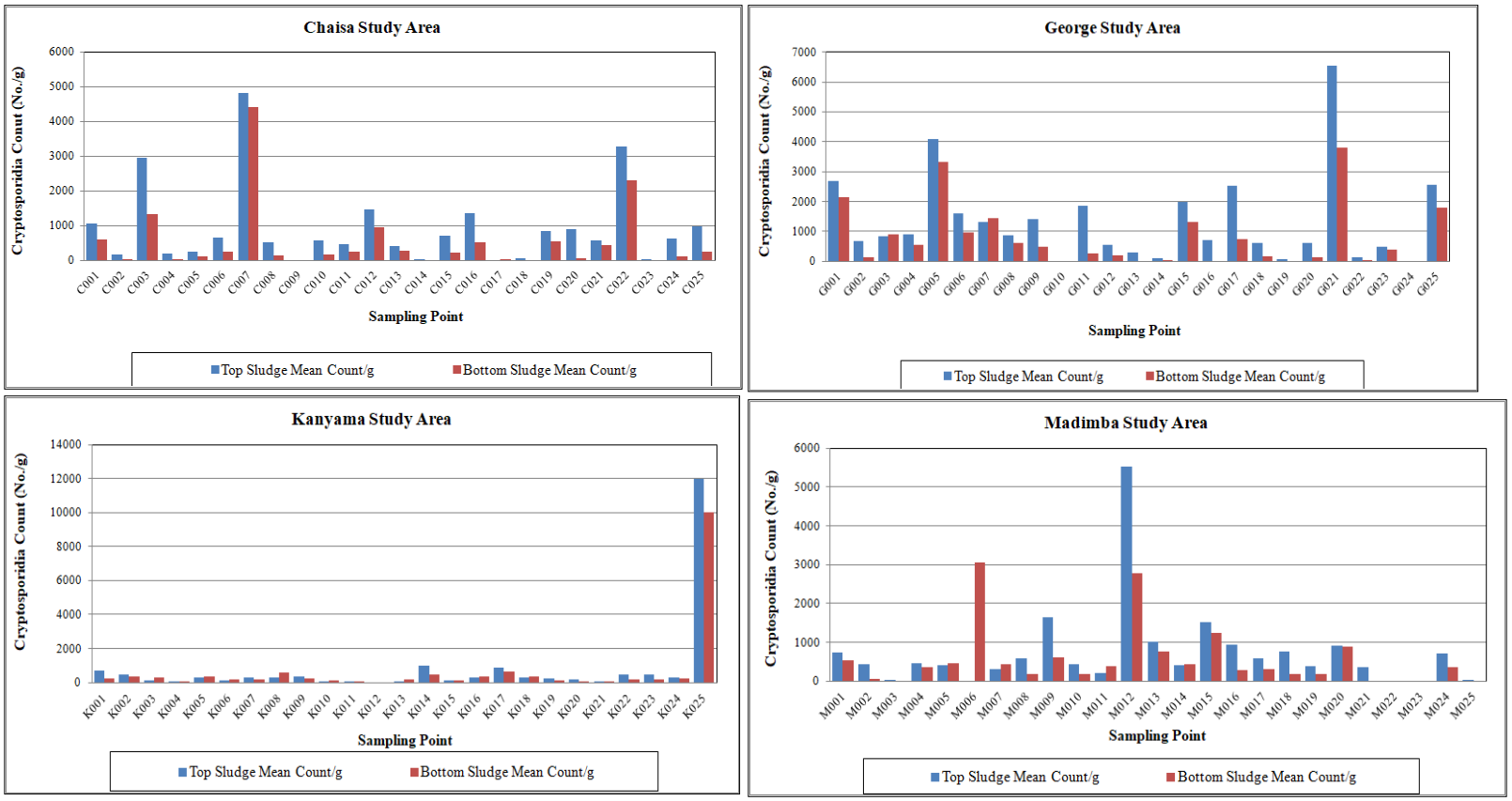


Figure 4-23 : Prevalence of Cryptosporidium in faecal sludge samples and its variability with depth.

4.5 Variability in degree of biodegradation of faecal sludge with depth

Stemming from the objectives, the study sought to prove the hypothesis that *"In the pit latrine, parameters linked to biodegradation exhibit a significantly higher degree of stabilisation for bottom sludge compared to top sludge."* In order to prove or disapprove this hypothesis, parameters linked to biodegradation and those linked to microbiological quality of the sludge which included Total Solids, TVS, Total COD, Soluble COD, Total BOD, Faecal Coliforms, Viable *Ascaris* and *Cryptosporidium* were adopted. Microbiological parameters are not direct indicators of biodegradation. However, the survival and reproduction of these microorganisms is directly related to organic matter content (BOD). It is expected that as the BOD reduces, the populations of these microorganisms also reduce. It is therefore from this perspective that these parameters were adopted as indicators of biodegradation in this study. The Mann-Whitney U test was used for this purpose as presented in section 3.8.

The variability of all the identified parameters with depth was presented in section 4.4. All parameters exhibited a reduction in concentration with increasing depth. However, only TVS, Viable *Ascaris* and *Cryptosporidium* had results that were significantly different (Table 4-33).

Table 4-33: Summary of variability of the selected parameters with depth

Parameter	**Where mean was higher**	**Where More Samples had higher Values**	**P – Value**	**Comment on how the means differed statistically**
Total Solids	Top sludge	Top sludge	0.4237	Not significantly different
TVS	Top sludge	Top sludge	0.0005	Significantly different
Total BOD	Top sludge	Top sludge	0.8103	Not significantly different
Total COD	Top sludge	Top sludge	0.0549	Not significantly different
Soluble COD	Top sludge	Top sludge	0.8026	Not significantly different
Faecal Coliforms	Top sludge	Top sludge	0.5552	Not significantly different
Viable *Ascaris*	Top sludge	Top sludge	0.0021	Significantly different
Cryptosporidium	Top sludge	Top sludge	0.0.002	Significantly different

4.6 Variability of faecal sludge quality with geological characteristics of the study areas

The study sought to address the objective on whether geological characteristics have an impact on the quality of the faecal sludge in the pit latrines. To this effect, a hypothesis stating that *"Faecal sludge quality significantly differs for pit latrines located in areas with different geological formations"* was developed and needed to be proved. As elaborated in Section 3.4, selection of study areas ensured that all geological categories upon which the city is sited namely dolomite/limestone and schist were covered with Chaisa study area being the only one sited on a different type of geology (schist) while the other three are on dolomite/limestone.

Only results for bottom sludge were adopted in this analysis based on the assumption that if there are differences due to the different geological formations, the differences would be more pronounced in the bottom sludge. This is because ideally, bottom sludge would be expected to have been in the pit for a longer period of time to be affected by the surrounding environmental conditions.

4.6.1 Results on differences in means from all the study areas

Comparisons on how results differed among the datasets were done using the Kruskal-Wallis H Test as the data sets were found to be non parametric (Table D1 in Appendix D). A summary of the results is presented in Table 4-34. A detailed compilation of the results from the Kruskal-Wallis H test for all the parameters is presented in Appendix D in Table D3.

Table 4-34: Significance of variance of mean results for selected parameters from the four study areas

Parameter	Chi-Square	Rejection Region	p-Value	COMMENT/ CONCLUSION
Density	1.765	7.815	0.6226	Not significantly different
Moisture Content	7.91	7.815	0.0479	Significantly different
Total Solids	7.91	7.815	0.0479	Significantly different
TVS	5.727	7.815	0.1257	Not significantly different
pH	18.007	7.815	0.0004	Significantly different

Table 4-34: Continued

Parameter	Chi-Square	Rejection Region	p-Value	COMMENT/ CONCLUSION
Total COD	7.814	7.815	0.0500	Not significantly different
Soluble COD	-165	7.815	1.0000	Not significantly different
Total BOD	10.844	7.815	0.0126	Significantly different
Ammonia	7.765	7.815	0.0511	Not significantly different
Sulphates	5.691	7.815	0.1277	Not significantly different
Phosphates	7.059	7.815	0.0701	Not significantly different
Faecal Coliforms	24.509	7.815	0.0000	Significantly different
Total *Ascaris*	1.188	7.815	0.7560	Not significantly different
Viable *Ascaris*	0.119	7.815	0.9895	Not significantly different
Cryptosporidium	2.01	7.815	0.5704	Not significantly different
Potassium	-162	7.815	1.0000	Not significantly different
Sodium	-162	7.815	1.0000	Not significantly different
Calcium	-162	7.815	1.0000	Not significantly different
Magnesium	-162	7.815	1.0000	Not significantly different

From Table 4-34, it is evident that only five out of the 19 parameters that were analysed registered statistically significant differences. These included moisture content, Total Solids, pH, Total BOD and Faecal coliforms. To ascertain whether the differences were due to geological differences or not, the data sets that presented significant differences were further subjected to the Mann-Whitney U Test as indicated in section 3.8.5.

4.6.2 Results of the Mann-Whitney U test on parameters that registered significant differences

The sections below present results for the Mann-Whitney U Test on parameters whose results using the Kruskal-Wallis H Test revealed significant differences. In this analysis, the test was designed to analyse all the possible combinations among the study areas in order to check whether it was the results for Chaisa that contributed to the significant differences observed in section 4.6.1. The test was therefore conducted on all possible combinations eminent from the four study areas as follows: Chaisa-George; Chaisa-Kanyama; Chaisa-Madimba; George-Kanyama; George-Madimba; and Kanyama Madimba. Results are presented in ensuing sections.

4.6.2.1 Moisture Content

The results for the Mann-Whitney U Test on Moisture Content for the results from the four study areas are presented in Table 4-35.

Table 4-35: Summary of the Mann-Whitney U Test results for moisture content

Areas compared	n	U	z	P-Value	Conclusion
Chaisa-George	n_1=15; n_2=15	52.5	2.4680	0.0135	Significantly Different
Chaisa-Kanyama	n_1=15; n_2=15	73	1.6176	0.1052	Not Significantly Different
Chaisa-Madimba	n_1=15; n_2=13	83	0.6449	0.5222	Not Significantly Different
George-Kanyama	n_1=15; n_2=15	95	-0.7051	0.4777	Not Significantly Different
George-Madimba	n_1=15; n_2=13	50	-2.1651	0.0300	Not Significantly Different
Kanyama-Madimba	n_1=15; n_2=13	76.5	-0.9443	0.3472	Not Significantly Different

4.6.2.2 Total solids

The results for the Mann-Whitney U Test on Total Solids for the results from the four study areas are presented in Table 4-36.

Table 4-36: Summary of the Mann-Whitney U Test results for Total Solids

Areas compared	n	U	z	P-Value	Conclusion
Chaisa-George	n_1=15; n_2=15	52.5	-2.4680	0.0135	Significantly Different
Chaisa-Kanyama	n_1=15; n_2=15	73	-1.6176	0.1052	Not Significantly Different
Chaisa-Madimba	n_1=15; n_2=13	83	-0.6449	0.5222	Not Significantly Different
George-Kanyama	n_1=15; n_2=15	95	0.7051	0.4777	Not Significantly Different
George-Madimba	n_1=15; n_2=13	50	2.1651	0.03	Not Significantly Different
Kanyama-Madimba	n_1=15; n_2=13	76.5	0.9443	0.3472	Not Significantly Different

4.6.2.3 pH

The results for the Mann-Whitney U Test on pH for the results from the four study areas are presented in Table 4-37.

Table 4-37: Summary of the Mann-Whitney U Test results for pH

Areas compared	n	U	z	P-Value	Conclusion
Chaisa-George	n_1=15; n_2=15	94.5	-0.7259	0.4654	Not Significantly Different
Chaisa-Kanyama	n_1=15; n_2=15	29	-3.4427	0.0006	Significantly Different
Chaisa-Madimba	n_1=15; n_2=13	36.5	-2.7870	0.0053	Significantly Different
George-Kanyama	n_1=15; n_2=15	40.5	-2.9668	0.0030	Significantly Different
George-Madimba	n_1=15; n_2=13	46.5	-2.3263	0.0198	Significantly Different
Kanyama-Madimba	n_1=15; n_2=13	85.5	0.5298	0.5961	Not Significantly Different

4.6.2.4 Total Biochemical Oxygen Demand

The results for the Mann-Whitney U test on Total BOD for the results from the four study areas are presented in Table 4-38.

Table 4-38: Summary of the Mann-Whitney U Test results for BOD

Areas compared	n	U	z	P-Value	Conclusion
Chaisa-George	n_1=13; n_2=15	82	-0.6910	0.4902	Not Significantly Different
Chaisa-Kanyama	n_1=13; n_2=15	78	-0.8752	0.3787	Not Significantly Different
Chaisa-Madimba	n_1=13; n_2=13	72	-0.6154	0.5353	Not Significantly Different
George-Kanyama	n_1=15; n_2=15	111	-0.0441	0.9681	Not Significantly Different
George-Madimba	n_1=15; n_2=13	28.5	-3.1555	0.0015	Significantly Different
Kanyama-Madimba	n_1=15; n_2=13	25.5	-3.2937	0.0.0010	Significantly Different

4.6.2.5 Faecal Coliforms

The results for the Mann-Whitney U Test on Faecal Coliforms for the results from the four study areas are presented in Table 4-39.

Table 4-39: Summary of the Mann-Whitney U Test results for faecal coliforms

Areas compared	n	U	z	P-Value	Conclusion
Chaisa-George	n_1=25; n_2=25	255	1.1060	0.2670	Not Significantly Different
Chaisa-Kanyama	n_1=25; n_2=24	83	4.3300	<0.00001	Significantly Different
Chaisa-Madimba	n_1=25; n_2=21	230	0.7057	0.4777	Not Significantly Different
George-Kanyama	n_1=25; n_2=24	124	3.5100	0.0004	Significantly Different
George-Madimba	n_1=25; n_2=21	240	-0.4852	0.6241	Not Significantly Different
Kanyama-Madimba	n_1=24; n_2=21	81	-3.8790	0.0001	Significantly Different

4.6.3 Summary of the Mann-Whitney U Test on parameters that registered significant differences

A summary of the Mann-Whitney U Test for the above pair-wise comparisons is presented in Figure 4-24. It should be noted that Chaisa is the only area that has a different geological formation (Schist) while the other three are all on dolomite/Limestone. From the figure, out of the 26 combinations that produced statistically significant different results, Chaisa appeared in only five (5) combinations which was the least number of appearances registered accounting for only19.2 percent.

Parameter	Area combinations resulting in statistically significantly different results
Moisture content	Chaisa-George; George Madimba
Total Solids	Chaisa-George; George Madimba
pH	Chaisa-Kanyama; Chaisa-Madimba; George-Kanyama; George-Madimba
Total BOD	George-Madimba; Kanyama-Madimba
Faecal Coliforms	Chaisa-Kanyama; George-Kanyama; Kanyama-Madimba

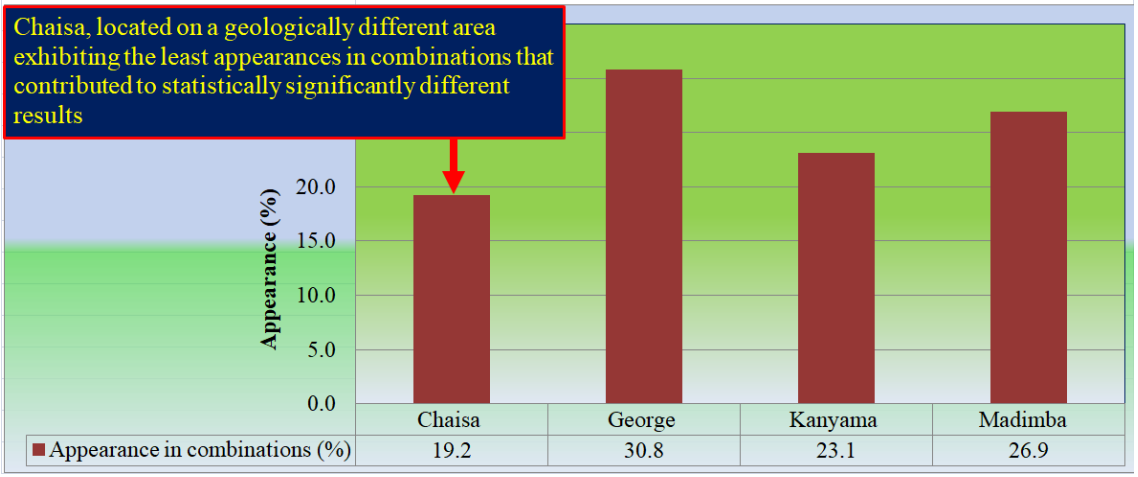


Figure 4-24: Summary of appearances by percentage in combinations of results from the different study areas that accounted for the statistically different results in the pair-wise comparisons.

4.7 Proposed Operations Framework for Enhanced FSM services Provision

The last objective of the study was to come up with an Operations Framework based on the findings of the study. Therefore, one of the major outputs of this study was an Operations Framework which was designed to integrate the identified reuse potential of the faecal sludge and measures to address the identified challenges that may contribute to low uptake of faecal sludge in reuse initiatives. The framework's aim is to promote reuse of the faecal sludge which would ultimately result in improved FSM services

provision in peri-urban areas thereby contributing to improved sanitation in these areas. The proposed operations framework is therefore anchored on three major pillars namely:

- Quality aspects;
- Demand creation; and
- Regulation.

The three 'pillars' were identified through the research results. Quality plays a pivotal role in valorisation of the sludge. Various parameters relevant to valorisation were analysed in this study and are presented in this Chapter. The results have demonstrated that the sludge has potential for reuse. At the same time, the results have highlighted some of the major challenges, mostly of which hinge on the non regulation of design, construction and utilisation of the latrines. Practices that compromise the quality of the sludge have also been highlighted. Based on these three pillars, the proposed Framework for enhanced FSM Operations was designed and is presented in Figure 4-25.

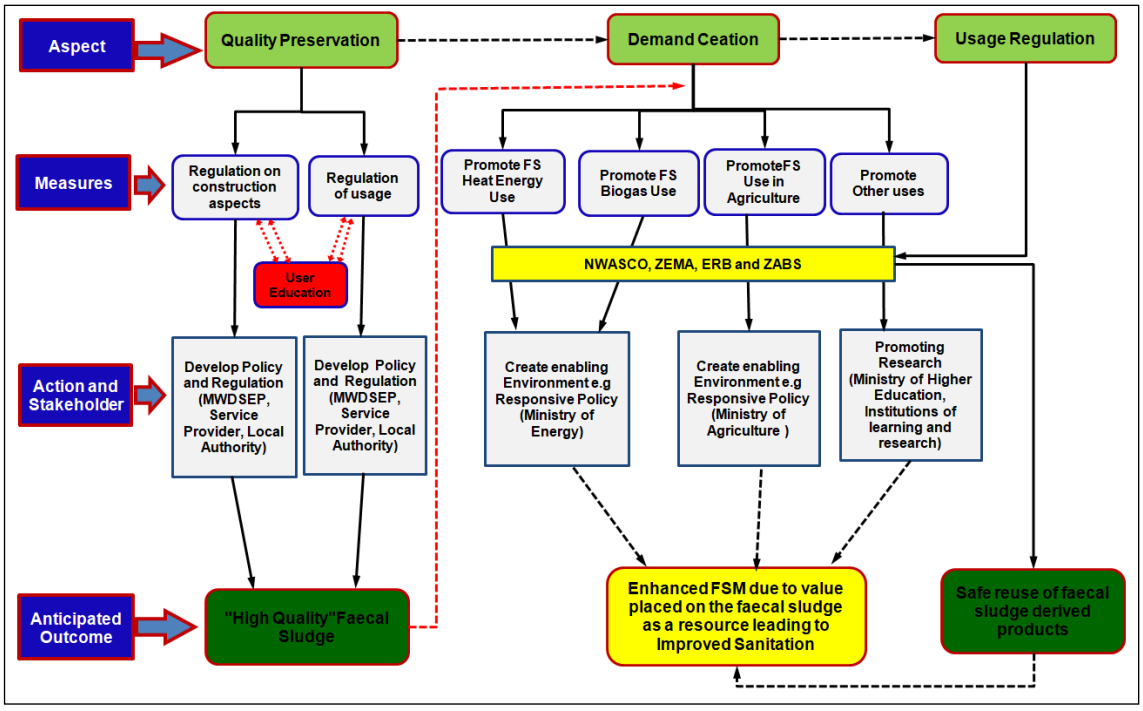


Figure 4-25: Proposed Operations Framework for FSM based on study findings

4.8 Chapter Summary

This chapter aimed at presenting the findings of the study and did so in line with the set research questions/hypotheses. Findings on latrine construction and usage which would potentially impact on the faecal sludge quality were elaborated. Other faecal sludge characteristics that would impact on faecal sludge quality from the perspective of valorisation including physical, rheological, chemical and microbiological characteristics were presented. The chapter then presented results on variability of faecal sludge quality with latrine depth and geological characteristics of the area where the latrines are located before finally presenting the proposed Operations Framework for enhanced FSM which has been designed based on the findings of the study. The next Chapter discusses the results presented in this chapter in order to respond to the research questions and hypotheses.

CHAPTER 5 : DISCUSSION

5.1 Introduction

The previous chapter presented findings of the study in line with the set objectives. This chapter discusses the results linking them to the respective research questions and hypotheses. As the aim of the study was to characterise the faecal sludge in order to contribute to enhanced sanitation through improved FSM, the chapter discusses the results from the context of valorisation in line with the conceptual framework (See section 1.8). It therefore first discusses the sanitation practices and their implications on faecal sludge quality before discussing valorisation prospects from the context of the analysed parameters. Under the section discussing valorisation potential, some parameters are grouped so that those parameters addressing the same aspects appear under the same heading. This implies that parameters like TVS, BOD and COD are discussed under the same umbrella heading as they are all a measure of organic matter content. The chapter then delves into variability of faecal sludge with depth within the latrine and also with geological formations of the project areas. It is concluded with an introduction to proposed operations framework for enhanced FSM in peri-urban areas which has been designed based on the findings of the study.

5.2 Sanitation practices and implications on faecal sludge quality

Faecal sludge characteristics do not only depend on socio-cultural factors but also on numerous factors including the nature of the facility, sanitation practices, environmental conditions and so on (Strande et al., 2014). In this study, factors that were identified to have possible impacts on faecal sludge quality included: latrine design and construction; and latrine operational aspects.

5.2.1 Latrine design and construction

Results on latrine construction revealed non availability of standards for latrine designs and construction. The partial lining affects the rate and extent of sludge stabilisation in a pit latrine since it affects the amount of moisture available in the latrine. Depending on the surrounding conditions, a partially lined latrine will admit or lose moisture at a

faster rate compared to one that is lined. Moisture is one of the factors that affect reactions in a pit latrine (Bhagwan et al., 2008). Partially lined elevated latrines in areas with high ground water table can exhibit unexpected solids arrangement in the pit where top sludge has higher solids content floating on a watery sludge in the deeper layers of the pit as evidenced from the rheological results in sections 4.4.2. This type of construction therefore possibly contributed to variability of sludge quality in a manner not possible in a dry pit latrine. In this study, the foregoing could not clearly be established. Although 98 percent of the latrines were said to be fully lined, the extent of the effectiveness of the lining in preventing the leaching of pit contents into the surrounding environment could not be ascertained. As highlighted in section 4.2.1, most of the latrines said to be lined may only be partially so.

The difficulty to dig deep latrines which is due to the rocky geological formation favours a construction practice where the latrine depth is shallower. Evaluation of the latrine depths in the study areas indicated that the majority are between 0.5 and 2.5m. This deviates from the latrine depths suggested by Brikké and Bredero (2003) who contend that pit latrines usually range from 3 to 5m. Pit latrines in the study areas are therefore comparatively shallower. The shallow pits resulted in marginal height differences between samples from the top and bottom parts of the latrine. In most cases, it was less than one meter as presented in sections 4.3 and 4.4.6. This small difference in height, especially when combined with high moisture content can impact on the results. As observed, for some of the parameters, unexpected results were obtained where the results between the top and bottom sludge appeared to be reversed. Ideally, where the sludge is well layered, as the case is in a VIP, this is an unlikely occurrence. However, where height difference between the top and bottom sludge is minimal, and moisture content is high, mixing of the latrine contents is possible which can lead to such results.

5.2.2 Latrine usage and operational aspects

Results on latrine usage and operational aspects were presented under three subheadings which included: the use of the pit latrines as receptors of sullage; use of the latrines as

receptors of solid waste; the practice of adding chemicals like chlorine and lime to the pit contents; and desludging aspects of latrines in the study areas. A discussion on each of these three aspects is presented in the ensuing sections.

5.2.2.1 Use of the latrines as receptors of excreta and sullage

Latrines in the study areas are constructed to either just serve as excreta disposal facilities or to also serve as bathrooms as elaborated in section 4.2.2). For facilities serving the dual purposes, sullage from bathing activities finds its way into the pit. This contributes to exaggeration of some parameters like phosphates which averaged 1,740±964 and 1,235±812 mg/L (PO_4^{3-}-P) for the top and bottom sludge, respectively (Section 4.4.3.7). These values are considerably higher than those reported by NWSC (2008) in Strande et al. (2014) where the highest reported figure was only 450 mg/L (PO_4^{3-}-P) and also figures reported for VIP latrines from Durban for the various types of latrines for which the reported concentrations were less than 1 mg/L PO_4^{3-}-P. Results on the comparison of the faecal sludge quality in terms of phosphates between facilities used exclusively for excreta disposal and those that are also receptors of sullage presented obvious differences as presented in section 4.2.2.1. This clearly demonstrates that faecal sludge quality is affected by the practice of using the facilities as receptors of sullage.

Sullage is also expected to increase the moisture content of the faecal sludge which can lead to dilution effects. However, an assessment of the moisture content in pit latrines exclusively used as excreta disposal facilities and those that are used for disposal of both excreta and sullage did not support this assertion (section4.2.2.1).

Ideally, if two facilities are compared where all other parameters are constant, it is expected that dilution effects of sullage would be evident. In this case, although the sullage would be contributing to the dilution, this was not explicitly evident from the result presented in section 4.2.2.1. This observation is obviously because the facilities under comparison had a lot of other parameters affecting moisture content beyond

sullage. Examples include number of users, effectiveness of the lining, ground water levels and so on.

Notwithstanding the foregoing, it is evident that the practice of using a latrine for other purposes apart from excreta disposal introduces parameters from other sources beyond what would normally be found in faecal matter. The practice also alters the moisture content and therefore contributes to the variability of the results.

5.2.2.2 Use of the latrines as receptors of solid waste

Qualitative field observations revealed high content of solid waste in the pit latrines. Quantitative analysis of the faecal sludge for solid waste content (Section 4.2.2) confirmed the observed high content of solid waste with the mean value being 32.8±13.9 percent of the total mass of the dry solids. Treatment of this sludge would therefore be expensive as extra facilities would be required to address this high content of solid waste. The operations and maintenance costs of the treatment facilities would also be exaggerated due to high content of the waste.

The observed high content of solid waste can partly be blamed on the socio-cultural perceptions and stigma attached to menstruation in most of the Zambian culture. This leads to disposal of menstruation waste in a manner that ensures maximum secrecy. In peri-urban areas, pit latrines serve as the most appropriate means of disposal that ensure secrecy. Additionally, in almost all the peri-urban areas, solid waste management systems are not available which is also a factor contributing to the deliberate disposal of the waste in pit latrines (Tembo et al., 2016). Textiles comprising sanitary pads, rugs, diapers sacks and so on ranked the highest, at 54.4 percent of the dry solids for the physical fractions of the pit latrines faecal sludge solid waste content (section 4.2.2).

Sources of grit can partly be blamed on the non user-friendliness to young children of most latrine interfaces. Some facilities have large squatting holes beyond the 25cm recommended by WHO (1996) making them dangerous for young children. Others are just not accessible to children due to the way they are constructed (Figure 5-1).

Figure 5-1: Example of interfaces that discourage direct latrine usage by children (Source: This study)

Because of this, children usually defeacate on the ground within the premises of the household after which the excreta is picked and deposited into the latrine. The picking up of the excreta is through a scooping tool like a shovel or hoe. Therefore, when the excreta is picked, an appreciable amount of soil is also collected and this ends up in the latrine. Grit also comes from the unlined portions of the latrines (Tembo et al., 2016). However, the majority of the grit ending up in the emptied sludge was observed to have been due to the desludging method used. Desludging was observed to be a "two-stage" scooping system. The sludge was first scooped from the pit using modified garden tools into a temporary pit that was dug to receive the sludge from the pit. The sludge was then scooped from the temporary pit into the barrels (Figure 5-2). As the temporally pit was not lined, it was obviously a source of the grit.

Figure 5-2: The pit latrine desludging process (Note the possible mixing of the sludge with the loose sand from the newly dug pit) (Source: This study).

From the analytical perspective, solid waste and grit affect faecal sludge quality as it adds to the weight of the sludge being considered in formulation of the sample for analysis such that in the final analysis, where a result is presented as mass of a parameter per mass of dry sample, the actual mass of dry sample is exaggerated as a part of what was weighed was waste (i.e. grit). Therefore the presence of solid waste in faecal sludge exaggerates the solids content and consequently the fixed solids in a

sample but will lead an understatement of the other parameters. This impacts on the variability of results for aliquots and hence the standard deviations on results may be exaggerated as was observed for some results in this study.

At treatment and reuse stage, high solid waste content complicates the processes. Where treatment of the sludge is through closed reactors, high content of solid waste, especially in form of grit, leads to system blockages requiring high frequency of reactor cleaning. This requires putting the reactor out of service for some time disrupting the treatment process. This was observed for the two pilot plants managed by LWSC through the delegated management of the Water Trusts in Kanyama and Chazanga. At reuse stage, high solid waste content also poses challenges. For example, in the valorisation of faecal sludge to generate power, demineralised water and ash using an omni processor, grit serious hampers the processes. For sludge with grit content in excess of 5 percent of the dry mass, the Omni processors operations are impaired (Malo, 2017).

Non-biodegradable waste like rags and plastics, which are present in large quantities in the pit latrines within the study areas, compromise the ultimate reuse of the sludge in agricultural activities. When present in form of sharp objects like broken glass and needles, solid waste may also pose health and safety risks especially to workers handling the sludge. Solid waste may also promote proliferation of vectors which may lead to disease outbreaks (IWMI, 2003).

From what has been discussed in this section, it is evident that non availability of standards for construction of pit latrines results in construction of facilities that are not user friendly especially to children resulting in practices that introduce grit into the faecal sludge contents. Grit content is also exacerbated by the adopted method of desludging which is due to inappropriate construction. High solid waste content in the sludge due to indiscriminate disposal of waste into the latrines was another problem that was highlighted. All these challenges point to the need for regulation of latrine

construction and usage if the full benefits associated with valorisation of faecal sludge are to be realised.

5.2.2.3 Addition of Chemicals to pit latrine contents

As observed in section 4.2.2, more than 50 percent of the latrines (n=100), were treated with chemicals among which the most prominent were chlorine and lime. This is besides chemicals from cleaning and bathing activities which are often daily activities in these facilities.

Regardless of the reasons why chemicals are added, the practice alters the natural characteristics of faecal sludge quality. Addition of chemicals like chlorine and lime has long been known to alter the quality of sludge. Addition of chlorine substances will oxidize and disinfect the organic matter (Deborde and von Gunten, 2008). This would lead to a reduction in the organic matter content and microbial populations due to inactivation. As microorganisms are responsible for the biodegradation processes, addition of chlorine would retard biodegradation processes. Lime dosing to pit contents increases the pH. Increased pH results in inactivation of microorganisms. It is reported that sanitisation of faecal sludge can be achieved through addition of lime and that faecal coliforms can be reduced to less than 1000CFU/100 mL just after one hour from the time of lime dosing (Bina et al., 2004; Thole et al., 2016). Sanitisation effects of lime were also observed by Hooijmans et al. (2015) who reported *Escherichia Coli* (*E. Coli*) reduction levels to below detection limit at a pH $\geq$11 in just one hour. Bina et al. (2004) also observed a reduction in volatile solids content indicating that lime degrades or stabilises organic matter in sludge. It therefore implies that where these chemicals are added, the quality of sludge is greatly altered.

As presented in section 4.2.2.3, results indicated marginal differences among the results for parameters adopted to analyse the impacts of chemical addition to pit latrines which included pH, faecal coliforms, Total COD and Total BOD. The results showed that the means for pH for sludge from pit latrines where chemicals were reportedly added and those where chemicals were reportedly not added were almost the same. This implies

that although over 50 percent of the latrines were reportedly treated with chemicals, it is obvious that the impacts were marginal resulting in insignificant differences. Hooijmans et al. (2015) report significant reduction in microorganism counts at pH ≥11. In this study, the maximum pH recorded was just around 8 (section 4.4.3.1) which is not sufficient to result in sanitisation of faecal sludge. Similarly, the metrics of organic matter biodegradation between samples from latrines where chemicals were dosed and those where no chemicals were dosed were not statistically significantly different. No significant differences in microbiological quality were observed either despite the reported use of chlorine as has been presented in Table 4-3. It is therefore prudent to suggest that addition of chemicals to pit latrines, unless added in sufficient quantities, may not have significant impacts on the faecal sludge quality.

5.2.2.4 Desludging frequency of the latrines

Although desludging of facilities is expected to significantly impact on the faecal sludge quality, a comparison of the quality data between latrines reported to have been desludged within a year prior to the study and those reportedly never desludged did not yield statistically significant results (section 4.2.2.4). This odd observation may be attributed to the fact that desludging done in the study areas is usually partial with the aim being to just create space in the latrine for continued usage. Going by the existing formal desludging brackets (see section 3.6.3.1), where 12 barrels are desludge, it is only about $0.7m^3$ of sludge that is desludged. The quantities are even less were the desludging is done by informal operators. It may therefore be postulated that partial desludging of pit contents, especially if the quantities removed are small, may not lead to significant faecal sludge quality variations.

5.3 Valorisation potential of the faecal sludge

Valorisation potential of the faecal sludge was assessed through quality determination for selected parameters which were grouped in four categories namely physical, rheological, chemical and microbiological. Variation with depth and study areas for all these parameters are also discussed but in later sections.

5.3.1 Valorisation potential – Physical parameters and organic matter

The analysed physical parameters relevant to valorisation potential included density, moisture content, total solids, TVS and solid waste.

5.3.1.1 Density

The average density of the faecal sludge for the study areas was in the vicinity of 1,100kg/m^3. This compares to density results reported by Radford and Sugden (2014) who found a mean of 1001kg/m^3 for latrines assessed in Kampala. The "Final Assessment Report on Rheological Properties of Faecal Sludge" reported density results for the wet bottom sludge from septic tanks to be between 1,092 to 1,159 kg/m^3 (AIT, 2012). However, results from AIT, 2012 may not be a suitable basis for comparisons as this was sludge from a different technology; septic tanks. Strande et al. (2014) reports densities of between 1,350 and 1,450Kg/m^3 for latrines in South Africa. These facilities were however VIP latrines unlike the latrines that were studied in this research which were ordinary pit latrines.

Density plays an important role in the emptying of facilities. It affects pumpability of faecal sludge as it determines the static head required to lift the sludge and hence limits the maximum emptying depth (Radford et al., 2015). As observed by Bösch and Schertenleib (1985), sludges with a higher density require more suction to move them as compared to sludge of a lower density if all the other parameters are kept constant. The results for this sludge indicate marginal difference from the density of water implying that density would not be a limiting factor to the pumpability of this sludge.

Faecal sludge density also has high implications on FSM specifically on the transportation aspect. Higher density entails more tonnage per unit volume of sludge. Therefore, carrying the same volume of sludge with different densities would require more resources for sludge with higher density. This is because in terms of transportation, higher density entails reaching the tonnage specifications of a transportation vehicle with a smaller volume.

5.3.1.2 Moisture and Total Solids content

The overall mean for moisture content results were found to be 81 and 82 percent for the top and bottom sludge, respectively, signifying an increase of moisture content with depth. This contradicts findings from other researchers who have found that moisture content decreases with depth (Zuma et al., 2015; Buckley et al., 2008). This difference can be accounted for by the differences between the latrines studied by Zuma and Buckley and the ones that were investigated in this study. Whereas the findings of Zuma and Buckley are based on VIP latrines whose construction was guided by standard guidelines that ensure proper layering of sludge in the latrines, the facilities sampled in this study differed from one latrine to the other in terms of various aspects including design, construction and operations. For example, partially lined decked latrines in a water logged area would present situations where there are more solids floating on top of a watery layer (refer to sections 4.4.2.4 and 5.3.2).

Moisture content of over 80 percent implies that the bigger proportion of the faecal sludge is water. These findings are comparable to results reported by Semiyaga et al. (2016) for unlined pit latrines in Uganda who reported mean moisture content results of 83.4 percent. Locally, no data on moisture content in pit latrine faecal sludge was available.

Moisture content is critical to valorisation at the stages of containment, transportation and treatment. High moisture content exaggerates the filling rates of the containment facilities leading to increased frequency of desludging. High moisture content also negatively impacts on transportation as a bigger proportion of the faecal sludge transported to treatment plants would be water. An added expense would also be incurred at the treatment stage as additional processes to concentrate the sludge before treatment would be required (Semiyaga et al., 2016). However, at about 20 percent solids content, the sludge would not need to be further concentrated before treatment.

Whatever is not moisture in the faecal sludge falls within the category of total solids. This implies that the sludge has about 20 percent total solids content by mass (refer to

section 4.4.1.3). Solids in the faecal sludge contribute to the COD/BOD of the sludge and hence contribute to the amount of biogas that can be generated per unit mass of the sludge. Total solids are also a source of energy. In their research on the calorific value of faecal sludge from three African cities, Murray-Muspratt et al. (2014) established that a kilogram of faecal sludge solids yields 17.3 MJ of energy which they indicated was comparable to other biomass fuels. Zuma et al. (2015) reports a calorific value of 14 MJ/kg of dry solids. Going by the lower calorific value reported by Zuma and the computed density of the sludge which was about 1,100kg/m^3, a cubic metre of the sludge would potentially yield 3,080MJ of energy. Combining this with the estimated faecal generation rate of 165m^3/day for the city (section 1.2) about 508,200MJ of energy can be generated from the faecal sludge on a daily basis. However, since no research on calorific value potential of the sludge has ever been conducted at the local level, it is imperative that a research is conducted on this aspect to ascertain the energy potential of the faecal sludge and assess the feasibility of utilising this energy to drive industrial processes.

From the foregoing, it is clear that the solids in the faecal sludge can potentially be utilised as a direct source of energy. When faecal sludge is used to generate energy, its management would most likely improve. This would lead to reduced environmental pollution. The use of faecal sludge would also reduce reliance on fossil fuels thereby contributing to environmental preservation (e.g. by reducing usage of fossil fuels like wood). It is therefore imperative that as ways of safely disposing of faecal sludge in the city are being designed, the energy content of the solids in the faecal sludge need to be acknowledged and taken into consideration for the betterment of both the physical and socio-economic environment.

5.3.1.3 Total Volatile Solids, COD and BOD

Organic matter content in the faecal sludge contributes to its valorisation potential. In this study, organic matter content was assessed through TVS, COD and BOD (Sections 4.4.1.4, 4.4.3.2, 4.4.3.3 and 4.4.3.4).

The mean TVS (g/g dry solids) for results from all the study areas was over 50 percent with the mean for the top and bottom sludge being 0.63±0.145g/g and 0.55±0.107g/g dry solids, respectively. These findings are in agreement with the findings of Semiyaga et al. (2016) who reported a mean value of 0.50±0.16g/g dry solids for unlined pit latrines and Strande et al. (2014) who reported a mean of 0.54g/g dry solids for wet VIP latrines. These values are close to what was found in this study indicating that the type of latrine does not so much affect TVS results. This is justified as the test is done on the dry solids. A study by Zuma et al. (2015) on VIP latrines found TVS results of between 0.31 to 0.81g/g with sludge on top having a significantly higher TVS when compared to the bottom sludge. Similar results were obtained in this study with means for the top and bottom sludge being significantly different ($U=1,057$, $n_1=n_2=58$, $P=0.001$). However, it is imperative that further research taking into account seasonal variations is conducted to see whether season may affect the quality differently.

Total COD averaged about 129,407±55,088 and 112,052±51,467 while Soluble COD averaged 66,659±40,223 mg O_2/L and 54,667±38,143 mg O_2/L for the top and bottom sludge, respectively. These results yield a Total COD/Soluble COD ratio of about two for both the top and bottom sludge which entails that particulate matter accounts for about 50 percent of the COD in the samples. The implication of this finding is that removal of solids from the faecal sludge would not in itself result in adequately treated effluent. Adequate treatment of this sludge would only be possible through the use of a combination of methods.

On a comparative basis, researchers who have characterised faecal sludge have come up with mean values that are significantly lower than the findings of this research (Table 5-1).

Table 5-1: A comparison of COD results from the study and those from other faecal sludge characterisation studies

Parameter	Faecal sludge Source			Reference
	Pit Latrine	**Public Latrine**	**Septic Tanks**	
COD (mg/L)	-	49,000	1,200 – 7,800	Koné and Strauss (2004).
	-	30,000	10,000	NWSC (2008)
		20,000–50,000	<10,000	Heinss et al. 1998
Total COD (Top sludge) (mg/L)	129,407±55,088	-	-	Author
Total COD (Bottom sludge) (mg/L)	112,052±51,467	-	-	Author

Source: Modified from Strande (2014)

The huge differences in the means observed between the results obtained in this study and results from other studies (Table 5-3) above may be attributed to the different nature of the facilities. Sludge from a pit latrine is expected to be more concentrated in terms of organic matter compared to public latrines and septic tanks which use huge amounts of water for flushing. The added water induces significant dilution effects leading to low COD values.

In contrast, the mean BOD results obtained from this study was found to be comparatively lower averaging 1,045±527 and 1,006±470 mg O_2/L of sludge. Koné and Strauss (2004) reported BOD values of 7,600 mg O_2/L and 840 – 2,600 mg O_2/L of wet faecal sludge for the public toilets and septic tanks, respectively. It would be expected that the BOD for pit latrine faecal sludge should be higher than that for samples from public toilets and septic tanks as it is more concentrated. A comparative assessment of the COD and BOD results for the top and bottom sludge yielded significantly higher COD/BOD ratios (Table 5-2).

Table 5-2: COD/BOD ratios for research results and other systems

Sample Source	COD/BOD Ratio			
	Research Results (Pit Latrines)	**Public Toilets**	**Septic Tanks**	**Municipal Wastewater**
Top Sludge	129	-	-	-
Bottom sludge	112	-	-	-
Other sources*	-	5.0	1.43-3.0	2.0-2.5

Data extracted from (Strande et al., 2014)

According to Buckley *et al. (*2008), approximately 80 percent of the organic material in faecal matter deposited in a pit latrine is biodegradable material of which 30 percent is bacteria. Comparing this assertion to the results from this study, the ratio obtained is significantly higher. Several factors may be cited for this observation one being inhibition that may possibly arise from practices identified in section 4.2.2 of adding chemicals and detergents to the latrines. However, more research on this aspect is imperative.

The use of faecal sludge for the generation of biogas is an aspect that depends on the biodegradable component of the organic matter which is the BOD. It is therefore prudent to suggest that although the COD is high, the sludge in this study would only be able to generate a maximum average of about 0.35 L of methane per every litre of this sludge based on the BOD results. This translates to 250 gCH_4/m^3 of wet sludge. This follows from the assertions of Araujo et al. (2008) and the stoichiometry of biogas generation presented in section 2.10.1. Using the energy yield potential of methane which is 1g CH_4 yielding 50.1KJ of energy, a cubic metre of this sludge would therefore yield approximately 12.5MJ of energy derived from methane. The energy that can be captured from this sludge is therefore reasonable especially if it is coming in as a by product of the treatment process. This would ultimately incentivise the desludging process ensuring that the sludge ends up in a treatment facility and would thus contribute to improved sanitation in peri-urban areas in line with the conceptual framework. It is therefore cardinal that the design of disposal initiatives for the faecal sludge generated in the city takes cognisance of its biogas generation potential. If appropriately integrated in the service chain, this may incentivise the chain and at the

same time lead to a reduction in the cost of FSM services provision and would hence contribute to enhanced sanitation in peri-urban areas.

5.3.2 Rheological Characteristics

Rheological characteristics of faecal sludge are critical especially at the desludging stage as it provides a basis upon which desludging methods may be designed. Results of the relationship between shear stress and viscosity revealed an inverse relationship. Generally the shear stress reduced with increasing moisture content which is a phenomenon also observed by Radford and Fenner (2013). This also entails an increased shear stress with increasing viscosity as viscosity varies inversely with moisture content. At the maximum shear rate that was possible to attain with the equipment, the maximum shear stress recorded was 1,400Pa for a sample with a moisture content of about 74 percent. However, at moisture content of above 82 percent, the majority of samples recorded shear stresses of less than 400Pa and 200Pa at shear rates of $100s^{-1}$ and $0.1s^{-1}$, respectively. This sludge could easily be pumped out of a pit assuming the content of the solid waste was low.

In their analysis of shear stresses of faecal sludge from pit latrines, Bösch and Schertenleib (1985) found mean results of around 400Pa which are not different from the findings of this study. However, Radford and Sugden (2014) indicated that remoulded samples usually have a lower shear stress as compared to in-situ sample. It is therefore cardinal to repeat these tests using equipment that would allow for in-situ characterisation of the sludge. It should be noted that the method of analysis for rheological properties in this study required removal of the solid waste from the sample. This obviously reduced the yield stress. Where solid waste is present including grit, the yield stress may be higher.

Shear stress varied unpredictably with depth. Results were obtained where the shear strength increased with depth but other results were also observed as presented in the Figure 5-3 below.

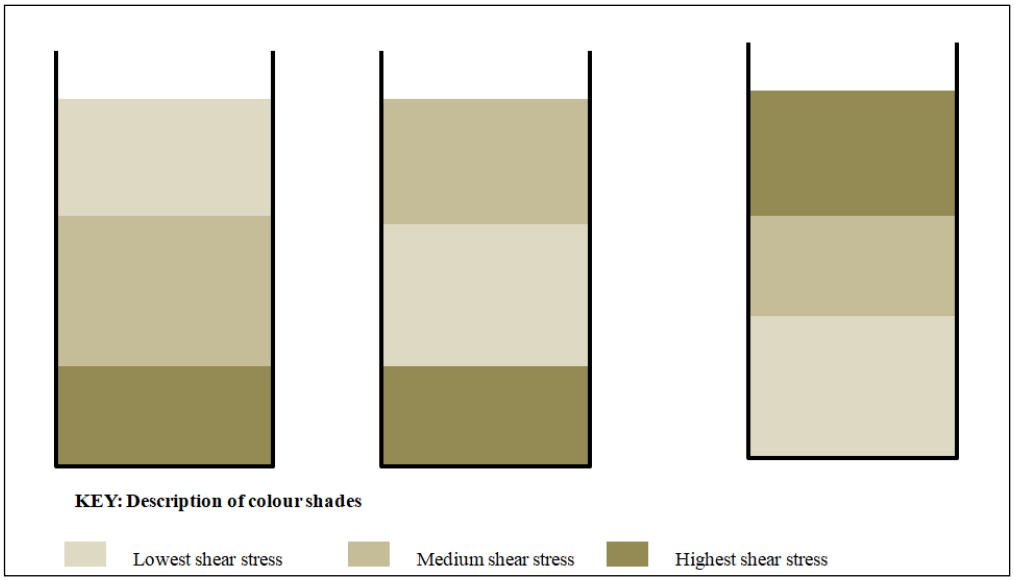


Figure 5-3: Illustration of variability of shear stress with depth in pit latrines

These findings are consistent with the findings of Radford and Sugden (2014) who observed similar variations. They observed that in some cases, the top sludge may not necessarily be representative of the pit contents. They reported formation of high strength crustal layer on top which overlay the weak sludge at the bottom as in the example above. For all the analysis, the samples exhibited a shear thinning behaviour (i.e. the viscosity reduced with increasing shear rate) indicating that faecal sludge falls within the group of pseudo plastics. Based on the moisture content in the pits which was found to average around 82 percent, it is evident that most of the latrines in the project areas would be emptied using a vacuum pump provided the amount of solid waste is not high. The fact that the faecal sludge is a pseudo-plastic material implies that the design of desludging mechanisms needs also to incorporate mechanisms for agitation of the pit contents. This would facilitate desludging as the pumping would then be on sludge whose shear resistance has been reduced.

5.3.3 Nutrients (Phosphates, Ammonia and Potassium)

Nutrient content in faecal sludge can be measured using the above parameters. In this study, phosphates, ammonia and potassium were analysed to give an indication on the nutrient content of the faecal sludge.

Phosphates in this study were comparatively higher than what is reported in other studies. It averaged 1,740±964 mg/L and 1,235±812 mg/L PO_4^{3-}-P for the top and bottom sludge, respectively. A study by NWSC (2008) reported phosphorus concentrations of 450 mg/L, 150 mg/L and 9 to 63 mg/L phosphates for public toilets, septic tanks and in wastewater treatment sludge. It may be argued that the analysis by NWSC was on facilities with significantly diluted sludge compared to that of pit latrines. Apart from this obvious difference among the facilities being compared, introduction of chemicals and detergents would also be another reason for the observed higher concentrations. For example, detergents contain phosphates and these may significantly contribute to the observed high concentration of the parameter in the faecal sludge as was illustrated in section 4.2.2.3.

Ammonia was also found to be in high concentrations. As indicated in section 2.8.4.1, ammonia is an important source of nitrogen for plant growth. The means for the top and bottom sludge were 1,996±1,615mg NH_3-N/l and 2,231±1,749mg NH_3-N /l, respectively, indicating that faecal sludge has high content of nitrogen as ammonia is just one of the various compounds in faecal sludge from which nitrogen can come.

Potassium in the samples analysed averaged 23,249±33,057 mg/kg dry solids and 20,072±24,450 mg/kg dry solids for the top and bottom sludge, respectively. According to Prajapati and Modi (2012), potassium content of around 2 percent in soils meant for crop production is considered suitable. Therefore, the sludge contains potassium in appropriate concentrations.

The high concentration of these three parameters in faecal sludge is a positive pointer to valorisability of faecal sludge. To start with, nutrients are essential for the growth of microorganisms (Todar, 2008) and hence their presence in high concentrations would enhance the anaerobic digestion of faecal sludge for the generation of biogas (also refer to section 2.8.3). However, it is important that these parameters do not exceed maximum allowable concentrations beyond which they become toxic to microorganisms. These parameters are also important where faecal sludge is used in

agricultural activities. From this perspective, it can therefore be concluded that the faecal sludge has high potential for valorisation in both biogas generation as well as in agricultural and horticultural activities.

5.3.4 Inhibitory and toxic substances (Ammonia and heavy metals)

Results for ammonia revealed a wide variation among the sampled latrines. The means were generally high at 1,996±1,615 mg NH_3-N/L and 2,231±1,749 mg NH_3-N /L for top and bottom sludge, respectively. These results fall within the ranges for public toilets as reported by various researchers in Strande et al., (2014) (Table 5-3).

Table 5-3: Ammonia concentration in faecal sludge from different systems

Parameter	**Type of facility**			**Reference**
	Public toilet	Septic tank	WWTP sludge	
NH_3-N	3,400	1,000	-	Katukiza *et al.* (2012)
(mg/L)	3,300	150-1,200	-	Koné and Strauss (2004)
	2,000	400	2-168	NWSC (2008)
	2,000-5,000	<1,000	30-70	Heinss *et al.* (1998)

Source: Adapted from Strande et al, (2014)

According to data reviewed and presented in section 2.8.4.1, ammonia concentration of around 600 mg/L is required for microbial growth but in excess of 5,000 mg/L, it becomes inhibitory. Considering the above, it can be concluded that the average ammonia concentration is within tolerable limits with respect to anaerobic digestion. However, it should be noted that ammonia inhibition is also dependent on other factors like pH and temperature.

Generally, mean heavy metals concentrations in the faecal sludge were found to be in very low concentrations. They were also not detectable in all the samples with chromium and lead posting the least in terms of prevalence at 0 and 1.9 percent, respectively (Table 5-4).

Table 5-4: Mean concentrations of heavy metals in samples and their prevalence

Element	Mean for Top Sludge	Mean Bottom for Bottom	Prevalence (%)	No. of Samples Analysed
Co (mg/kg TS)	5.5±17.74	7.9±33.80	43.4	53
Cd (mg/kg TS)	1.9±4.09	5.0±18	66.0	53
Zn (mg/kg TS)	8.8±21.75	8.2±18.77	58.5	53
Cu (mg/kg TS)	17.2±57.0	18.8±65.2	30.2	53
Fe (mg/kg TS)	185.4±343.3	218.9±472.8	85.0	53
Cr (mg/kg TS)	0.0±0.0	0.0±0.0	0.0	53
Pb (mg/kg TS)	0.0001±0.0008	0.0002±0.002	1.9	53

Among the various beneficiation prospects of faecal sludge are its potential as a feed stock in biogas generation and the use of the treated sludge as a soil conditioner or (Hussein and Mona, 2014). As highlighted in Section 2.8.4.3, for both usages, it is imperative that the concentration of heavy metals is within the recommended guideline values. The mean heavy metal concentrations in the analysed sludge samples were all below the toxicity levels with respect to the anaerobic digestion process as reported by Kouzeli-Katsiri et al. (1988). This shows that heavy metals would not be a hindrance to the valorisation of this sludge for biogas generation.

A comparative assessment of the mean heavy metal results obtained in this study and the guideline values presented by Herselman et al. (2005) on the allowable maximum concentration of heavy metals in the soil for agricultural purposes also revealed concentrations within the limits (see section 2.8.4.3). However, the results for the mean cadmium concentration in the bottom sludge exceeded all the guideline values save for the USA guideline which is set at 20 mg/kg. However, the higher mean cadmium concentrations may not be representative as a check on the results shows that the average result was possibly affected by just two results from sampling points M008 and M010 which were obvious outliers (see section 4.4.5.2) as is exhibited from the quartile parameters were the median is recorded as 0 mg/kg of the dry solids. It can therefore be safely concluded that heavy metals in the faecal sludge would not be a source of concern in valorising faecal sludge for the use as feed stock in the production of biogas or as a soil conditioner in agricultural activities. Overall, based on the findings

discussed in this section, it can be presupposed that inhibitory substances would not be present in faecal sludge in concentrations that would compromise its reuse.

5.3.5 Microbiological quality

The microbiological quality of the faecal sludge was assessed using faecal coliforms, *Ascaris* and *Cryptosporidium*. Comparatively higher counts for faecal coliforms were recorded in this study which averaged over $1x10^9$ CFU/100 mL when compared to other studies reported by Strande et al. (2014) presented in Table 5-5. One reason for the significantly high difference is that the results presented in the Table were for sources that generally receive less concentrated faecal sludge as indicated in previous sections (see section 5.3.1.3).

Table 5-5: Concentration of selected microbiological parameters in faecal sludge from different sources

Parameter	Faecal sludge Source		Reference
	Public Latrine	Septic Tanks	
Faecal Coliform (CFU/100 mL	49,000	1,200 – 7,800	Koné and Strauss (2004).
	30,000	10,000	NWSC (2008)
	20,000 – 50,000	<10,000	Heinss et al., (1998)
Ascaris No./g dry solids	15 - 150	30 – 150	Koné et al., (2004)

Source: Adapted from Strande et al., (2014)

Results for viable *Ascaris* revealed higher prevalence levels in top sludge and ranged from 0 to 471 with the mean being about 40No./g of sludge which is within the ranges presented in Table 5-7 above.

Implications of these results are that before treatment, this sludge is a hazard and should be handled with great care. The results also indicate that for this sludge to be of a quality fit for reuse in unrestricted agriculture for which the guideline value for faecal coliforms is 1,000CFU/100 mL (WHO, 2006), the treatment should aim at removal efficiency to the tune of at least 7 log units.

Average viable *Ascaris* results in this study were less than those reported by Koné et al., (2004) for public toilets and septic tanks. The mean concentration in the top sludge was about 40No./g while that for the bottom sludge was 1No./g dry solids. Therefore, all faecal sludge should be handled as a public safety risk until it is adequately treated.

5.4 Variability of faecal sludge quality with depth of the pit latrines

A selected number of physical, chemical and microbiological parameters were used in establishing the variability of faecal sludge quality with depth (section 4.5). For the parameters that were selected to measure biodegradability which included Total Solids, TVS, Total BOD, Total COD, Faecal Coliforms, Viable *Ascaris* and *Cryptosporidium*, three presented statistically significantly different results. These included TVS ($p=0.0005$), Viable *Ascaris* ($p=0.0021$) and *Cryptosporidium* ($p=0.0002$). For detailed Mann-Whitney U Test results for these parameters, refer to Table D2 in Appendix D.

Ideally, in a latrine where the faecal sludge is layered according to age, it is expected that all the parameters above would show significant differences between the top and bottom sludge with the concentration of the parameters being higher in the top sludge except for Total Solids where the concentration would be higher in bottom sludge. This is because it is expected that the samples at the bottom would have been in the pit for a longer period of time as postulated by Buckley et al. (2008) and Nwaneri et al. (2008). Buckley theorises that in a VIP latrine, the degree of biodegradation increases with increasing depth. In their investigations on 10 VIP latrines, Nwaneri et al. (2008) confirmed the Buckley theory.

Elmitwalli et al. (2011), through mathematical simulations, reported a reduction in the biodegradability of fresh faecal sludge from 0.81 to 0.25g/g dry solids with an increase in the inert solids fraction from 0.19 to 0.75 g/g dry solids after a 90 days retention time of the faecal sludge in onsite facilities. This finding is also in tandem with the Buckley theory and the findings of Nwaneri et al. (2008).

For the results obtained in this study, although it was generally found that more top samples registered higher organic matter content (measured through TVS, COD and BOD) and higher microorganisms counts (measured through faecal coliforms, viable *Ascaris* and *Cryptosporidium*), statistical analysis of the results did not show statistically significant differences for the majority of parameters (Table 4-30 in Chapter Four) hence disproving the hypothesis stating that: *"In the pit latrine, parameters linked to biodegradation exhibit a significantly higher degree of stabilisation for bottom sludge compared to top sludge"*. Several factors contribute to this observation as follows:

- Most of the studied facilities had higher moisture content compared to those upon which the Buckley Theory is based and those studied by Nwaneri et al. (2008). Whereas the pits studied by Nwaneri had moisture content of less than 0.8g/g of sample, in this study moisture content for more than 50 percent of the pits (n=58) was over 0.83g/g sample;
- In VIP latrines, the sludge is well layered with the oldest being at the bottom. The same could not be said about a number of latrines in this study. It is possible that latrines with higher moisture content may operate as mixed reactors resulting in distortion of results. Rheological results from some latrine samples revealed intriguing results where the highest content of solids in the pits was not at the bottom as in VIP latrines but on top (See sections 4.4.2 and 5.3.2). This arrangement of solids may contributed to the observed results;
- The 'obscured' differences in characteristics between the top and bottom sludge could also be due to marginal differences in sludge depth which averaged 93±38cm for samples used in the physical and chemical analysis and only 51.2± 43cm for samples used in the microbiological analysis (see sections 4.3 and 4.4.6);
- A number of facilities sampled in this study did not only serve as receptors of faecal sludge, but of sullage as well. Sullage contributes to high moisture content and also introduces chemical parameters that may introduce irregularities in the pit latrine processes leading to anomalies in results;

- The practices of adding various types of chemicals to pit latrines may affect the biodegradation process of the pit contents; and
- Lastly, the high variability of the results, some of which registered standard deviations in the range of 50 percent could also distort trends in results.

All the above areas require confirmation which would be in form of further research on all the aspects presented.

5.5 Variability of faecal sludge quality with geological formation

In section 4.6, differences in the mean values of results with study areas for a selected number of parameters were assessed. For making comparisons among study areas on different geological formations, only results for bottom sludge were used for this purpose. . The Kruskal-Wallis H Test was first applied on results from all the areas for selected parameters (Section 4.6). For all the parameters where the Kruskal-Wallis H Test indicated statistically significant differences, the Mann-Whitney U Test was applied to establish whether the results for samples from Chaisa were the ones contributing to the observed statistically significantly different results observed under the Kruskal-Wallis H Test and results indicated that Chaisa, which was in a geologically different area, contributed the least to the observed statistically significantly different results (section 4.6). Therefore, no clear trend could be established to link the observed differences to the differences in the geological formation hence disproving the hypothesis stating that: *"Faecal sludge quality significantly differs for pit latrines located in areas with different geological formations"*. One obvious reason for this observation is the fact that the comparisons are being made among facilities of different characteristics both in terms of design and construction and also usage and maintenance.

It should be recalled that the results presented in this study are for the dry season (refer to section 3.6.3.2). The movement of the water in and out of the latrines is affected differently by the different seasons. It is therefore cardinal that a similar study taking into consideration seasonal variations is undertaken to confirm whether these findings

apply to both the dry and rainy season. Geology alone, according to the findings, does not significantly impact of faecal sludge quality.

5.6 The proposed Operations Framework for enhanced FSM provision

An Operations Framework was designed based on the findings from the study and is presented in section 4.7. Critical aspects in the framework include regulation of construction and usage to preserve the quality so that its uses for downstream activities are not impaired. The Framework also proposes user education to go with the proposed regulation. This is a critical aspect in that the "abuse" of latrines is sometimes due to inadequate knowledge on the functioning aspects of the systems.

The Framework also assumes that the uptake of faecal sludge in resource recovery activities is only possible if demand is created. This requires an FSM system that addresses all stages of the sanitation service chain and such a system requires that a number of factors are put in place. Section 2.5.1.1 summarises some of the key requisites for the successful implementation of an effective FSM system among which is the socio-cultural acceptance of the proposed facilities and technologies by communities which the systems intend to serve. The need to have the systems embraced by communities they intend to serve and to clearly spell out the perceived benefits is a critical aspect to consider for the sustainability of any FSM system. The Framework would only work if the products have demand. This needs to be generated through formulation of deliberate policies to promote reuse of waste derived products. Fortunately, this is an issue that is already being promulgated by a number of strategies in Zambia like the Vision 2030 and the Urban and Peri-urban Sanitation Strategy. The Framework therefore only brings in the aspect on stakeholders to move the strategy forward.

Formal reuse of faecal sludge derived products is an aspect that is still new in Zambia. There is need for research on the subject to generate data on the various usages the faecal sludge can be put to at the local scale. For this aspect, the Framework proposed involvement of institutions of higher learning and research through the Ministry of

Higher Education. These institutions are key as there is need for further research on the FSM systems and the reuse of the faecal sludge derived products.

Results indicated that the microbiological quality of the sludge did not favour direct usage in activities like application for crop production. The poor microbiological quality entails that measures need to be put in place to ensure safe usage. This makes it imperative that adequate regulatory measures are put in place to safeguard both the public health and the environment from the adverse impacts that would result if usage is not regulated.

It should be noted that in the proposed framework, three ministries which are not part of the institutions involved in sanitation services provision in the current institutional framework are incorporated. These include the Ministry of Energy, the Ministry of Agriculture and the Ministry of Higher Education. The rationale for the inclusion of these ministries together with the other stakeholders is to ensure marketability of the faecal sludge derived products.

5.7 Implications of the study findings

The study findings have indicated that the faecal sludge has valorisation potential. It has also been established that there are a number of aspects that may impact negatively on reuse prospects of the sludge like high quantities of solid waste. The study also revealed that variability of the faecal sludge with both depth and geological formations is not significant. These findings imply that efforts to promote reuse of the faecal sludge should be coupled with measures for preservation of the faecal sludge quality which would entail regulation of the design, construction and usage of the facilities. The statistically insignificant differences in quality with respect to depth of pits and geological formations of the areas indicate that the measures for the management of this faecal sludge need to be universal. This implies that the design of facilities for the management of the faecal sludge need not distinguish between the top and bottom sludge and sludge from areas with different geological formations.

5.8 Chapter Summary

This chapter discussed the findings that emerged from this study. The findings revealed that the design/construction and usage of latrines in peri-urban areas is unregulated. This was identified as a contributing factor to the high solid waste content in the latrines. The chapter also revealed operations and maintenance aspects that possibly impact on the quality of the sludge. Aspects on valorisation were also discussed and several issues were identified that require further investigations including the observed high COD/BOD ratio and aspects on variability of faecal sludge with depth and also with the different geological formations which produced statistically insignificantly different results. The chapter is concluded with the presentation of an introduction to the proposed operations framework which combines the identified reuse potential of the faecal sludge with measures to be instituted for enhanced FSM services provision in order to ultimately contribute to improved sanitation in the peri-urban areas. The next chapter presents conclusions and recommendations of the study.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This research sought to characterise pit latrine faecal sludge from selected peri-urban areas in order to generate faecal sludge quality data that could be used in the design of measures for effective FSM systems. The research had four objectives as presented in section 1.6.1.

This chapter presents conclusions on each of the above objectives before presenting on aspects of generalisability of the results and issues of validity and reliability of the findings. These are followed by a summary on contribution to the body of knowledge. The chapter then presents recommendations which are presented in two sections as follows:

i) General recommendations based on the findings of the study which also include the proposed operations framework; and
ii) Recommendations for future research work.

6.2 Conclusions

The first objective of the study was to establish sanitation practices in the study areas that may impact on the faecal sludge quality. It was found that facilities varied widely in terms of design and construction as well as usage. Some latrines are constructed with elevated vaults while others have underground vaults. It was also established that two distinct types of latrines exist in the project area from the context of usage. While some latrines exclusively serve as excreta disposal facilities, others are also used as receptors of sullage. It was also observed both qualitatively and quantitatively that most latrines also serve as solid waste “dump sites”. These findings clearly indicate that practices exist in the study areas which have implications on the ultimate quality of the faecal sludge in the pit latrines.

Valorization potential of the faecal sludge was assessed using several parameters including BOD, COD, TVS, nutrients, rheological parameters and inhibitory substances

present in the faecal sludge. The results revealed that the sludge has high organic matter and nutrient content. Variability with depth for most parameters including BOD and COD were found to be statistically insignificant ($p<0.05$). The concentration of possible inhibitory substances including ammonia and heavy metals were found to be in concentrations that would not adversely impact on microbiological processes as well as on agricultural activities. Based on these findings, it was concluded that the sludge has high potential for valorisation. However, the microbiological quality assessed through faecal coliforms, *Ascaris* and *Cryptosporidium* revealed very poor quality leading to the conclusion that the faecal sludge should be considered as a health hazard until adequately treated.

On variability with depth of parameters indicative of biodegradation, only TVS and viable *Ascaris* presented statistically significantly different results where the concentrations of the parameters were significantly higher in the top sludge. The other parameters differed marginally ($p>0.05$). It was therefore concluded that most parameters did not differ significantly with depth.

Concerning the variability of parameters with different geological formations, there was no clear trend in the results that would link the differences in quality to the differences in the geological formations. It was thus concluded that geology in itself has no significant impacts on the quality of faecal sludge.

6.3 Contribution to the body of knowledge

The primary aim of this study was to generate faecal sludge quality data for pit latrines in peri-urban areas of Lusaka city which is critical for the design of measures for adequate management of the sludge from these facilities. To this effect, the study contributed to the body of knowledge in the following ways:

1. To date, there has been no study on this aspect for the city of Lusaka. This study analysed faecal sludge characteristics for parameters critical to the design of treatment facilities and valorization potential of the pit latrine faecal sludge which was not available.

2. Data has been generated from this study that will serve as an important source of information to support further studies on the subject matter.
3. The study has led to the development of an Operations Framework for enhanced FSM services provision for the enhancement of sanitation provision in peri-urban areas. This is a key output that will serve as a guiding tool that links up pit latrine sludge utilization and the ultimate outcome of enhanced sanitation provision.
4. Lastly, the study has contributed to the global data base on pit latrine faecal sludge quality data which has been identified by several researchers as lacking.

6.4 Generalisability

In the design of the research, four peri-urban areas were selected from within the city of Lusaka as study areas where samples for the generation of the faecal sludge quality data were collected. With the assumptions that the socio-economic characteristics of the peri-urban areas are the same, selection of the study areas took into consideration the geological differences of the study areas. Therefore, the results of the study are based on all the existing geological characteristics of the city. The results are therefore generalisable at a city level. These findings can also be extended to other districts within the country and possibly to other Sub-Saharan countries most of which have a similar socio-economic status and similar layout and character of the peri-urban areas or shanty compounds as these areas are referred to in most countries within the region.

6.5 Validity and reliability

This study adopted a realism ontology and adopted a positivist paradigm where the overarching principle assumption is that “the social world exists externally, and that its properties should be measured through objective methods rather than being inferred subjectively through sensation. Naturally, for the adopted ontology and epistemology, the methodological approach was predominantly quantitative with the interpretation of the results being guided by quantitative procedures including statistical analyses. Statistical analyses of the significance of associations between the various relevant variables are not subjective hence reduce on chances of confounding errors. This

methodological approach is not prone to errors and misinterpretations as it is objective. In the gathering of data, a fairly large sample was used. Over 50 sampling points were used in the analysis for the majority of the presented results. A large sample is key to the validity of the results. The selection of sampling points was also done in a way that ensured representativeness. The collection and analyses of samples were guided by standard protocols hence preserving the meaning of the results. Lastly, all samples were analysed in triplicates which improved the reliability of the results.

6.6 Recommendations

As indicated in section 6.1, the recommendations are presented in two sub headings which are presented below.

6.6.1 Recommendations based on study findings

The following are the recommendations based on the study findings:

i) An evaluation of facilities revealed high content of solid waste which was an indication that the latrines in peri-urban areas do not only serve as excreta disposal facilities, but also as receptors of solid waste. This complicates the emptying, treatment and disposal/reuse of the sludge. It is therefore imperative that user education is instituted as a way of averting challenges inherent with solid waste disposal in pit latrines. It should be noted that for there to be a change resulting from awareness campaigns, there has to be an alternative for the disposal of solid waste. It would therefore be cardinal to also have a sustainable solid waste management plan for peri-urban areas.

ii) Construction and usage of the latrines in peri-urban areas is an aspect that is currently not regulated. Regulation is critical especially where the sludge needs to be used for beneficiation prospects as regulation would ensure that the designs and construction of the facilities, including usage is in a way that “preserves” the quality of the sludge and facilitate implementation of critical operational stages like emptying; and

iii) The study concluded that there is potential in terms of quality for valorising faecal sludge which would ultimately transform the sludge from a waste to a resource. This requires strong collaboration among critical stakeholders to ensure preservation of the faecal sludge quality, create demand and foster regulation of usage.

6.6.2 Recommendations for future research work

This study resulted in the identification of a number of areas that require to be researched on to compliment the findings of this study. The following are therefore recommendations for future research work:

i) This study was confined to the dry season. Therefore, results presented here may only be representative of the dry season. Designing of intervention measures for FSM requires faecal sludge quality data that is representative of the whole year. It is therefore recommended that further research be done building on the findings of this study but taking into consideration seasonal variations;

ii) The ratio between the mean COD and BOD values revealed a very high ratio which may be due to a number of factors. The biodegradable matter in the faecal sludge is key to anaerobic digestion processes and is thus a critical input in the design of treatment facilities. It is therefore important that confirmatory research is undertaken on this subject which may also include other analysis to ascertain biodegradability and methane production potential of the sludge;

iii) One area considered in the valorization potential of the sludge was energy production from the solids. This was quantified based on literature review. It is imperative that the analysis on the calorific value of the local sludge is also assessed so that local actual figures are used in computing the valorization potential from the solids perspective;

iv) Characterisation of the rheological properties of the faecal sludge yielded results indicating that at higher moisture content of above 82 percent of the wet mass,

the shear stress of the samples were below 200Pa and 400Pa when tested at shear rates of $0.1s^{-1}$ and $100s^{-1}$, respectively. However, these results are based on remoulded samples from which solid waste had been removed. It is therefore imperative that further research is undertaken on this aspect using equipment that would allow for in-situ testing of the faecal sludge rheological properties;

v) The design of the operations framework assumes that the faecal sludge derived products would have a market. This aspect requires detailed investigations on marketability of the products from both the industrial and the socio-cultural perspectives. This is important especially that the faecal sludge products may possibly have to be used by other people not necessarily the ones generating the sludge. It is therefore imperative that studies are conducted on the following aspects:

   a) Feasibility of the uptake of faecal sludge derived products for driving industrial processes; and
   b) Acceptability of faecal sludge derived products from the social-cultural perspective;

vi) This study brought to the fore faecal sludge quality aspects relevant for valorization which are also critical for the design of treatment facilities. The study did not investigate the aspect of faecal sludge quantification which is also critical for both valorization and treatment. A study on this aspect is therefore cardinal so that both quality and quantity data is available;

vii) The research highlighted the significance of capturing and utilizing methane from faecal sludge for energy generation in reducing global warming (Section 2.10.1). Since the faecal sludge in pit latrines also undergoes the processes of anaerobic biodegradation, it is recommended that a study is undertaken to make a comparative analysis between pit latrine desludging frequency and methane production;

viii) This study analysed the content of solid waste and grit in the desludged faecal sludge. The analysis was based on only eight samples (section 3.6.3.1). It is imperative that a detail study on this aspect that considers a wider sampling frame is undertaken to have a city-wide perspective of the problem; and

ix) The study revealed that high content of solid waste was deposited in pit latrines. This practice compromises the quality of the faecal sludge. A study to investigate the challenges of solid waste management in peri-urban areas and subsequently designing responsive solid waste management mechanisms suitable for these areas is imperative.

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APPENDICES

APPENDIX A: THE FOCUS GROUP DISCUSSION GUIDE

Name of Study Area: _____

Name of Facilitator(s): _____

Number of Participants: _____

Date of FGD: _____

Introduction

- Explain importance of the FGD: I and the team are here to find out a few things concerning sanitation in your area. This is a follow-up to the inaugural meeting conducted at Mika Hotel attended by some community's leaders present in this meeting. Ultimately, the findings of the research being undertaken will aid the design of measures to address FSM challenges in peri-urban areas of Lusaka.

Sanitation systems in use in the community

- Request for an opening prayer
- Introduction of participants (Name and Position in community)

Sanitation systems in use in the community

- What type of sanitation facilities are in use in your area?
- Which of the systems are predominant?

Construction of the facilities

- How are the latrines constructed?
- What are the common challenges faced in construction of the facilities

Operations and maintenance

- How are the facilities maintained (in terms of cleaning)?
- What chemicals are generally used in cleaning facilities?
- Are there chemical added to facilities to reduce the volume of the contents (as a management strategy for latrines that are full)
- Do you face the challenge of full pit latrines, and if so who desludges and where is the sludge disposed of.

APPENDIX B: GOOGLE MAPS FOR STUDY AREAS SHOWING LOCATION OF THE SAMPLING POINTS

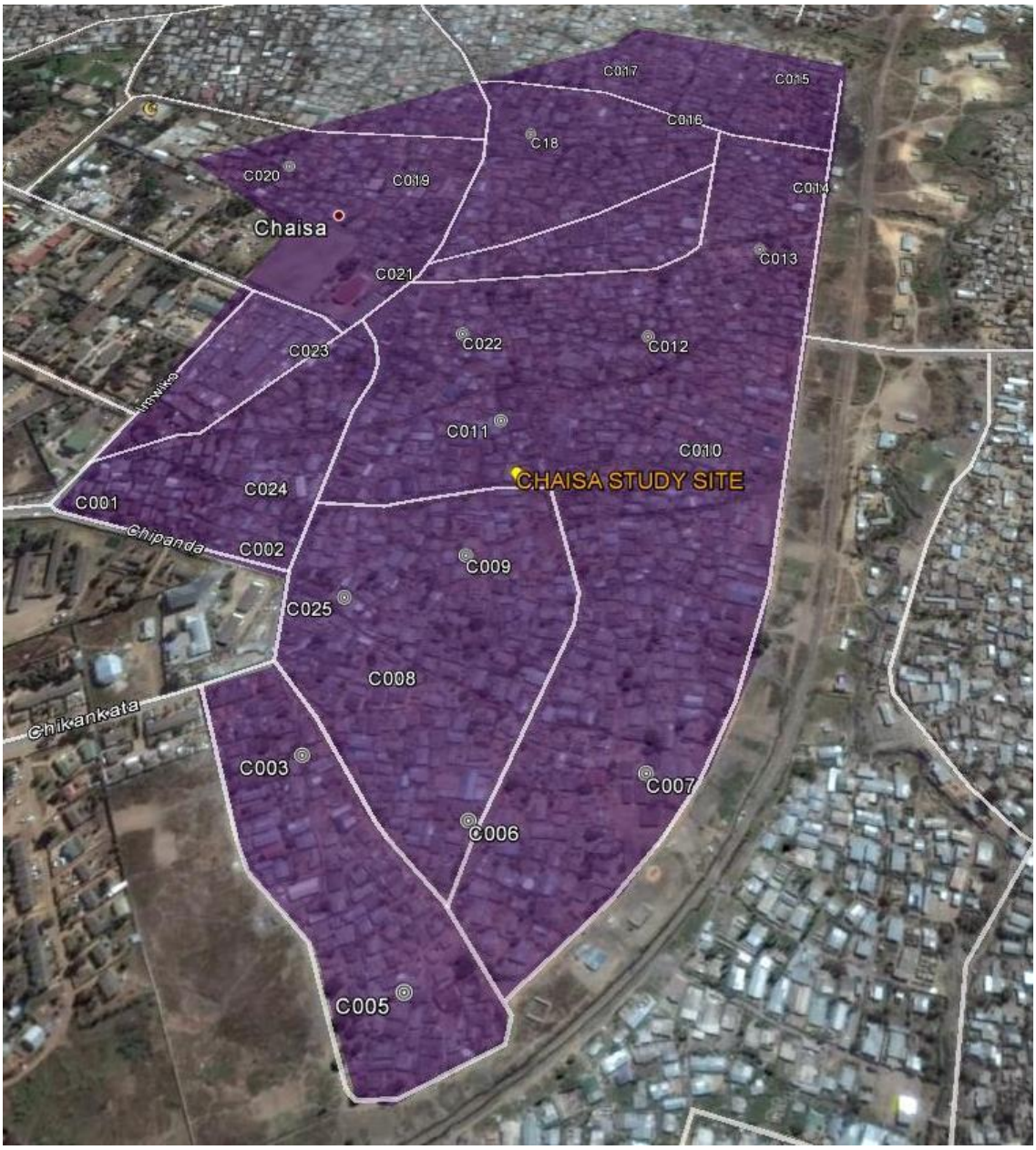

Figure B2-1: Google Map of Chaisa study area and location of sampling points

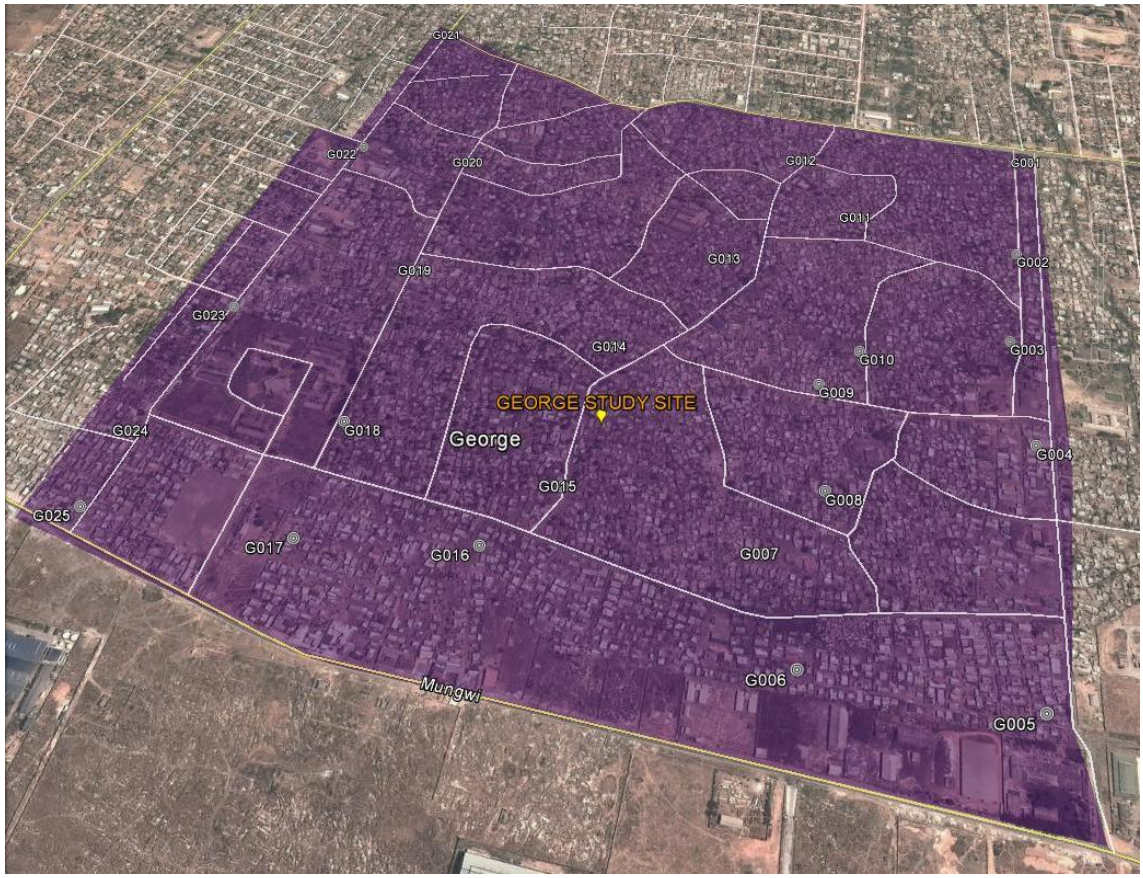

Figure B2-2: Google Map of George study area and location of sampling points

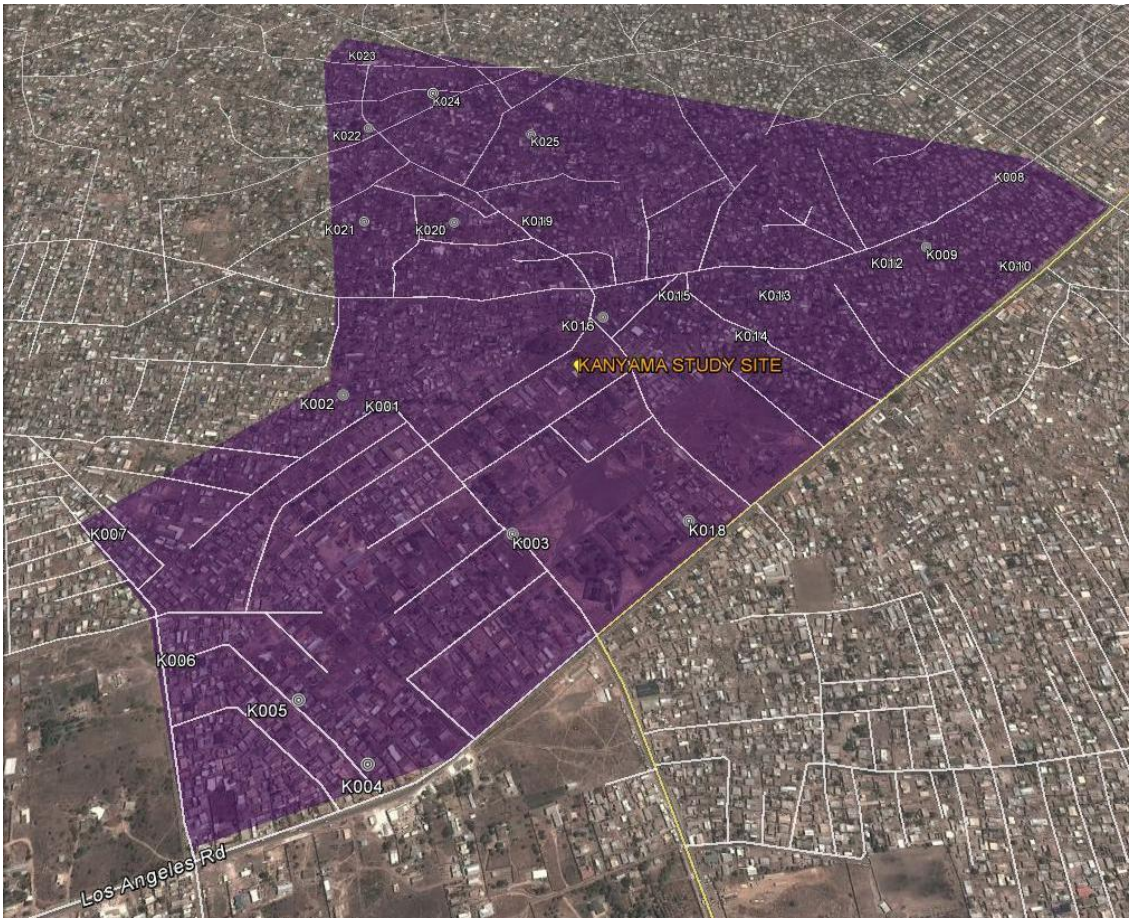

Figure B2-3: Google Map of Kanyama study area and location of sampling points

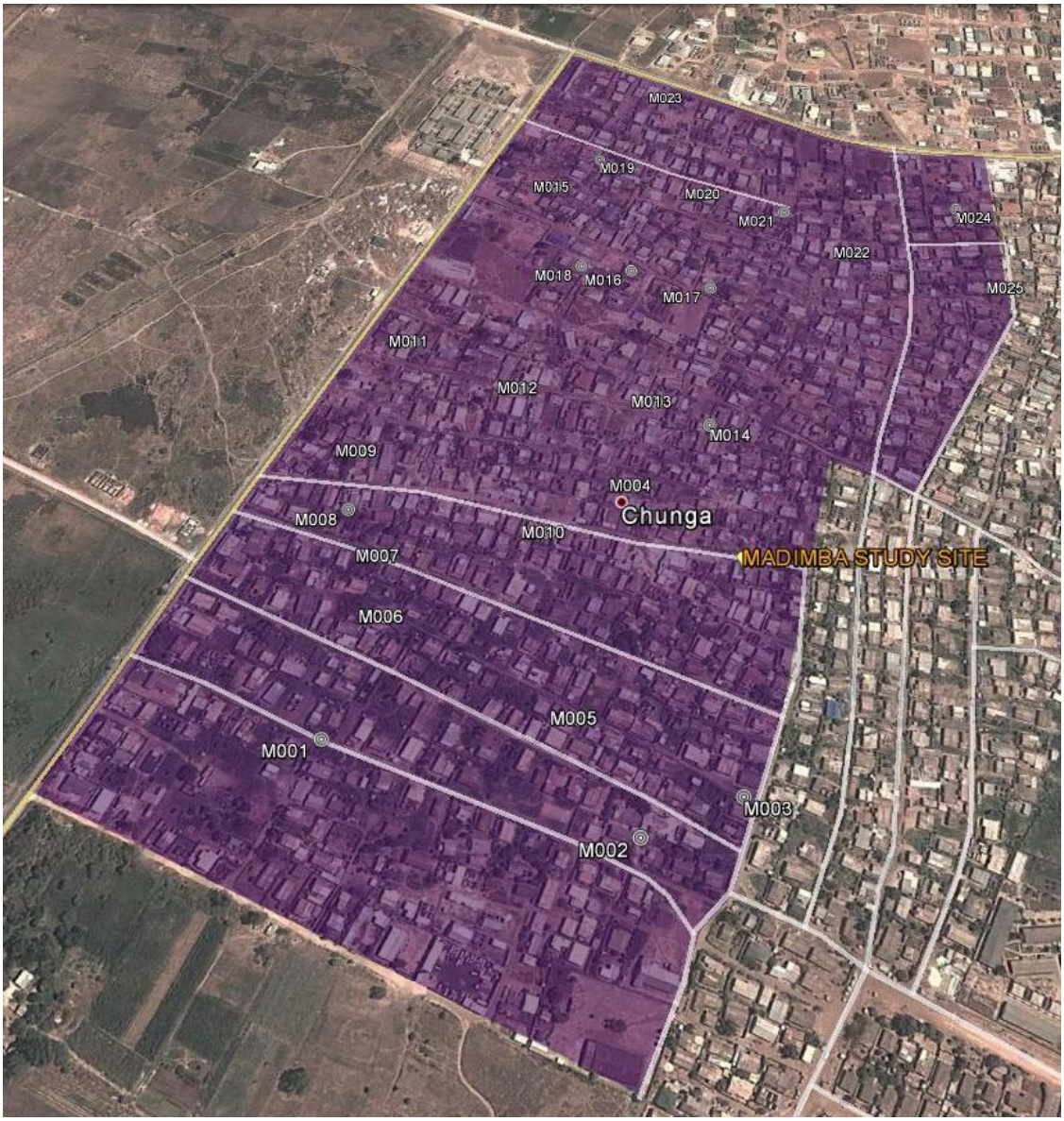

Figure B2-4: Google Map of Madimba study area and location of sampling points

APPENDIX C: LATRINE DATA COLLECTION TOOL AND RESULTS

APPENDIX C1: Sample of the household survey questionnaire

SECTION I: QUESTIONNAIRE IDENTIFICATION			
1. Survey Form Number *(counting from 001)*		2. Name of H/H Owner	
3. Compound		4. Date of Survey	
5. Zone		6. GPS Coordinates	S: _____ E: _____ Elev: _____
The Surveyor must first introduce himself/herself. **Explain importance of this survey:** We collecting information on pit latrines from which we will be collecting faecal sludge samples for about 15 months. This is for a project we are undertaking at the University of Zambia – Integrated Water resources Management centre which is aimed at developing scientific approaches to addressing some of the challenges associated with pit latrine operations and maintenance. We will be glad if you would allow us use your latrine as one of our sampling points.			
SECTION II: DEMOGRAPHICAL INFORMATION			
7.	Sex of Household Head	☐ 1. Male ☐ 2. Female	
8.	Number of household members above 15 years	_____	
9.	Number of Household members below 15 years	_____	

SECTION III: GEO-PHYSICAL CHARACTERISTICS OF LATRINE LOCATION		
10.	How is the geology where the latrine is located?	☐ 1. It is normal ☐ 2. It is rocky Other, please specify…..…….
11.	Is the area water logged or not?	☐ 1. Yes ☐ 2. No ☐ 3. Other, please specify _____
12.	If your answer to 11 above is yes, how does the flooding affect the latrine?	☐ 1. Latrine is flooded throughout the year ☐ 2. Latrine is only flooded in the rain season ☐ 3.Latrine is never flooded ☐ 4. Other, please specify: _____
SECTION IV: LATRINE DETAILS – LATRINE PHYSICAL CHARACTERISTICS		
13.	Latrine Dimensions	☐ 1. Average Depth _____ ☐ 2. Average Length _____ ☐ 3. Average width _____ ☐ 4. Average Diameter _____
14.	How is the pit constructed?	☐ 1. It is lined ☐ 2. It is just a pit in the ground ☐ 3. Other, please specify
15.	How is the latrine superstructure constructed	☐ 1. Superstructure is roofed ☐ 2. Superstructure is open
16.	Is the pit ventilated?	☐ 1. Yes ☐ 2. No
17.	What is the quantity of sludge in the pit? Get average depth	☐ 1. _____
18.	How is squatting hole	☐ 1. Always covered

	maintained	☐ 2. Sometimes covered ☐ 3. Never covered ☐ 4. Other, please specify: _____
SECTION IV: LATRINE OPERATIONS AND MAINTENANCE DETAILS		
19.	Latrine usage	☐ 1. Exclusively used as a latrine ☐ 2. Also used as a bathroom
20.	When was the latrine last desludged?	☐ 1. Please specify _____
21.	How often do you empty your latrine?	☐ 1. N/A ☐ 2.Every year ☐ 3. Every after 3 years ☐ 4. Every after 5 years ☐ 5. Once in over 5 year
22.	Do you add chemicals to your latrine?	☐ 1. Yes ☐ 2. No
23.	If yes to 21above, what is the frequency and quantities added	_____ _____
END OF SURVEY		
Thank the person/people who has/have assisted with information and remind him/her/them that we would be calling on them from time to time for sample collection!		

APPENDIX C2: Collected Data on Latrines construction, usage and operational aspects

Table C2-1: Summary of data collected for each pit latrine or sampling point

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
C001	15o23'01.3"	028o16'54.8"	M	9	Normal	2	3	165	120	100	Yes	Yes	2	2	1	1 year ago	Yes	120
C002	15o23'02.9"	028o16'59.7"	M	8	Normal	2	2	185	190	170	Yes	Yes	3	2	1	Never	No	95
C003	15o23'08.9"	028o17'01.5"	M	24	Rocky	2	3	149	130	120	Yes	Yes	2	2	1	Never, They burry and build new one	No	140
C005	15o23'14.6"	028o17'04.6"	M	15	Normal	2		105	130	100	Yes	No		2	1	No Idea	No	80
C006	15o23'10.6"	028o17'05.8"	F	20	Normal	1	2	70	155	120	Yes	Yes	2	2	2	Never	Yes	70
C007	15o23'09.4"	028o17'10.2"	M	7	Normal	2	3	100	150	135	Yes	Yes	3	2	1	Never	No	34
C008	15o23'06.8"	028o17'03.7"	M	6	Normal	2	3	280	195	160	Yes	Yes	3	2	1	1 year ago	Yes	190
C009	15o23'03.1"	028o17'05.2"	M	14	Normal	2	3	230	170	100	Yes	Yes	3	2	1	Never	Yes	62
C010	15o22'59.5"	028o17'12.0"	M	11	Normal	2	3	210	130	95	Yes	No	3	2	2	Never	No data	35
C011	15o22'58.5"	028o17'05.9"	M	9	Normal	2	3	320	240	180	Yes	Yes	3	2	1	Never	Yes	260
C012	15o22'55.2"	028o17'10.3"	M	12	Normal	2	3	215	100	90	Yes	Yes	2	2	1	Never	Yes	55
C013	15o22'51.4"	028o17'14.0"	M	20	Normal	2	3	130	110	111	Yes	Yes	3	2	1	No Idea	No	55
C014	15o22'48.5"	028o17'16.1"	M	20	Normal	2	3	285	150	75	Yes	Yes	3	2	1	Never	No	185
C015	15o22'42.9"	028o17"15.8"	F	19	Normal	1	1	155	170	150	Yes	No	3	2	1	Never	Yes	110
C016	15o22'45.2"	028o17'11.8"	F	24	Rocky	2	3	285	160	170	Yes	No	3	2	2	Never	No	60

(Note: Under Latrine Code, the prefixes C, G, K and M are for Chaisa, George, Kanyama and Madimba, respectively; Under usage 1 denotes exclusively used for excreta disposal while 2 denotes usage for both excreta and sullage disposal).

Table C2-1: Continued

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
C017	15o22'42.6.4"	028o17'09.5"	F	15	Normal	2	3	100	100	90	Yes	No	3	2	1	Never	No	68
C018	15o22'46.0"	028o17'06.2"	F	24	Normal	2	3	170	170	150	Yes	No	3	2	2	Never	Yes	84
C019	15o22'48.3"	028o17'02.4"	M	14	Rocky	1		275	180	120	Yes	No	3	2	2	2 years ago	No	52
C020	15o22'47.6"	028o16'58.0"	M	10	Normal			85	120	100	Yes	Yes	3	2	1	Never	Yes	59
C021	15o22'52.6"	028o17'02.3"		12	Normal	1	2	250	115	100	Yes	No	3	2	2	Never	No	48
C022	15o22'55.1"	028o17'04.5"	F	10	Rocky	2	3	180			Yes	Yes	3	1	1	Never	No	54
C023	15o22'55.8"	028o17'00.0"	M	17	Normal	2	3	190	215	150	Yes	Yes	1	2	2	Never	No	68
C024	15o23'00.9"	028o16'59.5"	M	21	Rocky	1		180	135	120	Yes	Yes	3	2	1	Never	Yes	59
C025	15o23'04.4"	028o17'03.0"	F	21	Normal	2	2	200	200	130	Yes	Yes	3	2	2	Never	No	110
G001	15o22'47.8"	028o14'54.4"	F	5	Normal	1	2	187	115	100	Yes	Yes	3	2	2	Never	Yes	65
G002	15o22'56.0"	028o14'50.4"	F	3	Rocky			185	200	90	Yes	No		2		Never	No	60
G003	15o23'02.8"	028o1448.3"	M	20	Normal	2	2	200	160	100	Yes	No	1	2	1	Never	No	140
G004	15o23'10.0"	028o14'48.0"	M	10	Normal	1	2	140	180	120	Yes	Yes	1	2	2	No Idea	Yes	48
G005	15o23'25.0"	028o14'44.5"	M	5	Rocky	2	3	270	150	120	Yes	Yes		1	2	No Idea		135
G006	15o23'22.6"	028o14'32.6"	M	9	Normal	2	3	100	180	120	Yes	Yes	3	1	1	4 months ago	Yes	45
G007	15o23'16.4"	028o14'31.7"	M	10	Normal	2	3	160	120	100	Yes	Yes	3	2	2	Never	Yes	40
G008	15o23'12.7"	028o14'35.5"	M	6	Rocky	2	3	240	110	90	Yes	No	1	2	1	Never	No	35
G009	15o23'05.7"	028o14'36.2"	M	7	Rocky	2	3	270	170	130	Yes	No	2	2	1	Never	Yes	42
G010	15o23'03.4"	028o14'39.0"	M	14	Rocky	2	3	210	150	110	Yes	No	1	2	2	Never	Yes	47
G011	15o22'52.8"	028o14'40.8"	F	10	Normal	2	3	170	150	100	Yes	Yes	3	2	1	Never	Yes	64
G012	15o22'47.8"	028o14'54.4"	F	28	Rocky	2	3	250	180	140	Yes	Yes	3	2	1	Never	Yes	130
G013	15o22'56.2"	028o14'31.8"	M	9	Normal	2	3	180	140	100	Yes	Yes	2	2	2	Never	Yes	45

Table C2-1: Continued

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
G014	15o23'02.9"	028o14'24.2"	M	6	Rocky	2	3	120	170	120	Yes	Yes	3	2	2	Never	Yes	47
G015	15o23'12.2"	028o14'21.0"	M	27	Rocky	1	2	190	160	120	Yes	Yes	2	2	1	Never	Yes	60
G016	15o23'15.6"	028o14'16.5"	M	11	Rocky	2	3	195	140	110	Yes	No	2	2	1	Never	Yes	80
G017	15o23'15.0"	028o14'06.5"	F	9	Rocky	2	3	215	250	190	Yes	Yes	3	2	2	Never	Yes	35
G018	15o23'07.8"	028o14'08.5"	M	20	Normal	2	3	210	180	160	Yes	No	2	1	2	Never	Yes	58
G019	15o22'47.4"	028o14'15.1"	M	5	Normal	2	3	130	120	90	Yes	Yes	1	2	2	Never	Yes	50
G020	15o22'56.8"	028o14'12.1"	F	26	Rocky	2	3	210	190	110	Yes	Yes	2	2	2	Never	Yes	35
G021	15o22'34.0"	028o14'13.0"	F	19	Rocky	2	3	220	170	120	Yes	No	2	2	2	Never	Yes	110
G022	15o22'45.7"	028o14'07.6"	M	17	Rocky	2	3	210	220	120	Yes	Yes	3	2	1	Never	Yes	38
G023	15o22'59.5"	028o14'00.9"	M	18	Rocky	2	2	70	210	120	Yes	No	3	2	1	1 year ago	No	60
G024			M	11	Rocky	2	3	90	290	150	Yes	Yes	3	2	1	No Idea	Yes	42
G025	15o23'12.9"	028o13'54.6"	M	10	Rocky	2	3	80	200	130	Yes	Yes	2	2	1	Never	Yes	39
K001	15o26'25.0"	028o14'41.9"	F	13	Rocky	2	3	340	160	140	Yes	Yes	3	2	2	1 year ago	No	42
K002	15o26'24.1"	028o14'31.1"	F	10	Rocky	2	4	150	240	170	Yes	Yes	3	2	1	1 year ago	No	100
K003	15o26'33.6"	028o14'49.7"	F	4	Rocky	2	2	190	110	110	Yes	Yes	3	2		Never	Yes	100
K004	15o26'46.1"	028o14'42.6"	F	4	Rocky	2	2	90	220	110	Yes	Yes	3	2	1	Never	Yes	80
K005	15o26'42.8"	028o14'38.7"	M	12	Rocky	2	2	140	280	100	Yes	No	3	2	1	1 years ago	No	75
K006	15o26'40.6"	028o14'32.2"	M	5	Rocky	2	2	250	340	145	Yes	Yes	1	2	2	Never	No	51
K007	15o26'33.2"	028o14'27.0"	M	13	Rocky	2	2	130	200	180	Yes	Yes	1	2	1	Never	No	38
K008	15o26'06.9"	028o14'24.7"	M	16	Rocky	2	2	200	110	100	Yes	No	1	2	2	1 year ago	No	100
K009	15o26'13.4"	028o15'17.3"	F	10	Rocky	2	2	140	200	150	Yes	No	3	2	1	5 years ago	No	81
K010	15o26'14.9"	028o15'23.2"	M	11	Rocky	2	2	170	180	140	Yes	No	3	2	1	1 year ago	Yes	100
K011	15o26'12.2"	028o15'20.4"	F	24	Rocky	2	2	100	160	100	Yes	No	1	2	2	1 year ago	No	80

Table C2-1: Continued

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
K012	15o26'14.4"	028o15'14.7"	F	16	Rocky	2	2	165	210	150	Yes	No	3	2	2	Never	No	120
K013	15o26'17.0"	028o15'06.9"	F	-	Rocky	2	2	90	170	130	Yes	No	3	2	1	Never	No	80
K014	15o26'20.2"	028o15'05.0"	M	16	Rocky	2	3	180	160	160	Yes	Yes	3	2	1	Over 5 years	Yes	115
K015	15o26'16.9"	028o15'00.3"	F	14	Rocky	2	1	60	210	190	Yes	Yes	3	2	2	Never	No	115
K016	15o26'18.5"	028o14'55.3"	M	10	Rocky	2	3	115	140	100	Yes	Yes	1	2	1	Never	Yes	115
K017	15o26'21.8"	028o14'57.4"	F	128	Rocky	2	1	165	320	250	Yes	No	3	2	2	1 year ago	No	99
K018	15o26'33.0"	028o14'59.8"	M	25	Rocky	2	3	50	230	210	Yes	Yes	1	1	2	1 year ago	No	30
K019	15o26'10.3"	028o14'51.3"	F	11	Rocky	2	1	275	200	110	Yes	No	1	2	2	Over 5 years	No	60
K020	15o26'10.3"	028o14'45.3"	M	29	Rocky	2	3	120	200	100	Yes	No	2	1	2	Over 5 years	Yes	52
K021	15o26'10.1"	028o14'39.1"		14	Rocky	2	3	75	220	200	Yes	Yes	1	2	1	Never	Yes	80
K022	15o26'01.1"	028o14'36.6"	M	4	Rocky	2		115	170	130	Yes	No	3	2	2	Never	No	52
K023	15o26'53.3"	028o14'37.7"	F	18	Rocky	2	3	165	330	150	Yes	No		2	1	2 years ago	Yes	102
K024	15o25''57.6"	028o14'43.7"	M	7	Rocky	2	1	290	220	150	Yes	No	1	1	1	4 years ago	No	30
K025	15o26'02.0"	028o14'50.5"	M	21	Rocky	2	1	105	280	190	Yes	No		2	2	Over 5 years	No	70
K026	15o26'46.1"	028o14'42.6"	F	4	Rocky	2	2	180	220	110	Yes	Yes	3	2	1	Over 5 years	Yes	30
K012	15o26'14.4"	028o15'14.7"	F	16	Rocky	2	2	165	210	150	Yes	No	3	2	2	Never	No	120
K013	15o26'17.0"	028o15'06.9"	F	-	Rocky	2	2	90	170	130	Yes	No	3	2	1	Never	No	80

Table C2-1: Continued

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
K014	15o26'20.2"	028o15'05.0"	M	16	Rocky	2	3	180	160	160	Yes	Yes	3	2	1	Over 5 years	Yes	115
K015	15o26'16.9"	028o15'00.3"	F	14	Rocky	2	1	60	210	190	Yes	Yes	3	2	2	Never	No	115
K016	15o26'18.5"	028o14'55.3"	M	10	Rocky	2	3	115	140	100	Yes	Yes	1	2	1	Never	Yes	115
K017	15o26'21.8"	028o14'57.4"	F	128	Rocky	2	1	165	320	250	Yes	No	3	2	2	1 year ago	No	99
K018	15o26'33.0"	028o14'59.8"	M	25	Rocky	2	3	50	230	210	Yes	Yes	1	1	2	1 year ago	No	30
K019	15o26'10.3"	028o14'51.3"	F	11	Rocky	2	1	275	200	110	Yes	No	1	2	2	Over 5 years	No	60
K020	15o26'10.3"	028o14'45.3"	M	29	Rocky	2	3	120	200	100	Yes	No	2	1	2	Over 5 years	Yes	52
K021	15o26'10.1"	028o14'39.1"		14	Rocky	2	3	75	220	200	Yes	Yes	1	2	1	Never	Yes	80
K022	15o26'01.1"	028o14'36.6"	M	4	Rocky	2		115	170	130	Yes	No	3	2	2	Never	No	52
K023	15o26'53.3"	028o14'37.7"	F	18	Rocky	2	3	165	330	150	Yes	No		2	1	2 years ago	Yes	102
K024	15o25"57.6"	028o14'43.7"	M	7	Rocky	2	1	290	220	150	Yes	No	1	1	1	4 years ago	No	30
K025	15o26'02.0"	028o14'50.5"	M	21	Rocky	2	1	105	280	190	Yes	No		2	2	Over 5 years	No	70
K026	15o26'46.1"	028o14'42.6"	F	4	Rocky	2	2	180	220	110	Yes	Yes	3	2	1	Over 5 years	Yes	30
M001	15o21'37.0"	028o14'30.8"	M	10	Normal	1	1	180	150	110	Yes	No	1	2	1	Never	Yes	140
M002	15o21'39.4"	028o14'38.1"	M	7	Rocky	1	1	180	190	190	Yes	Yes	3	2	1	Over 5 years	Yes	50
M003	15o21'36.7"	028o14'46.5"	M	7	Normal	1	1	150	110	110	No	No	2	2	1	1 year ago	No	150
M004	15o21'37.6"	028o14'38.4"	M	6	Rocky	1	2	200	130	130	Yes	No	1	2	1	Never	No	110
M005	15o21'36.6"	028o14'36.8"	F	8	Rocky	1	2	200	130	110	Yes	Yes	2	2	1	2 years ago	Yes	150
M006	15o21'33.9"	028o14'32.1"	M	22	Rocky	1	1	100	220	220	Yes	Yes	1	1	1	Over 5 years	No	90
M007	15o21'32.2"	028o14'31.9"	M	7	Rocky	1	2	140	140	130	Yes	Yes	1	1	2	Over 5 years	No	90

Table C2-1: Continued

Latrine Code	GPS Northing	GPS Easting	Sex of HH Head	Number of users	Geology Type	1=Area water logged 2=Area not water logged	Latrine flooded? 1=All year 2= Rain season; 3 Not affected	Latrine Depth (cm)	Latrine Length (cm)	Latrine Width (cm)	Is pit lined?	Is toilet roofed? 1=Yes; 2=No	Squat hole covered? 1=Always; 2=Sometimes 3=Never	Type: 1=VIP; 2=Ordinary	Usage: 1=Excreta disposal; 2=Combination	When was latrine last desludged?	Chemicals added?	Height of Sludge (cm)
M008	15o21'30.8"	028o14'30.9"	M	7	Rocky	1	2	170	130	150	Yes	No	1	2	1	2 years ago	No	50
M009	15o21'29.0"	028o14'31.1"	M	8	Rocky	2	3	210	180	210	Yes	Yes	3	2	1	Over 5 years	Yes	70
M010	15o21'31.6"	028o14'36.1"	M	7	Rocky	1	2	230	110	215	Yes	Yes	3	2	1	1 year ago	No	180
M011	15o21'25.3"	028o14'32.3"	M	9	Rocky	2	3	210	130	190	Yes	No	3	2	1	Over 5 years	No	30
M012	15o21'27.0"	028o14'35.4"	M	15	Rocky	2	3	160	140	220	Yes	Yes	1	2	2	1 year ago	Yes	150
M013	15o21'27.5"	028o14'39.1"	M	8	Rocky	2	2	390	180	140	Yes	Yes	3	2	1	1 year ago	No	100
M014	15o21'28.3"	028o14'40.5"	F	17	Rocky	2	3	200	230	140	Yes	Yes	3	2	2	No Idea	Yes	100
M015	15o21'19.2"	028o14'36.4"	M	6	Rocky	2	2	280	250	155	Yes	Yes	2	2	1	Over 5 years	No	35
M016	15o21'22.7"	028o14'38.6"	M	2	Rocky	2	2	230	250	140	Yes	Yes	3	1	2	4 years ago	Yes	30
M017	15o21'23.4"	028o14'40.9"	M	4	Rocky	2	3	170	200	90	Yes	Yes	3	2	1	Over 5 years	Yes	40
M018	15o21'22.5"	028o14'43.2"	M	4	Rocky	2	2	245	175	120	Yes	Yes	1	1	1	1 year ago	Yes	45
M019	15o21'18.0"	028o14'37.8"	M	2	Normal	2	2	150	205	120	Yes	Yes	1	1	1	Over 5 years	Yes	39
M020	15o21'19.6"	028o14'41.0"	M	11	Normal	2	2	350	190	120	Yes	Yes	1	2	1	4 years ago	Yes	100
M021	15o21'20.4"	028o14'43.4"	M	7	Normal	2	1	225	205	160	Yes	No	1	2	1	Over 5 years	Yes	50
M022	15o21'22.1"	028o14'45.4"	M	6	Normal	2	2	350	195	180	Yes	Yes	1	2	2	Over 5 years	Yes	50
M023	15o21'15.2"	028o14'40.2"	M	5	Normal	2	2	160	150	140	No	Yes	3	2	2	4 years ago	Yes	40
M024	15o21'20.4"	028o14'48.7"	M	8	Normal	2	3	125	110	105	Yes	Yes	1	2	1	3 years ago	Yes	40
M025	15o21'23.6"	028o14'49.7"	F	15	Normal	2	2	160	115	110	Yes	Yes	3	2	2	Over 5 years	No	150

APPENDIX D: Summary of Statistical Distribution of results by parameter

Table D1: Analysed parameters with computed statistical parameters

parameters	Units	Source of Sample	No. of Samples Analysed	Minimum	Maximum	Range	Mean	Sample Standard Deviation	Quartile Parameters				Kurtosis	Skewness
									Q1	Q2 (Median)	Q3	IQR		
Density	m^3/kg	Top	58	899	1,469	570	1,098	119	1,018	1,093	1,153	135	1.21	-0.10
		Bottom	58	898	1,387	489	1,097	121	1,013	1,076	1,160	147	0.91	0.66
M. Content	g/g TS	Top	58	0.58	0.92	0.34	0.81	0.064	0.79	0.83	0.86	0.07	1.94	-1.22
		Bottom	58	0.58	0.97	0.39	0.82	0.079	0.77	0.83	0.88	0.11	0.36	-0.60
Total Solids	g/g TS	Top	58	0.08	0.42	0.34	0.19	0.064	0.14	0.17	0.21	0.07	1.94	1.22
		Bottom	58	0.03	0.42	0.39	0.18	0.079	0.12	0.17	0.23	0.11	0.36	0.60
TVS	g/g TS	Top	58	0.26	0.91	0.65	0.63	0.145	0.53	0.64	0.73	0.20	-0.30	-0.42
		Bottom	58	0.28	0.81	0.53	0.55	0.107	0.48	0.56	0.61	0.13	-0.26	-0.15
pH	-	Top	58	6.2	8.3	2.10	7.11	0.462	6.9	7.1	7.4	0.5	-0.22	0.08
		Bottom	58	6.5	8.1	1.60	7.44	0.397	7.2	7.5	7.8	0.6	-0.56	-0.42
Total COD	mg O_2/L	Top	58	22,613	314,667	292,054	129,407	55,088	89,227	122,240	167,947	78,720	1.08	0.77
		Bottom	58	26,453	246,400	219,947	112,052	51,467	75,093	104,320	143,307	68,213	0.46	0.84
Soluble COD	mg O_2/L	Top	54	17,280	165,653	148,373	66,659	40,223	33,440	55,787	88,587	55,147	-0.32	0.84
		Bottom	54	5,333	139,947	134,614	54,677	38,143	26,987	43,467	60,053	33,067	-0.16	1.04
Total BOD	mg O_2/L	Top	56	373	3,573	3,200	1045	527	743	927	1,198	455	9.25	2.48
		Bottom	56	347	3,107	2,760	1006	470	717	907	1,193	477	7.34	2.16
Ammonia	mg NH_3-N	Top	58	137	6,943	6,806	1,996	1,615	706	1,407	2,586	1,880	0.70	1.15
		Bottom	58	50	7,577	7,527	2,231	1,749	1,038	1,569	2,983	1,944	1.47	1.35
Sulphates	mg/L	Top	58	302	19,349	19,047	8,669	4,300	5,551	8,458	11,207	5,656	-0.25	0.52
		Bottom	58	969	19,057	18,088	6,344	4,443	2,862	5,344	8,359	5,497	0.76	1.14
Phosphates	mg/L	Top	58	61	4,049	3,988	1740	964	965	1,529	2,434	1,469	-0.34	0.69
		Bottom	58	170	4,241	4,071	1235	812	646	1,071	1,553	907	2.07	1.26

Table D1: Analysed parameters with computed statistical parameters Continued

parameters	Units	Source of Sample	No. of Samples Analysed	Minimum	Maximum	Range	Mean	Sample Standard Deviation	Quartiles Parameters				Kurtosis	Skewness
									Q1	Q2 (Median)	Q3	IQR		
Potassium	mg/kg TS	Top	53	1,166	195,179	194,013	23,249	33,057	7,451	12,779	22,025	14,574	14.60	3.50
		Bottom	53	46	115,118	115,072	20,072	24,450	7,968	11,097	22,771	14,803	5.56	2.43
Sodium	mg/kg TS	Top	53	2,375	164,275	161,900	17,520	28,316	5,406	7,919	13,029	7,624	14.60	3.58
		Bottom	53	691	182,368	181,677	17,953	33,117	3,717	8,174	15,290	11,573	13.51	3.56
Calcium	mg/kg TS	Top	53	1,370	160,884	159,514	16,003	28,150	3,634	7,564	14,323	10,688	15.74	10.78
		Bottom	53	1,508	135,729	134,221	15,999	30,017	3,716	7,020	11,577	7,861	3.82	3.38
Magnesium	mg/kg TS	Top	53	2,632	117,394	114,762	13,482	18,478	4,402	7,509	13,504	9,102	19.58	4.00
		Bottom	53	274	70,065	69,791	11,202	13,821	4,056	6,829	12,208	8,151	10.52	3.08
Zinc	mg/kg TS	Top	53	0	134	134	8.8	21.75	0	0	7	7	22.03	4.32
		Bottom	53	0	96	96	8.2	18.77	0	0	6	6	14.58	3.70
Cadmium	mg/kg TS	Top	53	0	23	23	1.9	4.09	0	0	2	2	16.04	3.75
		Bottom	53	0	121	121	5.0	18.00	0	0	3	3	34.75	5.70
Cobalt	mg/kg TS	Top	53	0	124	124	5.5	17.74	0	0	4	4	40.30	6.06
		Bottom	53	0	240	240	7.9	33.80	0	0	2	2	45.10	6.54
Copper	mg/kg TS	Top	53	0	300	300	17.2	57.0	0	0	2	2	14.51	3.80
		Bottom	53	0	345	345	18.8	65.2	0	0	0	0	15.10	3.88
Iron	mg/kg TS	Top	53	0	1,634	1,634	185	343	26	63	143	117	10.66	3.19
		Bottom	53	0	2,711	2,711	219	473	18	49	122	104	31.46	5.45
Chromium	mg/kg TS	Top	53	0	0	0	0	0	0	0	0	0	-	-
		Bottom	53	0	0	0	0	0	0	0	0	0	-	-
Lead	mg/kg TS	Top	53	0	0	0	0	0	0	0	0	0	53	7.28
		Bottom	53	0	0	0	0	0	0	0	0	0	53	7.28
F. Coliforms	#CFU/100 mL	Top	95	0	1,112	1,112	134	226	10	49	134	125	8.59	2.84
		Bottom	95	0	713	713	73	98	11	43	98	87	19.64	3.63

Table D1: Analysed parameters with computed statistical parameters Continued

parameters	Units	Source of Sample	No. of Samples Analysed	Minimum	Maximum	Range	Mean	Sample Standard Deviation	Quartiles Parameters				Kurtosis	Skewness
									Q1	Q2(Median)	Q3	IQR		
Total Ascaris	#/g TS	Top	100	0	471	471	54	98	0	0	64	64	7.11	2.62
		Bottom	100	0	683	683	49	99	0	0	56	56	18.20	3.76
Viable Ascaris	#/g TS	Top	100	0	471	471	38	96	0	0	20	2O	10.06	3.19
		Bottom	100	0	85	85	1	9	0	0	0	85	92.59	9.51
Cryptosporidium	#/g TS	Top	100	0	11,987	11,987	940	1,596	183	480	913	730	24.58	4.37
		Bottom	100	0	10,000	10,000	617	1,253	79	242	544	465	32.55	5.03

Table D2: Computed results of the Mann-Whitney U Test for top and bottom samples for all parameters analysed (Assumptions: Significance Level =0.05; Hypothesis = 2-tail).

Parameters	**U**	**$n_1=n_2$**	**Z**	**P**	**COMMENT/ CONCLUSION**
Density	1,653.00	58	0.15700	0.87300	Not Significant
Moisture Content	1,536.50	58	0.80064	-0.42370	Not Significant
Total Solids	1,536.50	58	0.80064	0.42370	Not Significant
TVS	1,057.00	58	3.44550	0.00056	Significant
pH	993.00	58	-3.80166	0.00014	Significant
Total COD	1,334.00	58	1.91880	0.05486	Not Significant
Soluble COD	5,716.00	54	0.25040	0.80258	Not Significant
Total BOD	1,527.00	54	0.23658	0.81034	Not Significant
Ammonia	1,510.00	58	-0.94696	0.34212	Not Significant
Sulphates	1,099.00	58	3.21637	0.00120	Significant
Phosphates	1,131.00	58	3.03967	0.00236	Significant
Potassium	5,556.00	53	-0.09192	0.98404	Not Significant
Sodium	5,208.50	53	0.80283	0.42370	Not Significant
Calcium	5,445.00	53	0.38626	0.69654	Not Significant
Magnesium	5,497.00	53	0.15222	0.88076	Not Significant
Zinc	1,373.00	53	-0.19588	0.84148	Not Significant
Cadmium	1,288.00	53	-0.73296	0.46540	Not Significant
Cobalt	1,381.00	53	0.14533	0.88076	Not Significant
Copper	1,344.00	53	0.37912	0.70394	Not Significant
Iron	685.50	53	4.53994	<0.00001	Significant
Chromium	1,404.50	53	0.00316	1.00000	Not Significant

Table D2: Continued.

Parameters	**U**	**n1=n2**	**Z**	**P**	**COMMENT/ CONCLUSION**
Lead	1,404.00	53	0.00000	1.00000	Not Significant
Faecal Coliforms	4,289.00	95	0.58838	0.55520	Not Significant
Total Ascaris	4,834.50	100	0.40316	0.68916	Not Significant
Viable Ascaris	3,738.00	100	3.08234	0.00208	Significant
Cryptosporidium	3,740.00	100	3.07745	0.00208	Significant

Table D3: Computed results of the Kruskal-Wallis H test for bottom sludge samples for all parameters analysed (Assumptions: Significance Level =0.05; Hypothesis = 2-tail).

Parameter	**n**	**Chi-Square**	**Rejection Region**	**p-Value**	**COMMENT/ CONCLUSION**
Density	n_1=15; n_2=15; n_3=15; n_4=13.	1.765	7.815	0.6226	Not Significant
Moisture Content	n_1=15; n_2=15; n_3=15; n_4=13.	7.91	7.815	0.0479	Significant
Total Solids	n_1=15; n_2=15; n_3=15; n_4=13.	7.91	7.815	0.0479	Significant
TVS	n_1=15; n_2=15; n_3=15; n_4=13.	5.727	7.815	0.1257	Not Significant
pH	n_1=15; n_2=15; n_3=15; n_4=13.	18.007	7.815	0.0004	Significant
Total COD	n_1=15; n_2=15; n_3=15; n_4=13.	7.814	7.815	0.05	Not Significant
Soluble COD	n_1=15; n_2=15; n_3=11; n_4=13.	-165	7.815	1	Not Significant
Total BOD	n_1=13; n_2=15; n_3=15; n_4=13.	10.844	7.815	0.0126	Significant
Ammonia	n_1=15; n_2=15; n_3=15; n_4=13.	7.765	7.815	0.0511	Not Significant
Sulphates	n_1=15; n_2=15; n_3=15; n_4=13.	5.691	7.815	0.1277	Not Significant
Phosphates	n_1=15; n_2=15; n_3=15; n_4=13.	7.059	7.815	0.0701	Not Significant
Potassium	n_1=13; n_2=13; n_3=14; n_4=13.	-162	7.815	1	Not Significant
Sodium	n_1=13; n_2=13; n_3=14; n_4=13.	-162	7.815	1	Not Significant
Calcium	n_1=13; n_2=13; n_3=14; n_4=13.	-162	7.815	1	Not Significant
Magnesium	n_1=13; n_2=13; n_3=14; n_4=13.	-162	7.815	1	Not Significant
Zinc	n_1=13; n_2=13; n_3=14; n_4=13.	9.727	7.815	0.021	Significant
Cadmium	n_1=13; n_2=13; n_3=14; n_4=13.	8.576	7.815	0.0355	Significant
Cobalt	n_1=13; n_2=13; n_3=14; n_4=13.	5.572	7.815	0.1344	Not Significant
Copper	n_1=13; n_2=13; n_3=14; n_4=13.	2.663	7.815	0.4465	Not Significant
Iron	n_1=13; n_2=13; n_3=14; n_4=13.	14.234	7.815	0.0002	Significant
Chromium	n_1=13; n_2=13; n_3=14; n_4=13.	0	7.815	1	Not Significant

Table D3: Continued.

Parameters	**Units**	**Chi-Square**	**Rejection Region**	**p-Value**	**COMMENT/ CONCLUSION**
Lead	n_1=13; n_2=13; n_3=14; n_4=13.	0.171	7.815	0.9821	Not Significant
Faecal Coliforms	n_1=25; n_2=25; n_3=24; n_4=21.	24.509	7.815	0.000	Significant
Total Ascaris	n_1=25; n_2=25; n_3=25; n_4=25.	1.188	7.815	0.756	Not Significant
Viable Ascaris	n_1=25; n_2=25; n_3=25; n_4=25.	0.119	7.815	0.9895	Significant
Cryptosporidium	n_1=25; n_2=25; n_3=25; n_4=25.	2.01	7.815	0.5704	Significant

APPENDIX E: RESULTS FOR THE ANALYSED PHYSICAL PARAMETERS

Table E-1: Results for density

PIT ID	Mean Top Sludge(kg/m^3)	STD Dev Top Sludge	Mean Bottom Sludge (kg/m^3)	STD Dev Bottom Sludge
C001	1102	165	974	168
C002	1168	53	957	152
C003	1002	60	1106	53
C004	1068	109	1273	105
C005	1096	58	1120	71
C007	1002	25	1117	13
C008	1113	65	940	13
C011	1114	86	1071	22
C012	1015	38	1092	93
C014	923	116	1045	138
C015	916	64	995	94
C017	1113	20	1238	33
C019	1154	52	1054	22
C020	1341	61	1327	18
C024	946	33	1059	44
G001	1040	59	1101	117
G002	1081	46	1043	108
G003	977	37	1009	24
G004	1112	18	1035	23
G013	1121	6	1284	36
G014	1431	85	1387	129
G015	1205	44	1190	106
G016	1277	93	1108	240
G024	1469	43	1348	7
GO12	1149	24	1086	51
GO13	996	77	1046	44
GO17	981	29	964	2
GO18	1037	65	1069	85
GO21	1095	93	1179	81
GO23	1011	40	1081	52
K004	1191	104	1218	49
K005	1056	12	1018	16
K008	1040	129	1009	94
K009	1236	64	985	67
K010	993	46	1012	65
K011	1190	73	1285	76
K013	1227	16	1091	77
K014	981	65	930	110
K016	1024	67	1039	47
K017	1024	11	960	32
K019	1295	55	1306	13
K020	1184	84	1157	79
K021	1129	109	1155	100
K023	1240	119	1181	38
K025	1051	136	1135	7
M001	1224	60	1123	157
M004	1059	34	1053	83
M005	1037	11	918	37
M006	954	92	910	104
M007	1056	52	994	32
M008	923	14	898	23
M009	1120	45	1174	87
M010	899	53	1161	148
M011	1092	96	1378	33
M013	1140	62	1016	109
M014	1056	21	1059	95
M020	1129	40	1138	53
M021	1106	88	1018	62

Table E-2: Results for moisture content

PIT ID	Mean Top Sludge (g/g Sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Sample)	STD Dev Bottom Sludge
C001	0.89	0.051	0.88	0.030
C002	0.71	0.063	0.80	0.029
C003	0.84	0.008	0.81	0.005
C004	0.79	0.014	0.76	0.021
C005	0.87	0.006	0.89	0.003
C007	0.86	0.002	0.97	0.057
C008	0.92	0.005	0.94	0.008
C011	0.90	0.005	0.89	0.011
C012	0.87	0.005	0.87	0.001
C014	0.85	0.012	0.95	0.032
C015	0.84	0.007	0.86	0.005
C017	0.87	0.008	0.83	0.000
C019	0.84	0.030	0.89	0.065
C020	0.85	0.038	0.73	0.059
C024	0.87	0.004	0.80	0.008
G001	0.81	0.016	0.76	0.091
G002	0.85	0.063	0.79	0.098
G003	0.86	0.021	0.90	0.050
G004	0.82	0.004	0.80	0.025
G013	0.80	0.016	0.83	0.008
G014	0.58	0.020	0.58	0.081
G015	0.75	0.107	0.77	0.027
G016	0.76	0.125	0.86	0.001
G024	0.71	0.010	0.68	0.077
GO12	0.77	0.132	0.84	0.065
GO13	0.86	0.018	0.78	0.057
GO17	0.84	0.021	0.86	0.005
GO18	0.74	0.082	0.72	0.071
GO21	0.79	0.102	0.73	0.081
GO23	0.80	0.022	0.82	0.012
K004	0.83	0.006	0.76	0.021
K005	0.90	0.088	0.84	0.008
K008	0.82	0.014	0.83	0.114
K009	0.82	0.025	0.91	0.059
K010	0.87	0.001	0.89	0.003
K011	0.76	0.029	0.72	0.010
K013	0.68	0.063	0.84	0.059
K014	0.85	0.073	0.93	0.065

Table E-2: Continued

PIT ID	Mean Top Sludge (g/g Sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Sample)	STD Dev Bottom Sludge
K016	0.81	0.003	0.80	0.035
K017	0.84	0.001	0.90	0.007
K019	0.72	0.009	0.69	0.010
K020	0.85	0.014	0.73	0.021
K021	0.77	0.057	0.79	0.120
K023	0.69	0.011	0.71	0.005
K025	0.83	0.010	0.79	0.013
M001	0.83	0.001	0.88	0.006
M004	0.81	0.023	0.71	0.029
M005	0.71	0.079	0.81	0.076
M006	0.84	0.018	0.87	0.034
M007	0.80	0.050	0.86	0.005
M008	0.84	0.013	0.79	0.063
M009	0.81	0.014	0.87	0.015
M010	0.73	0.053	0.86	0.097
M011	0.83	0.028	0.67	0.065
M013	0.82	0.026	0.87	0.001
M014	0.86	0.026	0.90	0.091
M020	0.86	0.121	0.91	0.036
M021	0.86	0.014	0.88	0.070

Table E-3: Results for total solids

PIT ID	Mean Top Sludge (g/g Sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Sample)	STD Dev Bottom Sludge
C001	0.11	0.051	0.12	0.030
C002	0.29	0.063	0.20	0.029
C003	0.16	0.008	0.19	0.005
C004	0.21	0.014	0.24	0.021
C005	0.13	0.006	0.11	0.003
C007	0.14	0.002	0.03	0.057
C008	0.08	0.005	0.06	0.008
C011	0.10	0.005	0.11	0.011
C012	0.13	0.005	0.13	0.001
C014	0.15	0.012	0.05	0.032
C015	0.16	0.007	0.14	0.005
C017	0.13	0.008	0.17	0.000
C019	0.16	0.030	0.11	0.065
C020	0.15	0.038	0.27	0.059
C024	0.13	0.004	0.20	0.008
G001	0.19	0.016	0.24	0.091
G002	0.15	0.051	0.21	0.098
G003	0.14	0.021	0.10	0.050
G004	0.18	0.004	0.20	0.025
G013	0.20	0.016	0.17	0.008
G014	0.42	0.020	0.42	0.081
G015	0.25	0.107	0.23	0.027
G016	0.24	0.125	0.14	0.001
G024	0.29	0.010	0.32	0.077
GO12	0.23	0.132	0.16	0.065
GO13	0.14	0.018	0.22	0.057
GO17	0.16	0.021	0.14	0.005
GO18	0.26	0.082	0.28	0.071
GO21	0.21	0.102	0.27	0.081
GO23	0.20	0.022	0.18	0.012
K004	0.17	0.006	0.24	0.021
K005	0.10	0.088	0.16	0.008
K008	0.18	0.014	0.17	0.114
K009	0.18	0.025	0.09	0.059
K010	0.13	0.001	0.11	0.003
K011	0.24	0.029	0.28	0.010
K013	0.32	0.063	0.16	0.059
K014	0.15	0.073	0.07	0.065

Table E-3: Continued

PIT ID	Mean Top Sludge (g/g Sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Sample)	STD Dev Bottom Sludge
K016	0.19	0.003	0.20	0.035
K017	0.16	0.001	0.10	0.007
K019	0.28	0.009	0.31	0.010
K020	0.15	0.014	0.27	0.021
K021	0.23	0.047	0.21	0.120
K023	0.31	0.011	0.29	0.005
K025	0.17	0.010	0.21	0.013
M001	0.17	0.001	0.12	0.006
M004	0.19	0.023	0.29	0.029
M005	0.29	0.079	0.19	0.076
M006	0.16	0.018	0.13	0.034
M007	0.20	0.050	0.14	0.005
M008	0.16	0.013	0.21	0.063
M009	0.19	0.014	0.13	0.015
M010	0.27	0.053	0.14	0.097
M011	0.17	0.028	0.33	0.065
M013	0.18	0.026	0.13	0.001
M014	0.14	0.026	0.10	0.091
M020	0.14	0.121	0.09	0.036
M021	0.14	0.014	0.12	0.070

Table E-4: Results for total volatile solids

PIT ID	Mean Top Sludge (g/g Dry sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Dry sample)	STD Dev Bottom Sludge
C001	0.79	0.141	0.67	0.407
C002	0.91	0.208	0.81	0.162
C003	0.76	0.012	0.48	0.227
C004	0.67	0.009	0.55	0.027
C005	0.74	0.057	0.56	0.010
C007	0.64	0.005	0.51	0.079
C008	0.82	0.003	0.60	0.115
C011	0.64	0.095	0.61	0.023
C012	0.71	0.034	0.70	0.000
C014	0.62	0.021	0.45	0.082
C015	0.73	0.006	0.61	0.027
C017	0.67	0.039	0.51	0.006
C019	0.55	0.003	0.51	0.000
C020	0.78	0.172	0.57	0.052
C024	0.71	0.092	0.61	0.055
G001	0.52	0.219	0.57	0.086
G002	0.64	0.134	0.71	0.125
G003	0.63	0.261	0.48	0.143
G004	0.72	0.249	0.42	0.074
G013	0.58	0.043	0.51	0.012
G014	0.26	0.106	0.45	0.420
G015	0.38	0.184	0.50	0.078
G016	0.51	0.034	0.48	0.016
G024	0.41	0.030	0.38	0.116
GO12	0.61	0.176	0.50	0.237
GO13	0.53	0.282	0.66	0.307
GO17	0.39	0.251	0.64	0.084
GO18	0.64	0.036	0.43	0.129
GO21	0.54	0.098	0.47	0.268
GO23	0.72	0.035	0.58	0.115
K004	0.79	0.020	0.52	0.022
K005	0.74	0.020	0.67	0.012
K008	0.78	0.014	0.52	0.269
K009	0.69	0.064	0.50	0.051
K010	0.68	0.015	0.66	0.007
K011	0.40	0.051	0.35	0.028
K013	0.59	0.075	0.65	0.185
K014	0.63	0.152	0.60	0.079

Table E-4: Continued

PIT ID	Mean Top Sludge (g/g Dry sample)	STD Dev Top Sludge	Mean Bottom Sludge (g/g Dry sample)	STD Dev Bottom Sludge
K016	0.77	0.006	0.61	0.020
K017	0.73	0.013	0.61	0.010
K019	0.33	0.018	0.28	0.013
K020	0.66	0.008	0.42	0.022
K021	0.44	0.064	0.42	0.025
K023	0.39	0.038	0.36	0.009
K025	0.66	0.059	0.36	0.035
M001	0.79	0.005	0.68	0.025
M004	0.60	0.116	0.43	0.179
M005	0.62	0.101	0.59	0.121
M006	0.43	0.103	0.56	0.172
M007	0.42	0.222	0.49	0.132
M008	0.55	0.042	0.64	0.089
M009	0.52	0.020	0.59	0.006
M010	0.58	0.284	0.60	0.273
M011	0.52	0.070	0.44	0.073
M013	0.77	0.016	0.72	0.005
M014	0.89	0.097	0.58	0.111
M020	0.67	0.028	0.60	0.000
M021	0.81	0.123	0.67	0.036

APPENDIX F: RHEOLOGICAL RESULTS

APPENDIX F1: Tables summarising rheological results for the samples

Table F1-1: Rheological results for sample 1 from Latrine C008

Point No.	Shear Rate $\dot{\gamma}$ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	200.54	2004.7	14.253
2	0.117	299.43	2568.8	21.282
3	0.136	329.76	2425.6	23.437
4	0.158	339.81	2144.2	24.151
5	0.185	345.76	1871	24.574
6	0.215	347.96	1615	24.731
7	0.251	351.05	1397.7	24.95
8	0.293	352.76	1204.5	25.072
9	0.341	354.67	1038.7	25.207
10	0.398	360.11	904.62	25.594
11	0.464	370.84	798.95	26.357
12	0.541	375.56	693.94	26.692
13	0.631	365.25	578.9	25.959
14	0.736	369.26	501.99	26.245
15	0.858	380.32	443.36	27.03
16	1	375.63	375.59	26.697
17	1.17	387.54	332.41	27.544
18	1.36	387.76	285.25	27.559
19	1.58	409.08	258.11	29.075
20	1.85	418.65	226.56	29.755
21	2.15	432.98	200.97	30.774
22	2.51	444	176.76	31.556
23	2.93	448.28	153.07	31.861
24	3.41	460.87	134.97	32.756
25	3.98	455.12	114.32	32.347
26	4.64	477.16	102.8	33.913
27	5.41	459.34	84.881	32.647
28	6.31	461.07	73.074	32.77
29	7.36	465.47	63.272	33.082
30	8.58	455.7	53.113	32.388
31	10	465.52	46.557	33.086
32	11.7	483.14	41.439	34.339
33	13.6	465.06	34.215	33.054
34	15.8	488.73	30.841	34.735
35	18.5	476.2	25.764	33.845
36	21.6	462.46	21.44	32.868
37	25.1	467.07	18.591	33.196
38	29.3	457.94	15.641	32.548
39	34.1	489.39	14.362	34.782
40	39.9	435.54	10.923	30.955
41	46.4	499.53	10.774	35.503
42	54.2	470.74	8.6914	33.457
43	63.1	472.34	7.4887	33.571
44	73.4	496.2	6.758	35.267
45	85.6	549.77	6.4254	39.074
46	101	410.11	4.0764	29.148

Table F1-2: Rheological results for sample 2 from Latrine C008

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	200.54	2004.7	14.253
2	0.117	299.43	2568.8	21.282
3	0.136	329.76	2425.6	23.437
4	0.158	339.81	2144.2	24.151
5	0.185	345.76	1871	24.574
6	0.215	347.96	1615	24.731
7	0.251	351.05	1397.7	24.95
8	0.293	352.76	1204.5	25.072
9	0.341	354.67	1038.7	25.207
10	0.398	360.11	904.62	25.594
11	0.464	370.84	798.95	26.357
12	0.541	375.56	693.94	26.692
13	0.631	365.25	578.9	25.959
14	0.736	369.26	501.99	26.245
15	0.858	380.32	443.36	27.03
16	1	375.63	375.59	26.697
17	1.17	387.54	332.41	27.544
18	1.36	387.76	285.25	27.559
19	1.58	409.08	258.11	29.075
20	1.85	418.65	226.56	29.755
21	2.15	432.98	200.97	30.774
22	2.51	444	176.76	31.556
23	2.93	448.28	153.07	31.861
24	3.41	460.87	134.97	32.756
25	3.98	455.12	114.32	32.347
26	4.64	477.16	102.8	33.913
27	5.41	459.34	84.881	32.647
28	6.31	461.07	73.074	32.77
29	7.36	465.47	63.272	33.082
30	8.58	455.7	53.131	32.388
31	10	465.52	46.557	33.086
32	11.7	483.14	41.439	34.339
33	13.6	465.06	34.215	33.054
34	15.8	488.73	30.841	34.735
35	18.5	476.2	25.764	33.845
36	21.6	462.46	21.44	32.868
37	25.1	467.07	18.591	33.196
38	29.3	457.94	15.641	32.548
39	34.1	489.39	14.362	34.782
40	39.9	435.54	10.923	30.955
41	46.4	499.53	10.774	35.503
42	54.2	470.74	8.6914	33.457
43	63.1	472.34	7.4887	33.571
44	73.4	496.2	6.758	35.267
45	85.6	549.77	6.4254	39.074
46	101	410.11	4.0764	29.148

Table F1-3: Rheological results for sample 3 from Latrine C008

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)

Table F1-4: Rheological results for sample 4 from Latrine C008

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.0989	0.19904	2.0117	0.014147
2	0.115	0.67948	5.9163	0.048293
3	0.136	0.16642	1.2247	0.011828
4	0.158	0.53485	3.3862	0.038014
5	0.184	0.33808	1.841	0.024028
6	0.213	0.46903	2.2054	0.033335
7	0.247	0.93448	3.7884	0.066416
8	0.292	0.68248	2.3376	0.048506
9	0.343	0.36107	1.0535	0.025662
10	0.396	0.57669	1.4556	0.040987
11	0.464	0.4437	0.957	0.031535
12	0.539	0.70357	1.3044	0.050005
13	0.63	0.69645	1.1057	0.049499
14	0.734	0.84134	1.1466	0.059797
15	0.857	0.87604	1.0228	0.062263
16	0.996	1.4691	1.4748	0.10441
17	1.17	0.9001	0.77009	0.063973
18	1.36	1.0052	0.73927	0.071441
19	1.58	1.6187	1.025	0.11505
20	1.85	1.5006	0.81112	0.10665
21	2.16	1.5667	0.72672	0.11135
22	2.52	0.82397	0.32666	0.058562
23	2.93	0.79004	0.26975	0.056151
24	3.41	0.9316	0.27285	0.066212
25	3.98	0.86266	0.21669	0.061312
26	4.64	1.1153	0.24023	0.079267
27	5.42	0.81556	0.15052	0.057965
28	6.3	1.1017	0.17477	0.078304
29	7.37	1.0511	0.14261	0.074704
30	8.59	0.97609	0.1137	0.069374
31	10	0.88451	0.088409	0.062865
32	11.6	1.4372	0.12342	0.10214
33	13.6	1.0221	0.07512	0.072646
34	15.8	0.96661	0.060986	0.0687
35	18.5	1.3158	0.071219	0.09352
36	21.5	1.2611	0.058527	0.089628
37	25.1	1.1279	0.044884	0.080163
38	29.3	1.3628	0.046533	0.096856
39	34.2	1.3522	0.039575	0.096108
40	39.8	1.9018	0.047767	0.13517
41	46.4	2.7116	0.058422	0.19273
42	54.1	2.1574	0.039858	0.15333
43	63.1	2.8568	0.045265	0.20304
44	73.6	3.7274	0.050662	0.26492
45	85.7	5.901	0.068849	0.4194
46	99.9	11.309	0.11324	0.80379

Table F1-5: Rheological results for sample 5 from Latrine C008

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.0995	0.001145	0.011511	8.14E-05
2	0.118	-0.29773	-2.5154	-0.02116
3	0.139	-2859	-2.0593	-0.02032
4	0.159	-0.04392	-0.27627	-0.00312
5	0.184	-0.12511	-0.67985	-0.00889
6	0.212	0.05306	0.2503	0.003771
7	0.248	0.044053	0.17786	0.003131
8	0.291	-0.1475	-0.50653	-0.01048
9	0.34	-0.09001	-0.265	-0.00697
10	0.398	-0.00588	-0.01478	-0.00042
11	0.46	-0.03796	-0.08258	-0.0027
12	0.54	-0.09027	-0.16705	-0.00642
13	0.633	-0.00872	-0.01379	-0.00062
14	0.735	-0.10806	-0.14709	-0.00768
15	0.861	-0.22032	-0.25587	-0.01566
16	1	-0.18264	-0.18203	-0.01298
17	1.16	0.030676	0.265	0.021803
18	1.36	-0.0126	-0.00925	-0.0009
19	1.58	0.039884	0.02528	0.002835
20	1.85	-0.0109	-0.00589	-0.00077
21	2.16	0.006655	0.003087	0.000474
22	2.51	0.029528	0.011752	0.002099
23	2.93	0.11332	0.038676	0.008054
24	3.41	0.23483	0.068779	0.01669
25	3.99	-0.09272	-0.02327	-0.00659
26	4.64	0.21445	0.04622	0.015242
27	5.41	0.076357	0.014106	0.005427
28	6.31	0.26205	0.041555	0.018625
29	7.36	0.13038	0.017718	0.009267
30	8.58	0.18535	0.021605	0.013174
31	10	0.24739	0.024739	0.017583
32	11.7	0.22473	0.019276	0.015973
33	13.6	0.23312	0.017146	0.016569
34	15.9	0.11008	0.006944	0.007824
35	18.5	0.1919	0.010386	0.013639
36	21.5	0.23782	0.011037	0.016903
37	25.1	0.16756	0.00667	0.011909
38	29.3	0.33899	0.011576	0.024093
39	34.1	0.47286	0.013848	0.033607
40	39.8	0.50541	0.012695	0.035921
41	46.4	0.64354	0.013863	0.045739
42	54.1	0.87538	0.016175	0.062216
43	63.1	0.99722	0.015803	0.070876
44	73.6	1.2861	0.01748	0.091404
45	85.8	1.7116	0.019954	0.12165
46	100	2.1473	0.021466	0.15261

Table F1-6: Rheological results for sample 6 from Latrine C005

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.0994	230.94	2322.6	16.414
2	0.117	282.29	2421.1	20.063
3	0.136	327.96	2412.6	23.309
4	0.158	359.14	2266.3	25.525
5	0.185	386.87	2094	27.496
6	0.215	420.25	1950.3	29.868
7	0.251	450.96	1795.1	32.051
8	0.293	488.8	1669.1	34.741
9	0.341	485.33	1421.4	34.494
10	0.398	521.37	1309.6	37.055
11	0.464	512.57	1104.4	36.43
12	0.541	542.23	1001.9	38.538
13	0.631	575.73	912.36	40.919
14	0.736	583.95	793.73	41.503
15	0.858	596.38	695.36	42.387
16	1	623.83	623.86	44.337
17	1.17	616.52	528.77	43.818
18	1.36	648.56	477.14	46.095
19	1.59	672.5	424.28	47.796
20	1.85	695.89	376.59	49.459
21	2.15	744.22	345.43	52.894
22	2.51	764.26	304.25	54.318
23	2.93	798.79	272.75	56.772
24	3.41	852.76	249.75	60.609
25	3.98	888.72	223.24	63.164
26	4.64	918.56	197.9	65.284
27	5.41	918.38	169.7	65.272
28	6.31	1063.9	168.62	75.612
29	7.36	934.33	127.01	66.406
30	8.58	918.85	107.14	65.305
31	10	911.88	91.185	64.81
32	11.7	928.22	79.617	65.971
33	13.6	1022.3	75.207	72.66
34	15.8	944.59	59.596	67.135
35	18.5	998.11	54.014	70.939
36	21.5	1031.4	47.882	73.304
37	25.1	965.57	38.437	68.626
38	29.3	960.23	32.791	68.247
39	34.1	1082.2	31.7	76.918
40	39.8	1169.9	29.41	83.148
41	46.4	1136	24.482	80.741
42	54.2	1136.7	20.988	80.786
43	63.2	1257.5	19.883	89.374
44	74.1	832.35	11.227	59.157
45	85.7	586.69	6.8488	41.698
46	99.8	563.73	5.6495	40.066

Table F1-7: Rheological results for sample 7 from Latrine C005

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	653.08	6527.6	46.416
2	0.117	922.78	7907.6	65.585
3	0.136	501.87	3693.9	35.67
4	0.158	520.81	3286.8	37.015
5	0.185	727.2	3934.8	51.684
6	0.215	770.98	3578.6	54.796
7	0.251	753.03	2997.4	53.521
8	0.293	751.72	2566.3	53.427
9	0.341	767.12	2246.4	54.522
10	0.398	796.47	2000.4	56.608
11	0.464	816.59	1759.1	58.038
12	0.541	818.28	1512.1	58.157
13	0.631	814.41	1290.8	57.883
14	0.736	849.35	1154.6	60.3 66
15	0.858	876.25	1021.8	62.278
16	1	864.98	865.03	61.477
17	1.17	918.26	787.67	65.264
18	1.36	913.68	672.15	64.938
19	1.58	948.72	598.6	67.429
20	1.85	974.06	527.12	69.229
21	2.15	982.03	455.79	69.796
22	2.51	1013	403.28	71.995
23	2.93	1063.5	363.17	75.587
24	3.41	1075.6	314.97	76.443
25	3.98	1136	285.33	80.738
26	4.64	1179.2	254.05	83.81
27	5.41	1203.4	222.35	85.527
28	6.31	1214	192.4	86.282
29	7.63	1256.1	170.75	89.274
30	8.58	1294.7	150.96	92.016
31	10	1310.2	131.02	93.119
32	11.7	1427.2	122.4	101.43
33	13.6	1438	105.79	102.2
34	15.8	1407.1	88.778	100.01
35	18.5	1402.6	15.903	99.69
36	21.5	1504.9	69.847	106.96
37	25.1	1568.8	62.456	111.5
38	29.3	1474.9	50.365	104.83
39	34.1	1602.5	46.936	113.9
40	39.8	1598	40.12	113.57
41	46.4	1400.8	30.185	99.558
42	54.1	14000	25.874	99.501
43	63.3	1211.8	19.142	86.123
44	73.7	1376.8	18.687	97.855
45	86.1	1137.9	13.22	80.876
46	100	1180.3	11.783	83.89

Table F1-8: Rheological results for sample 8 from Latrine C005

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	297.54	2974.4	21.147
2	0.117	351.65	3016.3	24.993
3	0.136	376.1	2766.7	26.731
4	0.158	391.92	2473.2	27.855
5	0.185	404.69	2190.4	28.762
6	0.215	411.06	1908.3	29.215
7	0.251	424.35	1689.7	30.16
8	0.293	436.59	1490.6	31.03
9	0.341	449.02	1315	31.913
10	0.398	471.58	1184.6	33.517
11	0.464	507.93	1094.3	36.1
12	0.541	528.1	975.88	37.534
13	0.631	534.87	847.8	38.015
14	0.736	574.97	781.59	40.865
15	0.858	602.24	702.17	42.803
16	1	608.89	608.91	43.276
17	1.17	655.8	562.46	46.61
18	1.36	672.64	494.82	47.807
19	1.58	713.18	450	50.688
20	1.85	732.39	396.34	52.053
21	2.15	750.09	348.16	53.312
22	2.51	786.26	313.01	55.882
23	2.93	821.52	280.53	58.388
24	3.41	847.22	248.11	60.215
25	3.98	846.1	212.54	60.135
26	4.64	839.62	180.9	59.674
27	5.41	858.83	158.7	61.039
28	6.31	860.76	136.41	61.177
29	7.36	875.28	118.99	62.209
30	8.58	901.83	105.14	64.096
31	10	953.57	95.366	67.774
32	11.7	1018.1	87.329	72.363
33	13.6	1064.6	78.319	75.663
34	15.8	1046.9	66.058	74.407
35	18.5	988.99	53.522	70.291
36	21.5	949.1	44.052	67.456
37	25.1	938.54	37.365	66.705
38	29.3	860.3	29.369	61.144
39	34.2	910.46	26.649	64.709
40	39.8	1031.5	25.941	73.314
41	46.3	1087	23.468	77.257
42	53.9	1361.1	24.397	93.539
43	63.1	1363.4	21.614	96.899
44	73.7	1221.6	16.585	86.822
45	85.4	1518.9	17.782	107.95
46	99.8	1384.5	13.874	98.402

Table F1-9: Rheological results for sample 9 from Latrine C005

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	257.65	2576.8	18.312
2	0.117	305.51	2619.6	21.714
3	0.136	313.17	2302.7	22.258
4	0.159	322.03	2031.6	22.888
5	0.185	342.9	1854.8	24.371
6	0.216	337.42	1565.4	23.981
7	0.251	331.1	1317.8	23.533
8	0.293	333.62	1138.9	23.712
9	0.342	341.18	998.96	24.249
10	0.398	338.85	850.76	24.083
11	0.464	348.61	751.01	24.777
12	0.541	351.26	648.89	24.965
13	0.631	348.72	552.61	24.784
14	0.736	345.86	470.16	24.582
15	0.858	363.09	423.36	25.806
16	1	363.23	324.7	25.816
17	1.17	378.6	284.22	26.908
18	1.36	386.36	252.4	27.46
19	1.58	399.97	216.32	28.427
20	1.85	399.69	189.56	28.407
21	2.15	408.35	169.67	29.023
22	2.51	426.19	169.67	30.291
23	2.93	452.87	154.65	32.187
24	3.41	487.18	142.69	34.626
25	3.98	502.42	126.22	35.709
26	4.64	514.62	110.86	36.575
27	5.41	527.71	97.521	37.506
28	6.31	601.35	95.303	42.74
29	7.36	619.27	84.186	44.014
30	8.58	626.47	73.047	44.525
31	10	620.82	62.087	44.124
32	11.7	664.24	56.973	47.21
33	13.6	659.3	48.503	46.858
34	15.8	677.06	42.726	48.121
35	18.5	730.01	39.498	51.884
36	21.5	770.7	35.771	54.776
37	25.1	787.56	31.354	55.975
38	29.3	714.68	54.403	50.794
39	34.2	731.52	21.389	51.991
40	39.8	708.49	17.781	50.355
41	46.5	654.37	14.078	46.508
42	53.9	824.62	15.313	58.608
43	63.2	662.49	10.479	47.085
44	73.8	677.54	9.1859	48.155
45	85.9	679.11	7.905	48.266
46	99.9	174.61	7.1516	50.79

Table F1-10: Rheological results for sample 10 from Latrine C003

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	28.287	282.85	2.0104
2	0.117	38.544	330.58	2.7395
3	0.136	44.575	327.9	3.1681
4	0.159	48.77	307.69	3.4662
5	0.185	51.849	280.58	3.6851
6	0.216	56.208	260.89	3.9949
7	0.251	61.461	244.7	4.3682
8	0.293	67.57	230.75	4.8024
9	0.342	73.086	214.04	5.1944
10	0.398	77.068	193.55	5.4775
11	0.464	81.786	176.2	5.8128
12	0.541	89.192	164.81	6.3392
13	0.631	99.419	157.57	7.0661
14	0.736	105.82	143.87	7.5211
15	0.858	107.59	125.46	7.6469
16	1	109.66	109.68	7.7938
17	1.17	111.73	95.827	7.9407
18	1.36	120.99	89.006	8.5989
19	1.58	125.67	79.297	8.932
20	1.85	136.61	73.928	9.7096
21	2.15	146.61	68.051	10.42
22	2.51	153.81	61.233	10.932
23	2.93	155.56	53.114	11.056
24	3.41	156.5	45.833	11.123
25	3.98	165.31	41.523	11.749
26	4.64	171.53	36.955	12.191
27	5.41	170.4	31.487	12.111
28	6.31	174.53	27.666	12.405
29	7.36	175.5	23.852	12.473
30	8.58	182.62	21.276	12.98
31	9.99	193.73	19.386	13.769
32	11.7	205.45	17.622	14.602
33	0.732	1758.7	24.02	125
34	0.00516	1758.7	3.41E+05	125
35	0.00222	1758.7	7.9079E+05	125
36	0.00152	1758.7	1.15E+06	125
37	0.000971	1758.7	1.81E+06	125
38	0.000845	1758.7	2.08E+06	125
39	0.000657	1758.7	2.68E+06	125
40	0.000598	1758.7	2.94E+06	125
41	0.000439	1758.7	4.00E+06	125
42	0.000414	1758.7	4.25E+06	125
43	0.000378	1758.7	4.66E+06	125
44	0.000292	1758.7	6.02E+06	125
45	0.000369	1758.7	4.7627E+06	125
46	0.000258	1758.7	6.82E+06	125

Table F1-11: Rheological results for sample 11 from Latrine C003

Point No.	Shear Rate $\dot{\gamma}$ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	25.196	251.95	1.7908
2	0.117	30.8	264.17	2.1891
3	0.136	34.54	254.08	2.4549
4	0.158	38.14	240.65	2.7108
5	0.185	40.958	221.67	2.911
6	0.215	43.951	204.02	3.1238
7	0.251	47.39	188.65	3.3681
8	0.293	50.112	171.1	3.5616
9	0.341	51.457	150.7	3.6572
10	0.398	53.508	134.42	3.803
11	0.464	56.522	121.76	4.0172
12	0.541	58.909	108.85	4.1869
13	0.631	63.184	100.13	4.4907
14	0.736	65.516	89.039	4.6564
15	0.858	66.321	77.33	4.7136
16	1	71.879	71.883	5.1087
17	1.17	72.334	62.037	5.141
18	1.36	78.197	57.539	5.5577
19	1.58	79.88	50.403	5.6773
20	1.85	85.562	46.304	6.0812
21	2.15	90.024	41.788	6.3983
22	2.51	94.115	37.469	6.6891
23	2.93	99.971	34.135	7.1052
24	3.41	105.65	30.939	7.5087
25	3.98	116.78	29.335	8.3001
26	4.64	118.85	25.603	8.4474
27	5.41	118.18	21.827	8.3994
28	6.31	118.07	18.711	8.392
29	7.36	123.83	16.82	8.8008
30	8.58	137.82	16.065	9.7952
31	10	142.98	14.283	10.162
32	11.7	144.71	12.411	10.285
33	13.6	151.04	11.099	10.735
34	15.9	151.18	9.5244	10.745
35	18.4	177.03	9.6113	12.582
36	21.6	169.76	7.8763	12.065
37	25.2	175.85	6.9854	12.498
38	29.3	188.23	6.4262	13.378
39	34.1	229.39	6.724	16.303
40	39.6	272.01	6.8642	19.332
41	46.6	236.23	5.0908	16.79
42	54.1	257.36	4.7606	18.291
43	63.1	264.97	4.198	18.832
44	73.6	265.68	3.6078	18.883
45	85.9	255.3	2.9713	18.145
46	100	274.15	2.7418	19.485

Table F1-12: Rheological results for sample 12 from Latrine C003

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	71.678	716.73	5.0944
2	0.117	77.009	660.46	5.4733
3	0.136	81.59	600.18	5.7989
4	0.158	86.896	548.25	6.176
5	0.185	90.63	490.46	6.4414
6	0.215	94.77	439.9	6.7356
7	0.251	98.726	393.04	7.0168
8	0.293	100.64	343.64	7.1529
9	0.341	105.71	309.58	7.513
10	0.398	109.23	274.4	7.7634
11	0.464	115.44	248.74	8.2045
12	0.541	123.26	227.77	8.7607
13	0.631	125.91	199.56	8.949
14	0.736	127.82	173.76	9.0849
15	0.858	135.38	157.84	9.6222
16	1	138.86	138.86	9.869
17	1.17	147.36	126.39	10.474
18	1.36	150.35	110.6	10.686
19	1.58	162.13	102.29	11.523
20	1.85	165.86	89.768	11.788
21	2.15	173.83	80.682	12.355
22	2.51	187.13	74.499	13.3
23	2.93	193.6	66.131	13.76
24	3.41	217.66	63.751	15.47
25	3.98	219.14	55.064	15.515
26	4.64	239.37	51.578	17.013
27	5.41	250.7	46.331	17.818
28	6.31	289.91	45.943	20.605
29	7.36	303.89	41.314	21.599
30	8.58	293.93	34.266	20.89
31	10	318.13	31.815	22.611
32	11.7	384.25	32.961	27.31
33	13.6	481.56	35.506	34.226
34	15.9	438.48	27.662	31.164
35	18.5	487.8	26.377	34.67
36	21.5	632.29	29.404	44.939
37	25.1	800.34	31.849	56.882
38	29.3	1044.4	35.634	74.227
39	34.2	1452.2	42.524	103.21
40	39.8	1618.8	40.672	115.05
41	46.4	1296.6	27.934	92.153
42	31.3	1758.7	56.121	125
43	57.8	1758.7	30.346	124.68
44	44	1758.7	39.953	125
45	0.022	1758.7	79945	125
46	0.0286	1758.7	61527	125

Table F1-13: Rheological results for sample 13 from Latrine C003

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	98.577	985.28	7.0062
2	0.117	134.21	1151.4	9.5385
3	0.136	120.21	884.57	8.5434
4	0.158	118	744.52	8.3864
5	0.185	332.32	1798.3	23.619
6	0.215	538.62	2500.2	38.281
7	0.251	407.23	1630.3	28.943
8	0.293	415.11	1417	29.503
9	0.341	501.65	1469.4	35.654
10	0.398	533.15	1339	37.893
11	0.464	615.26	1325.5	43.728
12	0.541	524.67	969.58	37.29
13	0.631	552.82	876.42	39.29
14	0.736	646.6	878.92	45.956
15	0.858	941.5	1097.5	66.915
16	1	60.386	60.385	4.2918
17	1.17	59.974	51.441	4.2625
18	1.36	64.752	47.63	4.6021
19	1.58	80.905	51.045	5.7502
20	1.85	104.17	56.349	7.4036
21	2.15	155.62	72.252	11.06
22	2.51	367.84	146.62	26.144
23	2.93	782.02	266.88	55.581
24	3.42	820.79	240.33	58.336
25	3.98	1034.6	259.97	73.535
26	4.64	1218.3	262.41	86.586
27	5.42	85.959	15.87	6.1094
28	6.32	87.486	13.852	6.2179
29	7.35	96.026	13.065	6.8249
30	8.44	192.05	22.743	13.65
31	10	143.49	14.335	10.198
32	11.7	100.49	8.616	7.1421
33	13.4	191.74	14.299	13.627
34	15.7	240.48	15.292	17.092
35	18.5	597.13	32.32	42.44
36	21.5	128.92	5.985	9.1625
37	25.2	134	5.3207	9.5239
38	28.8	304.96	10.589	21.675
39	34.2	256.21	7.4978	18.21
40	39.5	473.98	11.985	33.687
41	46.3	171.58	3.7073	12.194
42	54.1	181.23	3.3528	12.881
43	60.7	406.45	6.6994	28.887
44	0.556	1758.7	3163.9	125
45	1.26	1758.7	1393.6	125
46	0.0231	1758.7	76271	125

Table F1-14: Rheological results for sample 14 from Latrine C014

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	20.503	205.02	1.4572
2	0.117	27.31	234.21	1.941
3	0.136	31.604	232.48	2.2462
4	0.158	35.129	221.66	2.4968
5	0.185	38.311	207.36	2.7229
6	0.215	41.005	190.34	2.9143
7	0.251	43.67	173.83	3.1038
8	0.293	45.252	154.51	3.2162
9	0.341	48.099	140.86	3.4185
10	0.398	50.776	127.56	3.6088
11	0.464	54.241	116.84	3.8551
12	0.541	57.627	106.49	4.0958
13	0.631	58.693	93.004	4.1715
14	0.736	59.676	81.11	4.2414
15	0.858	64.505	75.202	4.5846
16	1	66.1	66.106	4.6979
17	1.17	68.242	58.53	4.8502
18	1.36	70.196	51.648	4.989
19	1.58	76.254	48.11	5.4196
20	1.85	76.277	41.281	5.4213
21	2.15	80.955	37.577	5.7538
22	2.51	88.062	35.058	6.2589
23	2.93	94.022	32.106	6.6825
24	3.41	104.36	30.563	7.4169
25	3.98	108.24	27.189	7.6929
26	4.64	119.6	25.762	8.5002
27	5.41	124.79	23.064	8.8692
28	6.31	133.96	21.238	9.5209
29	7.36	133.93	18.208	9.519
30	8.59	133.63	15.56	9.4972
31	10	141.17	14.111	10.033
32	11.7	153.93	13.198	10.941
33	13.6	149.86	11.038	10.651
34	15.9	147.6	9.3029	10.491
35	18.5	148.4	8.0262	10.547
36	21.6	153.29	7.112	10.894
37	25.1	164.76	6.5572	11.71
38	29.1	238.14	8.1952	16.925
39	34.4	234.97	6.8392	16.7
40	39.9	259.73	6.5138	18.46
41	46	395.85	8.6118	28.134
42	54.1	437.04	8.078	31.062
43	63.6	338.07	5.3156	24.027
44	73.6	340.78	4.6272	24.22
45	85.8	354.05	4.1245	25.164
46	100	375.88	3.7591	26.715

Table F1-15: Rheological results for sample 15 from Latrine C014

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	6.3619	63.628	0.45216
2	0.117	7.4022	63.478	0.5261
3	0.136	8.6135	63.377	0.61219
4	0.158	8.9233	56.323	0.63421
5	0.185	8.9739	48.532	0.63781
6	0.215	9.4324	43.813	0.67039
7	0.251	9.9016	39.426	0.70374
8	0.293	10.86	37.064	0.77186
9	0.341	11.031	32.305	0.78402
10	0.398	12.348	31.013	0.87764
11	0.464	15.227	32.806	1.0823
12	0.541	18.037	33.338	1.282
13	0.631	16.673	26.433	1.185
14	0.734	17.335	23.602	1.2321
15	0.855	18.507	21.637	1.3154
16	0.999	22.559	22.575	1.6033
17	1.17	25.292	21.706	1.7976
18	1.36	24.402	17.911	1.7343
19	1.58	28.617	18.128	2.0339
20	1.85	29.939	16.219	2.1279
21	2.16	27.815	12.878	1.9769
22	2.51	32.585	12.983	2.3159
23	2.93	37.421	12.789	2.6596
24	3.37	64.778	19.207	4.604
25	3.99	76.805	19.235	5.4588
26	4.65	70.888	15.242	5.0982
27	5.38	89.532	16.629	6.3633
28	6.32	81.422	12.884	5.7869
29	7.34	96.514	13.155	6.8596
30	8.58	96.481	11.246	6.8572
31	9.97	109.92	11.027	7.8127
32	11.7	115.58	9.9181	8.2144
33	13.6	129.45	9.4989	9.2008
34	15.8	147.18	9.3105	10.46
35	18.6	150.56	8.1142	10.701
36	21.6	176.29	8.1765	12.53
37	25	183.64	7.3515	13.052
38	29.2	179.1	6.1442	12.73
39	33.1	377.57	11.399	26.835
40	39.7	212.44	4.7178	13.315
41	46.5	212.44	4.5688	15.099
42	54	201.63	3.7307	14.33
43	63.1	250.19	3.9651	17.782
44	73.5	264.35	3.5963	18.788
45	84.8	402.7	4.7466	28.621
46	100	351.26	3.5113	24.965

Table F1-16: Rheological results for sample 16 from Latrine C014

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	3.0386	30.389	0.21596
2	0.117	3.957	33.96	0.28124
3	0.136	4.8512	35.678	0.34479
4	0.158	5.734	36.156	0.40753
5	0.185	6.1141	33.055	0.43455
6	0.215	6.9216	32.127	0.49194
7	0.251	7.2665	28.939	0.51645
8	0.293	7.6565	26.159	0.54417
9	0.341	8.4936	24.871	0.60367
10	0.398	8.8251	22.166	0.62723
11	0.464	9.6779	20.882	0.68784
12	0.541	10.321	19.09	0.73352
13	0.631	11.392	18.068	0.80964
14	0.735	12.087	16.443	0.85908
15	0.856	13.487	15.754	0.95859
16	0.996	17.571	17.64	1.2488
17	1.16	18.647	16.042	1.3253
18	1.35	23.348	17.242	1.6594
19	1.59	23.101	14.501	1.6419
20	1.85	22.413	12.114	1.593
21	2.16	20.081	9.2795	1.4272
22	2.51	21.681	8.6294	1.5409
23	2.93	22.697	7.7491	1.6132
24	3.42	25.161	7.3616	1.7883
25	3.98	25.187	6.3239	1.7901
26	4.63	25.231	5.4462	1.7932
27	5.41	26.519	4.9009	1.8848
28	6.29	29.847	4.7429	2.1213
29	7.35	39.646	5.3944	2.8178
30	8.57	41.985	4.8999	2.984
31	10	44.032	4.404	3.1295
32	11.7	43.25	3.6966	3.0739
33	13.6	34.665	2.5418	2.4637
34	15.7	36.709	2.3313	2.609
35	15.5	38.851	2.0995	2.7613
36	21.5	44.116	2.0491	3.1354
37	25.1	54.21	2.161	3.8529
38	29.2	58.751	2.0123	4.1757
39	32.9	71.941	2.186	5.1131
40	39.7	66.503	1.6737	4.7266
41	46.2	93.458	2.0229	6.6424
42	54.1	66.342	1.2273	4.7152
43	63.1	63.957	1.0138	4.5456
44	73.5	93.264	1.2683	6.6286
45	85.7	90254	1.0525	6.4146
46	100	86.933	0.8686	6.1786

Table F1-17: Rheological results for sample 17 from Latrine M009

Point No.	Shear Rate $\dot{\gamma}$ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	160.26	1602.4	11.39
2	0.117	204.43	1753.6	14.53
3	0.136	236.14	1737	16.783
4	0.158	257.08	1622.3	18.272
5	0.185	262.38	1420.3	18.648
6	0.215	272.94	1266.9	19.399
7	0.251	280.58	1117	19.942
8	0.293	287.37	981.19	20.424
9	0.341	288.74	845.63	20.522
10	0.398	293.6	737.53	20.867
11	0.464	299.52	645.29	21.288
12	0.541	314.52	581.18	22.354
13	0.631	329.32	521.91	23.406
14	0.736	332.06	451.46	23.601
15	0.8585	344.12	401.18	24.458
16	1	365.72	365.7	25.993
17	1.17	366.96	314.74	26.081
18	1.36	393.51	289.47	27.968
19	1.58	397.19	250.62	28.23
20	1.85	413.99	224.03	29.423
21	2.15	429.76	199.47	30.544
22	2.51	447.17	178.02	31.782
23	2.93	470.3	160.58	33.426
24	3.41	499.85	146.39	35.526
25	3.98	494.55	124.23	35.149
26	4.64	514.58	110.86	36.573
27	5.41	527.3	97.438	37.477
28	6.31	564.66	89.495	40.132
29	7.36	620.77	84.376	44.12
30	8.58	607.53	70.836	43.179
31	10	596.31	59.624	42.381
32	11.7	578.9	49.657	41.145
33	13.6	612.93	45.091	43.563
34	15.8	572.82	36.144	40.712
35	18.5	563.03	30.463	40.016
36	21.5	560.67	26.033	39.848
37	25.1	601.76	23.941	42.769
38	29.3	589.63	20.122	41.907
39	34.1	669.91	19.664	47.613
40	39.8	596.24	14.962	42.377
41	46.4	587.72	12.67	41.771
42	54.1	615.39	11.375	43.737
43	63.2	578.59	9.1584	41.122
44	73.5	629.48	8.5638	44.739
45	85.7	634.92	7.4055	45.126
46	100	642.93	6.4245	45.695

Table F1-18: Rheological results for sample 18 from Latrine M009

Point No.	Shear Rate $\dot{\gamma}$ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	70.039	700.34	4.9779
2	0.117	84.356	723.53	5.9954
3	0.136	93.55	688.18	6.6489
4	0.158	101.29	639.12	7.1993
5	0.185	106.87	578.35	7.5959
6	0.215	111.83	519.04	7.9481
7	0.251	116.24	462.78	8.8619
8	0.293	118.5	404.63	8.4222
9	0.341	121.69	356.38	8.649
10	0.398	125.21	314.53	8.8992
11	0.464	129.74	279.52	9.2209
12	0.541	136.04	251.41	9.669
13	0.631	136.28	215.99	9.6861
14	0.736	139.06	189.01	9.8838
15	0.858	147.64	172.15	10.494
16	1	151.85	151.85	10.793
17	1.17	159.26	136.6	11.319
18	1.36	166.96	122.82	11.867
19	1.59	176.86	111.58	12.57
20	1.85	175.34	94.898	12.462
21	2.15	177.41	82.351	12.609
22	2.51	183.94	73.232	13.073
23	2.93	188.93	64.514	13.428
24	3.41	192.03	56.241	13.648
25	3.98	180.17	45.259	12.805
26	4.64	187.72	40.442	13.342
27	5.41	196.49	36.308	13.965
28	6.31	206.6	32.742	14.684
29	7.36	216.35	29.411	15.377
30	8.58	234.04	27.289	16.634
31	10	264.51	26.444	18.799
32	11.7	241	20.669	17.129
33	13.6	235.75	17.33	16.756
34	15.9	224.02	14.112	15.922
35	18.5	228.11	12.327	16.213
36	21.6	221.44	10.267	15.738
37	25.1	227.02	9.0425	16.135
38	29.3	216.98	7.4048	15.422
39	34.2	221.85	6.4923	15.768
40	39.8	235.29	5.9157	16.722
41	46.4	255.07	4.8458	15.997
42	54.1	236.1	4.3633	16.78
43	63.2	239.75	3.7938	17.04
44	73.6	247.86	3.3687	17.616
45	85.4	441.98	5.1775	31.413
46	100	479.1	4.784	34.051

Table F1-19: Rheological results for sample 19 from Latrine M009

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	154.75	1547.3	10.999
2	0.117	194.46	1667.8	13.821
3	0.136	223.16	1641.9	15.861
4	0.158	244.22	1540.9	17.357
5	0.185	260.48	1409.6	18.513
6	0.215	274.12	1272.5	19.483
7	0.251	280.74	1117.7	19.953
8	0.293	289.34	987.89	20.564
9	0.341	297.99	872.71	21.179
10	0.398	310.15	779.07	22.043
11	0.464	319.35	688.01	22.697
12	0.541	323.04	596.9	22.96
13	0.631	328.49	520.63	23.347
14	0.736	348.05	473.14	24.737
15	0.858	361.91	421.92	25.722
16	1	368.55	368.55	26.194
17	1.17	398.13	341.47	28.296
18	1.36	401.49	295.36	28.536
19	1.58	429.67	271.09	30.538
20	1.85	455.81	246.68	32.396
21	1.15	468.14	217.28	33.272
22	2.51	493.71	196.56	35.09
23	2.93	527.59	180.16	37.498
24	3.41	535.33	156.78	38.048
25	3.98	558.65	140.32	39.705
26	4.64	560.37	120.73	39.827
27	5.41	575.48	106.34	40.901
28	6.31	577.69	91.556	41.058
29	7.36	613.11	83.339	43.576
30	8.58	632.98	73.801	44.988
31	10	647.78	64.782	46.04
32	11.7	671.65	57.602	47.736
33	13.6	660.73	48.606	46.96
34	15.9	707.96	44.662	50.317
35	18.5	667.79	36.141	47.462
36	21.5	658.73	30.568	46.818
37	25.1	671.51	26.733	47.726
38	29.3	680.56	23.232	48.37
39	34.1	672.8	19.723	47.818
40	39.7	748.97	18.842	53.232
41	46.6	662.61	14.229	47.094
42	54.2	656.87	12.125	46.686
43	63.1	633.33	10.039	45.013
44	73.6	679.35	9.2333	48.284
45	86	631.89	7.3506	44.91
46	100	612.31	6.1176	43519

Table F1-20: Rheological results for sample 20 from Latrine M009

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	96.865	968.57	6.8845
2	0.117	124.09	1064.3	8.8198
3	0.136	143.76	1057.5	10.217
4	0.158	158.65	1001	11.276
5	0.185	173.27	937.62	12.315
6	0.215	186.55	865.86	13.259
7	0.251	195.99	780.26	13.93
8	0.293	203.99	696.5	14.498
9	0.341	207.64	608.12	14.758
10	0.398	210.68	529.21	14.974
11	0.464	211.8	456.29	15.054
12	0.541	216.16	399.47	15.363
13	0.631	226.72	359.33	16.114
14	0.736	238.99	324.87	16.986
15	0.858	244.38	284.92	17.369
16	1	264.07	264.05	18.769
17	1.117	277.01	237.59	19.688
18	1.36	300.71	221.22	21.372
19	1.58	309.19	195.09	21.975
20	1.85	332.67	180.03	23.644
21	2.15	356.87	165.64	25.364
22	2.51	378.53	150.68	26.904
23	2.93	386.94	132.12	27.501
24	3.41	393.88	115.36	27.995
25	3.98	420.54	105.64	29.889
26	4.64	425.22	91.614	30.222
27	5.41	422.67	78.098	30.04
28	6.31	438.6	69.517	31.173
29	7.36	455.16	61.87	32.35
30	8.58	440.33	51.336	31.296
31	10	421.05	42.104	29.925
32	11.7	427.17	36.637	30.36
33	13.6	422.63	31.085	30.037
34	15.9	412.52	26.02	29.319
35	18.5	440.57	23.829	31.313
36	21.5	415.91	19.305	29.56
37	25.1	409.13	16.269	29.078
38	29.3	416.38	14.217	29.593
39	34.2	415.11	12.139	29.503
40	39.9	400.06	10.032	28.433
41	46.4	411.3	8.8591	29.232
42	54.1	425.64	7.8702	30.252
43	62.9	478.04	7.5948	33.976
44	73.6	454.83	6.1831	32.326
45	85.8	450.35	5.2489	32.008
46	100	447.12	4.4676	31.779

Table F1-21: Rheological results for sample 21 from Latrine M006

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	47.159	471.56	3.3517
2	0.117	62.114	532.75	4.4147
3	0.136	73.317	539.31	5.2108
4	0.158	83.839	528.99	5.9587
5	0.185	93.098	503.83	6.6168
6	0.215	100.82	467.99	7.1659
7	0.251	109.86	437.36	7.8083
8	0.293	117.77	402.12	8.3706
9	0.341	126.04	369.13	8.9583
10	0.398	133.45	335.25	9.4844
11	0.464	143.33	308.8	10.187
12	0.541	153.7	284.02	10.924
13	0.631	160.88	255	11.434
14	0.736	166.9	226.88	11.862
15	0.858	181.38	211.49	12.891
16	1	195.13	195.1	13.869
17	1.17	207.83	178.25	14.771
18	1.36	212.25	156.13	15.085
19	1.58	220.24	138.97	15.653
20	1.85	232.58	125.87	16.53
21	2.15	251.13	116.56	17.848
22	5.51	246.91	98.295	17.549
23	2.93	230.62	78.745	16.391
24	3.41	226.62	66.368	16.106
25	3.98	229.8	57.724	16.333
26	4.64	255.57	55.061	18.164
27	5.41	263.1	48.618	18.699
28	6.31	272.12	43.126	19.341
29	7.36	256.24	34.833	18.212
30	8.58	264.13	30.795	18.773
31	10	269.28	26.928	19.139
32	11.6	280.46	24.089	19.933
33	13.6	296.59	21.798	21.079
34	15.9	295.77	18.651	21.021
35	18.5	317.6	17.191	22.573
36	21.5	322.75	14.978	22.939
37	25.1	325.88	12.969	23.161
38	29.3	328.12	11.193	23.32
39	34.2	346.46	10.144	24.624
40	39.8	364.95	9.1679	25.938
41	46.4	373.94	8.0532	26.577
42	54.1	387.61	7.1619	27.548
43	63.1	406.07	6.434	28.861
44	73.5	429.64	5.8419	30.536
45	85.8	444.39	5.1795	31.584
46	100	462.71	4.6244	32.886

Table F1-22: Rheological results for sample 22 from Latrine M006

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	7.2903	72.901	0.51815
2	0.117	9.5635	82.039	0.67971
3	0.136	10.895	80.148	0.77435
4	0.158	12.54	79.125	0.89125
5	0.185	13.499	73.038	0.95938
6	0.215	14.645	67.954	1.0409
7	0.251	15.586	62.03	1.1078
8	0.293	16.592	56.667	1.1793
9	0.341	18.342	53.716	1.3036
10	0.398	20.2	50.732	1.4357
11	0.464	23.314	50.254	1.657
12	0.541	28.894	53.38	2.0536
13	0.631	34.066	53.982	2.4212
14	0.736	37.148	50.492	2.6402
15	0.858	42.172	49.168	2.9973
16	1	46.014	46.014	3.2704
17	1.17	49.323	42.302	3.5055
18	1.36	54.1	39.792	3.845
19	1.58	56.19	35.453	3.9936
20	1.85	58.893	31.876	4.1857
21	2.15	57.956	26.9	4.1191
22	2.51	58.508	23.292	4.1584
23	2.93	59.729	20.376	4.2451
24	3.41	67.178	19.699	4.7746
25	3.98	69.39	17.436	4.9318
26	4.65	68.438	14.732	4.8641
27	5.41	69.065	12.758	4.9087
28	6.3	78.885	12.525	5.6066
29	7.35	78.063	10.614	5.5482
30	8.6	72.521	8.4373	5.1543
31	10	73.241	7.3101	5.2054
32	11.7	74.325	6.3753	5.2825
33	13.7	77.363	5.6531	5.4984
34	15.9	77.105	4.8561	5.4801
35	18.5	84.127	4.5505	5.9792
36	21.6	81.608	3.7855	5.8002
37	25.1	91.469	3.6458	6.501
38	29.3	91.207	3.108	6.4824
39	34.1	95.206	2.7885	6.7666
40	39.8	96.345	2.4182	6.8475
41	46.4	101.42	2.1851	7.2085
42	54.1	114.37	2.1134	8.1289
43	63.1	123.7	1.961	8.7919
44	73.5	139.55	1.8984	9.9185
45	85.8	153.22	1.786	10.89
46	100	150.62	1.5065	10.705

Table F1-23: Rheological results for sample 23 from Latrine M006

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	37.021	370.18	2.6312
2	0.117	47.791	409.9	3.3967
3	0.136	56.695	417.08	4.0295
4	0.158	63.874	403.01	4.5398
5	0.185	70.433	381.13	5.0059
6	0.215	77.663	360.45	5.5198
7	0.251	85.173	339.09	6.0535
8	0.293	91.972	314.06	6.5368
9	0.341	99.17	290.44	7.0484
10	0.398	103.26	259.35	7.3388
11	0.464	105.95	228.27	7.5305
12	0.541	113.29	209.37	8.0522
13	0.631	120.69	191.27	8.5779
14	0.736	121.35	164.94	8.6248
15	0.858	125.93	146.83	8.9503
16	1	133.34	133.34	9.477
17	1.17	135.55	116.26	9.6343
18	1.36	150.98	111.07	10.731
19	1.58	161.52	101.91	11.48
20	1.85	165.99	89.831	11.798
21	2.15	173.26	80.422	12.314
22	2.51	188.83	75.177	13.421
23	2.93	181.76	62.006	12.918
24	3.41	184.11	53.921	13.086
25	3.98	198.67	49.905	14.12
26	4.64	199.22	42.92	14.159
27	5.41	196.92	36.388	13.996
28	6.31	191.65	30.378	13.621
29	7.36	190.03	25.833	13.506
30	8.58	208.56	24.312	14.823
31	10	222.4	22.245	15.807
32	11.7	215.44	18.466	15.312
33	13.6	259.13	19.098	18.417
34	15.9	254.5	16.032	18.088
35	18.5	271.72	14.701	19.312
36	21.5	283.36	13.153	20.139
37	25.1	298.92	11.892	21.245
38	29.2	333.67	11.423	23.715
39	34.2	326.49	9.5548	23.205
40	39.9	329.59	8.2684	23.425
41	46.4	353.85	7.6251	25.15
42	54.2	385.58	7.1182	27.405
43	63.1	386.71	6.1298	27.484
44	73.6	388.54	5.277	27.615
45	85.8	411.94	4.8012	29.278
46	100	452.43	4.5265	32.156

Table F1-24: Rheological results for sample 24 from Latrine G021

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	33.834	338.32	2.4047
2	0.117	44.22	379.27	3.1429
3	0.136	50.946	374.78	3.6209
4	0.158	56.76	358.15	4.0341
5	0.185	62.47	338.06	4.4399
6	0.215	67.164	311.73	4.7736
7	0.251	72.757	289.64	5.1711
8	0.293	77.551	264.79	5.5118
9	0.341	84.282	246.82	5.9902
10	0.398	92.286	231.87	6.559
11	0.464	100.07	215.61	7.1124
12	0.541	103.84	191.9	7.3804
13	0.631	108.97	172.7	7.7448
14	0.736	116.39	158.17	8.2721
15	0.858	124.95	145.69	8.8804
16	1	126.42	126.43	8.9854
17	1.17	138.65	118.92	9.8545
18	1.36	136.99	100.77	9.7361
19	1.58	147.06	92.785	10.452
20	1.85	151.66	82.077	10.779
21	2.15	158.3	73.478	11.251
22	2.51	173.21	68.957	12.311
23	2.93	171.7	58.632	12.204
24	3.41	178.51	52.278	12.687
25	3.98	175.28	44.027	12.458
26	4.64	180.44	38.877	12.825
27	5.41	188.52	34.838	13.399
28	6.31	205.63	32.589	14.615
29	7.36	202.74	27.559	14.41
30	8.58	198.06	23.089	14.076
31	10	215.21	21.517	15.295
32	11.7	219.33	18.825	15.588
33	13.6	221.76	16.322	15.761
34	15.8	243.89	15.414	17.334
35	18.5	245.44	13.261	17.444
36	21.5	271.13	12.596	19.27
37	25.1	280.57	11.186	19.941
38	29.3	281.16	9.609	19.983
39	34.1	301.8	8.841	21.45
40	39.7	329.67	8.3014	23.431
41	46.4	355.11	7.2157	23.817
42	54.1	328.99	6.0767	23.383
43	63.1	375.24	5.947	26.669
44	73.6	365.51	4.9652	25.978
45	85.9	373.57	4.3494	26.551
46	100	391.18	3.9111	27.803

Table F1-25: Rheological results for sample 25 from Latrine G021

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	15.363	153.63	1.0919
2	0.117	19.484	167.11	1.3848
3	0.136	22.585	166.13	1.6052
4	0.158	24.931	157.31	1.7719
5	0.185	27.465	148.65	1.952
6	0.215	30.075	139.59	2.1376
7	0.251	31.841	126.75	2.263
8	0.293	34.096	116.42	2.4233
9	0.341	35.534	104.06	2.5255
10	0.398	37.651	94.599	2.676
11	0.464	39.465	85.024	2.8049
12	0.541	42.202	77.984	2.9994
13	0.631	44.461	70.485	3.16
14	0.736	45.631	62.038	3.2431
15	0.858	47.88	55.837	3.403
16	1	50.459	50.457	3.5863
17	1.17	50.793	43.565	3.61
18	1.36	51.586	37.946	3.6664
19	1.58	52.565	33.168	3.376
20	1.85	54.841	29.678	3.8978
21	2.15	60.597	28.122	4.3068
22	2.51	62.796	24.996	4.4631
23	2.93	67.576	23.078	4.8028
24	3.41	75.647	22.166	5.3765
25	3.98	72.908	18.308	5.1818
26	4.64	74.419	16.003	5.2892
27	5.41	79.102	14.609	5.622
28	6.31	82.835	13.134	5.8874
29	7.35	86.543	11.776	6.1509
30	8.57	92.373	10.774	6.5653
31	10	90.135	8.9975	6.4062
32	11.6	98.167	8.4282	6.977
33	13.6	97.272	7.1421	6.9134
34	15.9	101.21	6.3759	7.1936
35	18.5	110.16	5.9692	7.8293
36	21.6	115.5	5.1686	7.9243
37	25.1	115.05	4.5813	8.177
38	29.3	121.96	4.1648	8.6684
39	34.1	121.97	3.5717	8.6685
40	39.8	130.99	3.2906	9.3096
41	46.4	133.3	2.8701	9.4737
42	54.2	138.36	2.555	9.8337
43	63.1	147.66	2.34	10.495
44	73.6	155.64	2.1142	11.062
45	85.8	159.35	1.8566	11.326
46	100	173.88	1.7388	12.358

Table F1-26: Rheological results for sample 26 from Latrine G021

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	5.4786	54.792	0.38938
2	0.117	7.6847	65.916	0.54617
3	0.136	9.1128	67.053	0.64768
4	0.158	10.5	66.232	0.74626
5	0.185	12.105	65.497	0.86033
6	0.215	13.458	62.447	0.95648
7	0.251	14.98	59.654	1.0647
8	0.293	16.174	55.237	1.1495
9	0.341	17.016	49.836	1.2094
10	0.398	18.329	46.039	1.3027
11	0.464	18.548	39.962	1.3182
12	0.541	20.649	38.16	1.4676
13	0.631	22.318	35.37	1.5862
14	0.736	22.382	30.414	1.5908
15	0.858	23.898	27.86	1.6985
16	1	26.212	26.211	1.863
17	1.17	30.109	25.826	2.1399
18	1.36	32.153	23.677	2.2852
19	1.58	35.096	22.155	2.4944
20	1.81	38.525	21.261	2.7381
21	2.15	45.93	21.386	3.2644
22	2.51	53.75	21.429	3.8202
23	2.91	56.282	19.353	4.002
24	3.41	63.352	18.568	4.5026
25	3.98	66.065	16.589	4.6955
26	4.64	72.001	15.514	5.1173
27	5.42	64.662	12.107	4.6668
28	6.34	77.675	12.248	5.5206
29	7.34	78.47	10.697	5.5771
30	8.58	60.472	7.0459	4.2979
31	9.98	64.801	6.4911	4.6056
32	11.7	66.579	5.6967	4.732
33	13.6	74.581	5.498	5.3007
34	15.8	84.15	5.3325	5.9808
35	18.5	93.712	5.0779	6.6604
36	21.5	106.64	4.9627	7.5789
37	25.5	118.46	4.7275	8.4192
38	29.5	83.995	2.8458	5.9698
39	35.1	92.49	2.6384	6.5735
40	39.8	94.837	2.3814	6.7404
41	41.2	1031.8	25.07	79.33
42	54.1	1110.7	20.532	78.942
43	64.4	113.07	1.756	8.0361
44	73.6	114	1.5497	8.1022
45	86	121.49	1.4128	8.6347
46	69	1758.7	25.475	125

Table F1-27: Rheological results for sample 27 from Latrine G015

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)

Table F1-28: Rheological results for sample 28 from Latrine G015

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	66.206	661.96	4.7055
2	0.117	70.845	607.61	5.0352
3	0.136	74.723	549.69	5.3108
4	0.158	75.384	475.58	5.3578
5	0.185	73.702	398.86	5.2382
6	0.215	65.621	304.57	4.6639
7	0.251	57.261	227.98	4.0697
8	0.293	57.678	196.97	4.0994
9	0.341	60.976	178.59	4.3338
10	0.398	64.92	163.05	4.6141
11	0.464	66.977	144.28	4.7603
12	0.541	67.709	125.11	4.8123
13	0.631	72.838	115.46	5.1768
14	0.736	92.434	125.65	6.5696
15	0.858	78.415	91.437	5.5732
16	1	78.646	78.652	5.5896
17	1.17	93.507	80.206	6.6458
18	1.36	90.358	66.482	6.4221
19	1.59	97.681	61.628	6.9425
20	1.81	105.37	57.023	7.4891
21	2.15	108.23	50.236	7.6922
22	2.51	102.37	40.756	7.276
23	2.93	100.93	34.464	7.1735
24	3.41	106.71	31.251	7.5843
25	3.98	117.72	29.585	8.3668
26	4.65	125.43	27.002	8.9145
27	5.41	129.91	24.014	9.2332
28	6.31	129.94	20.578	9.2356
29	7.36	119.76	16.266	8.5118
30	8.59	114.47	13.332	8.1356
31	10	98.755	9.8635	7.0188
32	11.7	100.86	8.6414	7.1682
33	13.6	99.632	7.3156	7.0812
34	15.9	97.972	6.1725	6.9632
35	18.4	122.21	6.6462	8.686
36	21.8	112.06	5.1493	7.9644
37	24.8	186.97	7.5524	13.289
38	29.6	135.84	4.5925	9.6547
39	33.8	162.33	4.7959	11.537
40	40.3	112.16	2.7852	7.9716
41	46.4	166.69	3.5903	11.847
42	54.5	129.14	2.3708	9.1785
43	63	119.19	1.8926	8.4709
44	73.6	137.76	1.8722	9.7908
45	84.5	247.04	2.9251	17.558
46	78.4	1758.7	22.424	125

Table F1-29: Rheological results for sample 29 from Latrine G015

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	197.78	1977.4	14.057
2	0.117	243.27	2086.2	17.29
3	0.136	251.73	1851.5	17.891
4	0.158	250.56	1580.7	17.808
5	0.185	253.04	1369.4	17.984
6	0.215	264.66	1228.5	18.81
7	0.251	267.3	1064.2	18.998
8	0.293	267.13	912.19	18.985
9	0.341	269.29	788.64	19.139
10	0.398	273.96	688.15	19.471
11	0.464	283.46	610.7	20.174
12	0.541	292.61	540.71	20.797
13	0.631	305.15	483.6	21.688
14	0.736	305.6	415.47	21.72
15	0.858	318.69	371.55	22.651
16	1	342.63	342.59	24.351
17	1.17	348.17	298.63	24.745
18	1.36	380.84	280.15	27.068
19	1.58	390.96	246.69	27.787
20	1.81	416.5	225.39	29.602
21	2.15	450.42	209.13	32.013
22	2.51	487.49	194.07	34.648
23	2.93	499.08	170.4	35.471
24	3.41	540.39	158.26	38.408
25	3.98	562.06	141.19	39.947
26	4.64	603.85	130.1	42.918
27	5.41	599.57	110.79	42.613
28	6.31	628.05	99.536	44.638
29	7.36	672.63	91.437	47.806
30	8.58	646.49	75.379	45.948
31	10	698.72	96.868	49.66
32	11.7	711..48	61.027	50.567
33	13.6	695.84	51.19	49.456
34	15.9	549.14	34.623	39.029
35	18.5	601.8	32.553	42.772
36	21.5	768.8	35.688	54.641
37	25.1	742.7	29.566	52.786
38	29.2	649.29	22.233	46.147
39	33.8	621.23	18.353	44.153
40	39.7	506.4	12.756	35.991
41	46.4	499.71	9.6828	31.963
42	54.1	470.07	8.6954	33.41
43	63.2	428.88	6.7869	30.482
44	73.8	446.87	6.0565	31.761
45	85.9	464.45	5.4071	33.01
46	100	436.9	4.361	31.052

Table F1-30: Rheological results for sample 30 from Latrine K009

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	9.3856	93.855	0.66106
2	0.117	12.634	108.37	0.89793
3	0.136	14.563	107.13	1.0351
4	0.158	16.041	101.2	1.1401
5	0.185	17.765	96.101	1.2626
6	0.215	19.366	89.88	1.3764
7	0.251	20.87	83.101	1.4833
8	0.293	23.078	78.801	1.6402
9	0.341	25.08	73.452	1.7825
10	0.398	27.153	68.171	1.9298
11	0.464	29.076	62.647	2.0665
12	0.541	30.59	56.528	2.1742
13	0.631	32.227	51.058	2.2905
14	0.736	34.786	47.28	2.4724
15	0.858	36.865	42.987	2.6201
16	1	37.757	37.768	2.6835
17	1.17	41.126	35.272	2.923
18	1.36	42.756	31.456	3.0388
19	1.59	44.789	28.256	3.1833
20	1.85	48.747	26.379	3.4646
21	2.15	51.192	23.774	3.6384
22	2.51	54.756	21.807	3.8917
23	2.93	59.091	20.198	4.1998
24	3.42	57.936	16.963	4.1177
25	3.98	61.575	15.468	4.3763
26	4.64	62.878	13.539	4.4689
27	5.41	65.698	12.14	4.6693
28	6.32	68.798	10.894	4.8897
29	7.36	72.406	9.832	5.1461
30	8.58	69.432	8.0917	4.9348
31	10	74.917	7.4945	5.3246
32	11.7	76.544	6.5588	5.4402
33	13.6	78.784	5.7952	5.5994
34	15.8	83.009	5.2377	5.8997
35	18.5	86.586	4.6828	6.1539
36	21.6	90.438	4.1919	6.4277
37	25.1	95.598	3.807	6.7945
38	29.3	98.606	3.3639	7.0082
39	34.2	105.94	3.0985	7.5294
40	39.8	110.75	2.781	7.8711
41	46.4	117.23	2.525	8.332
42	54.1	124.32	2.2976	8.8357
43	63.1	132.79	2.1048	9.4376
44	73.6	136.88	1.8601	9.7285
45	85.7	147.04	1.7149	10.451
46	99.5	157.87	1.5867	11.22

Table F1-31: Rheological results for sample 31 from Latrine K009

Point No.	Shear Rate Y (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	6.2414	62.414	0.44359
2	0.117	8.4649	72.602	0.60163
3	0.136	9.4232	69.326	0.66973
4	0.158	9.8495	62.139	0.70003
5	0.185	10.404	56.307	0.73944
6	0.215	10.836	50.275	0.77014
7	0.251	11.291	44.96	0.80249
8	0.293	11.88	40.583	0.84433
9	0.341	12.322	36.086	0.87577
10	0.398	12.688	31.879	0.90175
11	0.464	12.668	27.296	0.90038
12	0.541	13.143	24.287	0.93413
13	0.631	14.286	22.652	1.0154
14	0.736	15.161	20.603	1.0775
15	0.858	15.172	17.677	1.0784
16	1	15.637	15.632	1.1114
17	1.17	16.282	13.953	1.1572
18	1.36	17.398	12.803	1.2365
19	1.59	18.085	11.399	1.2854
20	1.81	20.79	11.26	1.4776
21	2.15	22.187	10.307	1.5769
22	2.51	23.323	9.2898	1.6576
23	2.93	25.467	8.7026	1.81
24	3.41	27.625	8..0905	1.9634
25	3.98	30.838	7.7469	2.1918
26	4.64	33.843	7.2935	2.4053
27	5.41	97.833	7.0053	2.6924
28	6.31	40.77	6.4623	2.8976
29	7.36	44.59	6.0586	3.1692
30	8.57	51.079	5.9574	9.6303
31	9.99	56.138	5.6202	3.9899
32	11.7	57.494	4.9297	4.0863
33	13.6	65.417	4.8192	4.6494
34	15.8	76.148	4.806	5.4021
35	18.5	80.227	4.3394	5.702
36	21.6	84.455	3.916	6.0025
37	25.1	95.162	3.7888	6.7635
38	29.3	107.78	3.6815	7.6602
39	34.2	109.63	3.2089	7.7916
40	39.8	118.56	2.9788	8.4262
41	46.3	145.08	3.1326	10.312
42	54.1	158.52	2.9304	11.266
43	63.2	167.11	2.6457	11.877
44	73.8	163.12	2.2104	11.593
45	85.8	162.41	1.8919	11.543
46	99.9	182.81	1.829	12.993

Table F1-32: Rheological results for sample 32 from Latrine K009

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	6.2414	62.414	0.44359
2	0.117	8.4649	72.602	0.60163
3	0.136	9.4232	69.326	0.66973
4	0.158	9.8495	62.139	0.70003
5	0.185	10.404	56.307	0.73944
6	0.215	10.836	50.275	0.77014
7	0.251	11.291	44.96	0.80249
8	0.293	11.88	40.583	0.84433
9	0.341	12.322	36.086	0.87577
10	0.398	12.688	31.879	0.90175
11	0.464	12.668	27.296	0.90038
12	0.541	13.143	24.287	0.93413
13	0.631	14.286	22.652	1.0154
14	0.736	15.161	20.603	1.0075
15	0.858	15.172	17.677	1.0784
16	1	15.637	15.632	1.1114
17	1.17	16.282	13.953	1.1572
18	1.36	17.398	12.803	1.2365
19	1.59	18.085	11.399	1.2854
20	1.85	20.79	11.26	1.4776
21	2.15	22.187	10.307	1.5769
22	2.51	23.323	9.2898	1.6576
23	2.93	25.467	8.7026	1.81
24	3.41	27.625	8.0905	1.9634
25	3.98	30.838	7.7469	2.1918
26	4.64	33.843	7.2935	2.4053
27	5.41	37.883	7.0053	2.6924
28	6.31	40.77	6.4623	2.8976
29	7.36	44.59	6.0586	3.1692
30	8.57	51.079	5.9574	3.6303
31	9.99	56.138	5.6202	3.9899
32	11.7	57.494	4.9297	4.0863
33	13.6	65.417	4.8192	4.6494
34	15.8	76.148	4.806	5.4121
35	18.5	80.227	4.3394	5.702
36	21.6	84.455	3.916	6.0025
37	25.1	95.162	3.7888	6.7635
38	29.3	107.78	3.6815	7.6602
39	34.2	109.63	3.2089	7.7916
40	39.8	118.56	2.9788	8.4262
41	46.3	145.08	3.1326	10.312
42	54.1	158.52	2.29304	11.266
43	63.2	167.11	2.6457	11.877
44	73.8	163.12	2.2104	11.593
45	85.8	162.41	1.8919	11.543
46	99.9	182.81	1.829	12.993

Table F1-33: Rheological results for sample 33 from Latrine K009

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	6.4934	64.94	0.46151
2	0.117	9.7885	83.945	0.6957
3	0.136	11.996	88.254	0.8526
4	0.158	14.317	90.348	1.0176
5	0.185	16.059	86.925	1.1414
6	0.215	17.527	81.382	1.2457
7	0.251	19.038	75.767	1.3531
8	0.293	19.984	68.219	1.4203
9	0.341	21.207	62.107	1.5073
10	0.398	21.932	55.101	1.5588
11	0.464	23.239	50.059	1.6516
12	0.541	24.882	45.98	1.7685
13	0.631	26.558	42.074	1.8876
14	0.736	27.878	37.881	1.9814
15	0.858	29.485	34.377	2.0956
16	1	32.118	32.124	2.2827
17	1.17	33.259	28.527	2.3638
18	1.36	36.205	26.639	2.5732
19	1.58	37.393	23.598	2.6576
20	1.85	39.804	21.535	2.829
21	2.16	41.99	19.482	2.9844
22	2.51	44.428	17.69	3.1577
23	2.93	45.751	15.614	3.2517
24	3.41	49.664	14.545	3.5298
25	3.98	49.732	12.487	3.5346
26	4.64	52.675	11.35	3.7438
27	5.42	52.458	9.6828	3.7283
28	6.31	59.897	9.4993	4.2571
29	7.35	63.782	8.6805	4.5332
30	8.59	63.691	7.4181	4.5267
31	10	68.926	6.89	4.8988
32	11.7	69.863	5.9885	4.9654
33	13.6	71.977	5.2936	5.1156
34	15.9	73.627	4.645	5.2329
35	15.5	82.917	4.4902	5.8932
36	21.5	89.357	4.1519	6.3509
37	25.1	87.282	3.4729	6.2034
38	29.3	94.598	3.2299	6.7234
39	34.1	97.877	2.8668	6.9564
40	39.8	105.25	2.6421	7.4808
41	46.4	110.17	2.3729	7.8301
42	54.1	122.97	2.2731	8.74
43	63.1	135.1	2.1414	9.602
44	73.6	139.85	1.9009	9.9393
45	85.7	151.15	1.7634	10.743
46	100	159.68	1.5968	11.349

Table F1-34: Rheological results for sample 34 from Latrine K010

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	7.8342	78.336	0.5568
2	0.117	10.567	90.621	0.751
3	0.136	12.236	90.003	0.86963
4	0.158	14.2	89.607	1.0092
5	0.185	15.328	82.974	1.0894
6	0.215	16.321	75.776	1.16
7	0.251	18.145	72.217	1.2897
8	0.293	19.489	66.539	1.3852
9	0.341	21.201	62.092	1.5068
10	0.398	23.526	59.091	1.6721
11	0.464	25.565	55.072	1.817
12	0.541	27.533	50.876	1.9569
13	0.631	28.601	45.315	2.0328
14	0.736	30.777	41.824	2.1874
15	0.858	33.111	38.605	2.3533
16	1	33.864	33.869	2.4069
17	1.17	36.445	31.259	2.5903
18	1.36	36	26.487	2.5587
19	1.59	38.141	24.057	2.7108
20	1.85	39.196	21.222	2.7858
21	2.15	42.236	19.6	3.0018
22	2.51	44.366	17.654	3.1532
23	2.93	45.459	15.517	3.2309
24	3.41	49.316	14.454	3.505
25	3.98	53.537	13.463	3.805
26	4.64	52.457	11.894	3.7283
27	5.41	52.781	9.7481	3.7513
28	6.32	52.75	8.3501	3.7491
29	7.35	55.931	7.6068	3.9752
30	8.58	56.227	6.5503	3.9963
31	9.99	63.979	6.4043	4.5472
32	11.7	66.139	5.6676	4.7007
33	13.6	67.844	4.985	4.8219
34	15.9	71.227	4.4937	5.0623
35	18.5	75.292	4.0716	5.3512
36	21.6	75.18	3.4873	5.3433
37	25.1	80.57	3.2088	5.7263
38	29.3	84.923	2.8981	6.0358
39	34.1	87.386	2.5591	6.2108
40	39.8	93.614	2.3511	6.6535
41	46.4	98.362	2.1188	6.9909
42	54.1	105.55	1.9501	7.502
43	63.1	108.16	1.7139	7.687
44	73.6	109.52	1.4878	7.77841
45	85.4	156.18	1.8299	11.1
46	100	121.98	1.2189	8.6694

Table F1-35: Rheological results for sample 35 from Latrine K010

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	8.9231	89.227	0.63419
2	0.117	10.412	89.307	0.74005
3	0.136	10.613	78.069	0.75431
4	0.158	11.341	71.566	0.80605
5	0.185	11.764	63.688	0.83612
6	0.215	12.363	57.363	0.87868
7	0.251	13.116	52.219	0.93216
8	0.293	13.249	45.258	0.94165
9	0.341	13.949	40.848	0.9914
10	0.398	14.581	36.643	1.0363
11	0.464	16.031	34.534	1.1394
12	0.541	17.151	31.693	1.219
13	0.631	18.063	28.629	1.2838
14	0.736	18.912	25.704	1.3442
15	0.858	21.185	24.694	1.5057
16	1	22.335	22.323	1.5874
17	1.17	24.114	20.691	1.7139
18	1.36	26.291	19.342	1.8686
19	1.59	29.253	18.485	2.0791
20	1.85	31.998	17.325	2.2742
21	2.15	35.236	16.349	2.5043
22	2.51	38.442	15.295	2.7322
23	2.93	41.963	14.322	2.9824
24	3.41	47.238	13.848	3.3573
25	3.98	49.907	12.542	3.547
26	4.64	53.608	11.533	3.8101
27	5.41	56.693	10.479	4.0293
28	6.31	60.721	6.629	4.3157
29	7.35	64.379	8.7559	4.5757
30	8.59	60.412	7.0361	4.2937
31	10	61.273	6.124	4.3549
32	11.6	68.19	5.8539	4.8465
33	13.6	69.736	5.127	4.9563
34	15.8	77.066	4.8656	5.4774
35	18.5	78.449	4.2392	5.5757
36	21.6	79.664	3.6953	5.662
37	25.1	92.796	3.7037	6.5953
38	29.3	81.53	2.783	5.7946
39	34.1	92.207	2.7018	6.5534
40	39.9	99.433	2.4947	7.067
41	46.5	105.3	2.2654	7.4843
42	54.1	109.44	2.0215	7.7785
43	63	117.99	1.8728	8.386
44	73.5	121.67	1.6551	8.6472
45	85.9	125.04	1.4561	8.8871
46	100	132.24	1.3225	9.3986

Table F1-36: Rheological results for sample 36 from Latrine K010

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	27.549	275.46	1.958
2	0.117	35.812	307.15	2.5453
3	0.136	37.876	278.64	2.692
4	0.158	36.83	232.38	2.6176
5	0.185	36.111	195.4	2.5665
6	0.215	35.643	165.44	2.5333
7	0.251	35.275	140.45	2.5071
8	0.293	34.732	118.61	2.4685
9	0.341	35.044	102.64	2.4907
10	0.398	35.155	88.27	2.4986
11	0.464	35.011	75.435	2.4883
12	0.541	34.371	63.515	2.4429
13	0.631	33.695	53.394	2.3948
14	0.736	34.467	46.854	2.4497
15	0.857	35.013	40.832	2.4885
16	1	34.135	34.144	2.4261
17	1.17	36.044	30.915	2.5617
18	1.36	36.371	26.761	2.585
19	1.58	39.165	24.714	2.7836
20	1.85	41.988	22.738	2.9842
21	2.15	43.671	20.271	3.1038
22	2.51	46.769	18.612	3.324
23	2.93	51.325	17.538	3.6478
24	3.41	55.892	16.38	3.9724
25	3.98	62.252	15.645	4.4245
26	4.63	71.786	15.489	5.1021
27	5.4	81.166	15.023	5.7687
28	6.31	90.254	14.307	6.4147
29	7.35	107.3	14.604	7.6264
30	8.56	121.96	14.241	8.6684
31	9.98	144.71	14.495	10.285
32	11.7	160.35	13.755	11.396
33	13.6	176.01	12.963	12.51
34	15.8	204.12	12.895	14.508
35	18.5	231.18	12.514	16.431
36	21.5	252.75	11.739	17.964
37	25.1	275.01	10.959	19.546
38	29.3	280.8	9.58	19.957
39	34.2	292.78	8.5669	20.809
40	39.8	278.67	6.9933	19.806
41	46.5	279.4	6.0114	19.858
42	54.2	279.6	5.1621	19.872
43	63.1	271.38	4.2979	19.288
44	73.7	265.97	3.6109	18.903
45	85.8	267.61	3.1191	19.08
46	100	267.62	2.675	19.021

Table F1-37: Rheological results for sample 37 from Latrine K010

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	28.741	287.39	2.0427
2	0.117	36.28	311.17	2.5786
3	0.136	39.343	289.41	2.7962
4	0.158	39.981	252.29	2.8416
5	0.185	39.511	213.86	2.8082
6	0.215	39.098	181.48	2.7788
7	0.251	39.4	156.82	2.8003
8	0.293	39.232	133.95	2.7883
9	0.341	39.572	115.89	2.8125
10	0.398	40.14	100.86	2.8529
11	0.464	39.432	84.94	2.8026
12	0.541	40.163	74.217	2.8545
13	0.631	41.764	66.186	2.9683
14	0.736	44.688	60.723	3.1761
15	0.858	45.495	53.049	3.2335
16	1	48.361	48.362	3.4372
17	1.17	51.74	44.377	3.6773
18	1.36	55.212	40.621	3.9241
19	1.58	58.875	37.147	4.1845
20	1.85	65.949	35.689	4.6872
21	2.15	71.726	33.29	5.0978
22	2.51	77.544	30.872	5.5113
23	2.93	83.598	28.545	5.9416
24	3.41	88.954	26.053	6.3222
25	3.98	99.156	24.909	7.0473
26	4.64	107.6	23.196	7.6478
27	5.41	118.47	21.909	8.4201
28	6.31	127.1	20.143	9.0336
29	7.35	143.13	19.463	10.173
30	8.57	163.84	19.121	11.645
31	9.99	177.71	17.791	12.63
32	11.7	185.22	15.882	13.164
33	13.6	201.58	14.843	14.327
34	15.9	213.83	13.489	15.198
35	18.5	218.71	11.833	15.545
36	21.6	217.23	10.074	15.439
37	25.1	219.37	8.7322	15.592
38	29.3	223.27	7.6213	15.869
39	34.2	217.03	6.3412	15.425
40	39.8	224.12	5.624	15.929
41	46.4	213.97	4.6067	15..208
42	54.1	223.9	4.1369	15.914
43	63.2	208.87	3.3036	14.845
44	73.6	211.24	2.8687	15.013
45	85.9	20053	2.3354	14.252
46	99.9	218.99	2.1912	15.564

Table F1-38: Rheological results for sample 38 from Latrine K017

Point No.	Shear Rate Ɣ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	16.347	163.46	1.1618
2	0.117	21.987	188.58	1.5627
3	0.136	26.095	191.96	1.8547
4	0.158	29.96	189.04	2.1293
5	0.185	33.48	181.2	2.3795
6	0.215	37.279	173.05	2.6495
7	0.251	40.642	161.78	2.8885
8	0.293	44.533	152.05	3.1651
9	0.341	47.404	138.83	3.3692
10	0.398	52.751	132.53	3.7492
11	0.464	59.541	128.24	4.2318
12	0.541	66.442	122.78	4.7222
13	0.631	70.349	111.5	5
14	0.736	74.665	101.47	5.3067
15	0.858	81.22	94.705	5.7726
16	1	84.661	84.659	6.0171
17	1.17	89.233	76.535	6.3421
18	1.36	86.276	63.474	6.1319
19	1.58	86.255	54.423	6.1304
20	1.85	81.723	44.226	5.8083
21	2.15	81.915	38.024	5.8219
22	2.51	85.402	34.001	6.0698
23	2.93	88.46	30.208	6.2871
24	3.41	98.627	28.886	7.0097
25	3.98	113.61	28.54	8.0749
26	4.64	103.25	22.24	7.3386
27	5.42	94.54	17.428	6.7193
28	6.3	108.02	17.15	7.6772
29	7.35	120.89	16.445	8.592
30	8.57	123.93	14.457	8.8081
31	10	125	12.485	8.8841
32	11.7	130.82	11.218	9.2975
33	13.6	132.43	9.7286	9.4122
34	15.9	128.32	8.0921	9.1203
35	18.5	144.47	7.8197	10.268
36	21.6	142.67	6.6248	10.14
37	25.2	142.49	5.6646	10.127
38	29.3	157	5.3622	11.159
39	34.1	160.08	4.6881	11.377
40	39.8	169.72	4.2624	12.062
41	46.5	170.53	3.6695	12.12
42	54.2	180.45	3.3307	12.825
43	63.1	199.71	3.1644	14.194
44	73.5	218.74	2.9744	15.547
45	85.8	219.54	2.5575	15.603
46	100	250.08	2.5018	17.774

Table F1-39: Rheological results for sample 39 from Latrine K017

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	28.217	282.16	2.0055
2	0.117	37.157	318.68	2.6408
3	0.136	42.145	310.03	2.9954
4	0.158	46.454	293.12	3.3017
5	0.185	50.378	272.66	3.5805
6	0.215	53.832	249.87	3.826
7	0.251	57.884	230.41	4.114
8	0.293	63.162	215.66	4.4891
9	0.341	69.963	204.9	4.9725
10	0.398	76.766	192.85	5.456
11	0.464	80.238	172.85	5.7027
12	0.541	85.943	158.8	6.6174
13	0.631	93.107	147.56	7.1146
14	0.736	100.1	136.06	7.3982
15	0.858	104.09	121.37	7.9083
16	1	11.27	111.28	8.6657
17	1.17	121.93	104.58	9.2087
18	1.36	129.57	95.328	9.629
19	1.58	135.48	85.477	10.347
20	1.85	145.59	78.786	10.808
21	2.15	152.07	70.586	10.938
22	2.51	153.9	61.268	10.971
23	2.93	154.37	52.71	10.971
24	3.41	148.75	43.564	10.572
25	3.98	157.47	39.554	11.192
26	4.64	161.75	34.845	11.496
27	5.41	163.29	30.173	11.606
28	6.31	157.54	24.977	11.197
29	7.37	160.64	21.805	11.417
30	8.57	172.14	20.076	12.234
31	10	166.26	16.619	11.817
32	11.7	170.23	14.593	12.099
33	13.6	185.76	13.672	13.203
34	15.9	185.51	11.692	13.185
35	18.5	188.84	10.219	13.422
36	21.6	195.4	9.065	13.888
37	25.1	195.55	7.7809	13.898
38	29.3	204.7	6.9896	14.549
39	34.2	212.91	6.2263	15.133
40	39.8	225	5.6497	15.991
41	46.4	239.47	5.1661	17.02
42	54.1	233.6	4.314	16.602
43	63.2	243.79	3.8602	17.327
44	73.5	257.88	3.5067	18.329
45	85.8	265.21	3.0918	18.329
46	100	275.81	2.7576	19.603

Table F1-40: Rheological results for sample 40 from Latrine K017

Point No.	Shear Rate $\dot{\gamma}$ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	7.1183	71.184	0.50592
2	0.117	9.2462	79.294	0.65715
3	0.136	10.742	79.036	0.76.348
4	0.158	12.268	77.392	0.87194
5	0.185	13.648	73.855	0.97001
6	0.215	15.245	70.769	1.0835
7	0.251	16.358	65.147	1.1626
8	0.293	17.617	60.164	1.2521
9	0.341	19.153	56.094	1.3612
10	0.398	20.322	51.051	1.4443
11	0.464	21.18	45.615	1.5053
12	0.541	22.453	41.502	1.5958
13	0.631	23.728	37.607	1.6864
14	0.736	24.498	33.296	1.7412
15	0.858	24.716	28.814	1.7567
16	1	26.623	26.623	1.8922
17	1.17	27.479	23.571	1.953
18	1.36	30.136	22.202	2.1419
19	1.59	31.547	19.894	2.2421
20	1.84	34.122	18.509	2.4252
21	2.15	37.424	17.391	2.6598
22	2.51	40.402	16.111	2.8715
23	2.93	40.158	13.701	2.8541
24	3.42	39.409	11.531	2.8009
25	3.98	41.129	10.33	2.9231
26	4.63	45.612	9.8438	3.2418
27	5.41	46.387	8.5772	3.2969
28	6.32	42.825	6.7767	3.0437
29	7.35	45.168	6.1415	3.2102
30	8.57	52.972	6.1846	3.7649
31	10	49.986	4.9956	3.5527
32	11.7	50.755	4.3453	3.6073
33	13.6	55.02	4.0471	3.9104
34	15.9	58.227	3.6695	4.1384
35	18.5	60.227	3.2605	4.2806
36	21.6	59.597	2.7636	4.2358
37	25.1	62.137	2.4722	4.4163
38	29.3	65.497	2.2347	4.6551
39	34.2	69.766	2.0413	4.9585
40	39.8	70.645	1.7735	5.021
41	46.4	74.28	1.5995	5.2794
42	54.1	81.721	1.5098	5.8082
43	63.1	85.374	1.353	6.0678
44	73.6	86.475	1.1742	6.146
45	85.8	95.574	1.114	6.7928
46	100	102.97	1.0297	7.3185

Table F1-41: Rheological results for sample 41 from Latrine K017

Point No.	Shear Rate ϒ (1/S)	Shear Stress τ (Pa)	Viscosity μ (Pa.s)	Torque M (mN.m)
1	0.1	3.9799	39.801	0.28287
2	0.117	5.4985	47.172	0.39079
3	0.136	6.8353	50.294	0.48581
4	0.158	8.1666	51.524	0.58042
5	0.185	8.5356	46.195	0.60665
6	0.215	10.094	46.814	0.71739
7	0.251	11.756	46.808	0.83551
8	0.293	13.174	45.008	0.93634
9	0.341	14.402	42.176	1.0236
10	0.398	15.276	38.38	1.0857
11	0.464	16.286	35.092	1.1575
12	0.541	18.434	34.063	1.3102
13	0.631	19.623	31.102	1.3947
14	0.736	19.99	27.166	1.4208
15	0.858	21.887	25.522	1.5556
16	0.999	24.144	24.158	1.716
17	1.17	25.032	21.465	1.7791
18	1.36	27.892	20.53	1.9824
19	1.58	29.396	18.563	2.0893
20	1.85	31.796	17.198	2.2598
21	2.15	33.847	15.708	2.4056
22	2.52	34.233	13.608	2.4331
23	2.93	31.856	10.857	2.2641
24	3.42	29.673	8.6747	2.109
25	3.98	29.855	7.4985	2.1219
26	4.64	33.04	7.1156	2.3482
27	5.41	36.358	6.718	2.5841
28	6.33	35.384	5.5941	2.5149
29	7.36	31.393	4.2642	2.2312
30	8.56	36.895	4.311	2.6223
31	10	38.073	3.7988	2.706
32	11.7	39.172	3.3565	2.7841
33	13.6	41.685	3.063	2.9627
34	15.8	42.703	2.6945	3.0351
35	18.5	42.087	2.2722	2.9912
36	21.5	47.232	2.1942	3.3569
37	25.1	45.804	1.8224	3.2554
38	29.3	50.29	1.717	3.5742
39	34.2	51.091	1.4954	3.6312
40	39.8	53.815	1.3521	3.8248
41	46.4	59.287	1.2777	4.2137
42	54.1	59.098	1.092	4.2003
43	63.1	63.835	1.0118	4.5369
44	73.6	70.938	0.96409	5.0418
45	85.7	79.012	0.92171	5.6156
46	100	80.249	0.80219	5.7036

APPENDIX F2: Graphs for the relationship between Viscosity and Shear rate

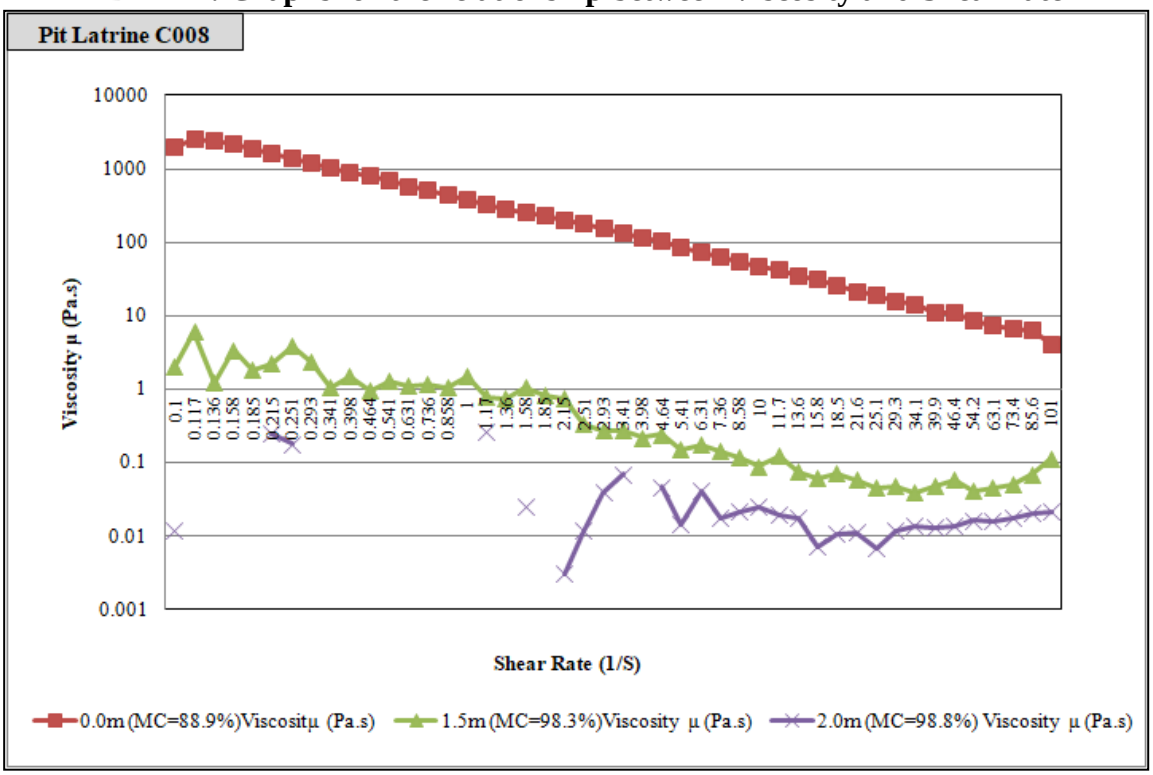

Figure F2-1: Graph of Viscosity against Shear Rate for samples 1,4 and 5 from Latrine C008

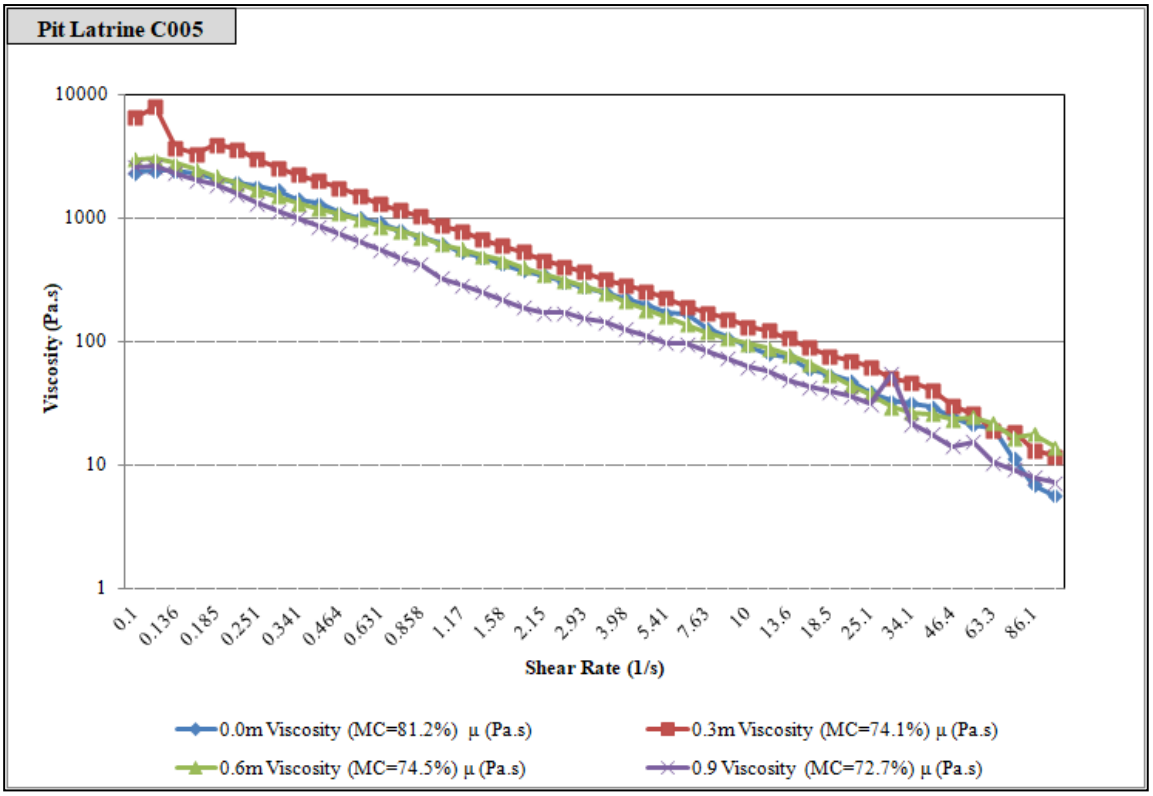

Figure F2-2: Graph of Viscosity against Shear Rate for samples 6, 7, 8 and 9 from Latrine C005

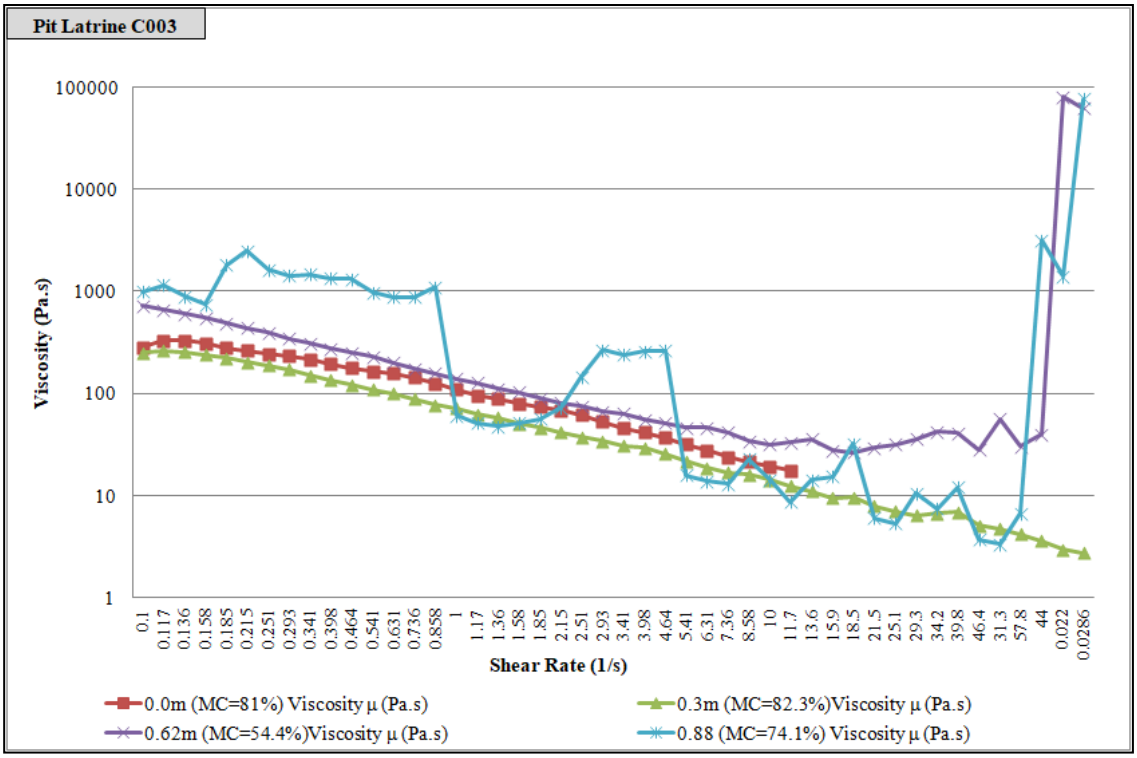

Figure F2-3: Graph of Viscosity against Shear Rate for samples 10, 11, 12 and 13 from Latrine C003

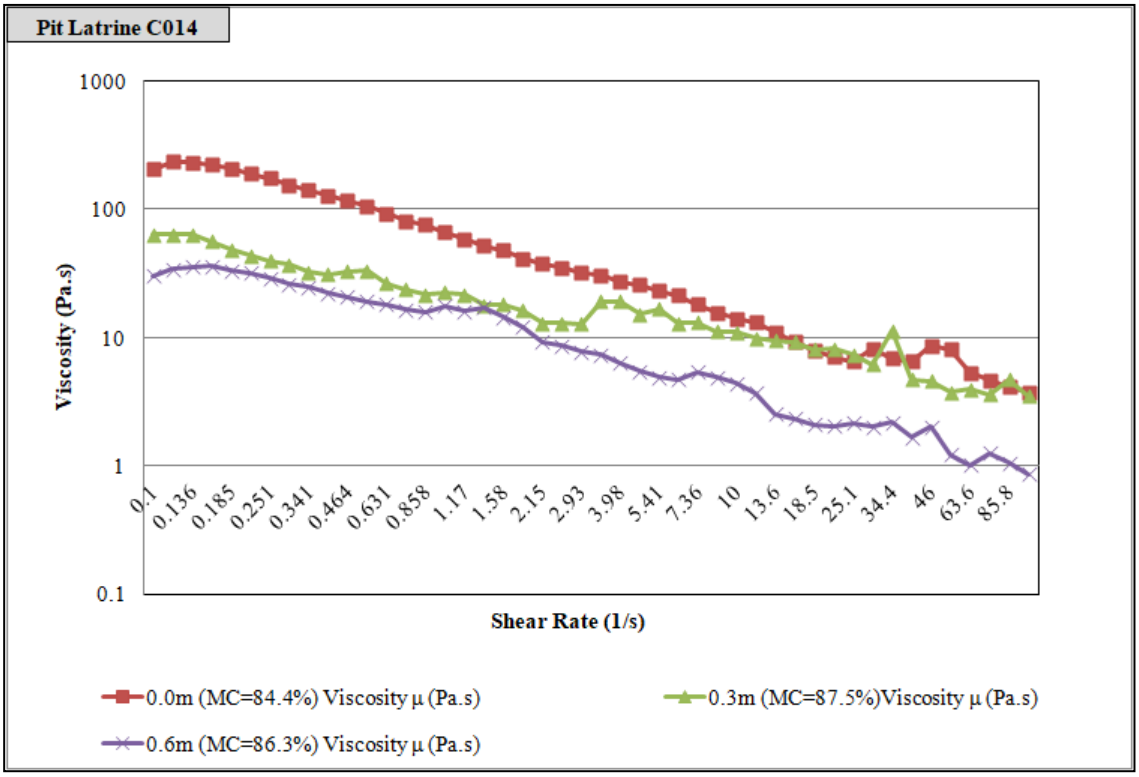

Figure F2-4: Graph of Viscosity against Shear Rate for samples 14, 15, and 16 from Latrine C014

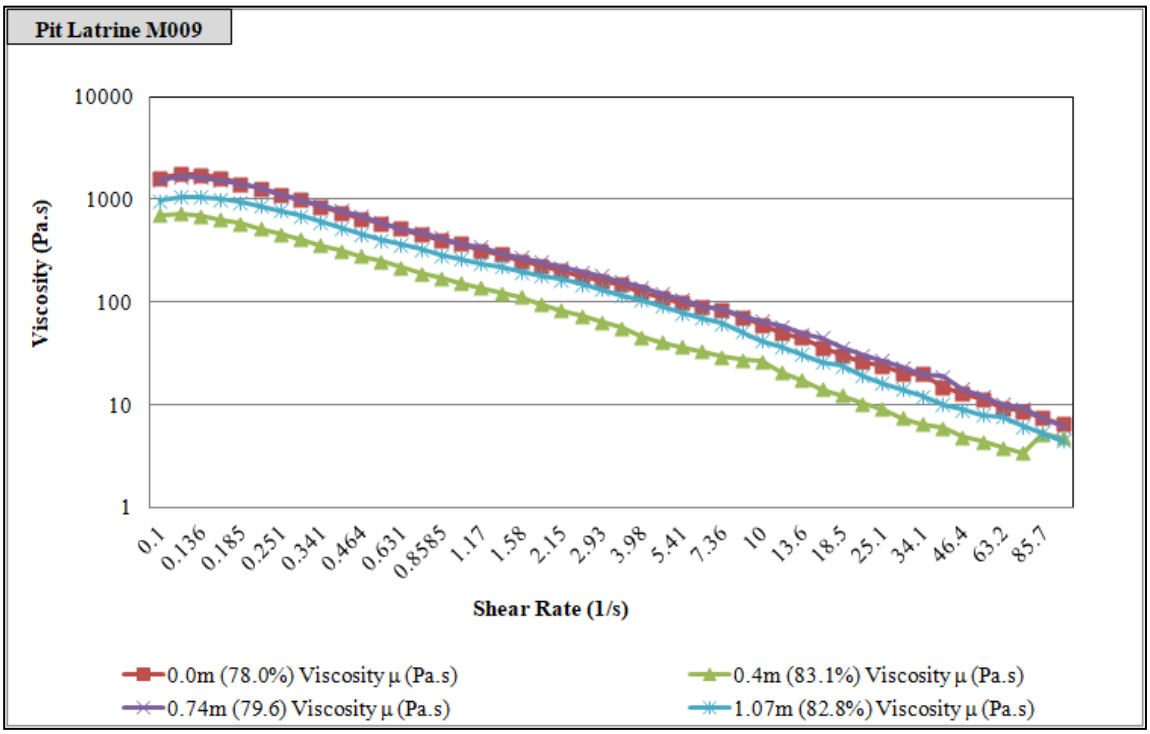

Figure F2-5: Graph of Viscosity against Shear Rate for samples 17, 18, 19 and 20 from Latrine M009

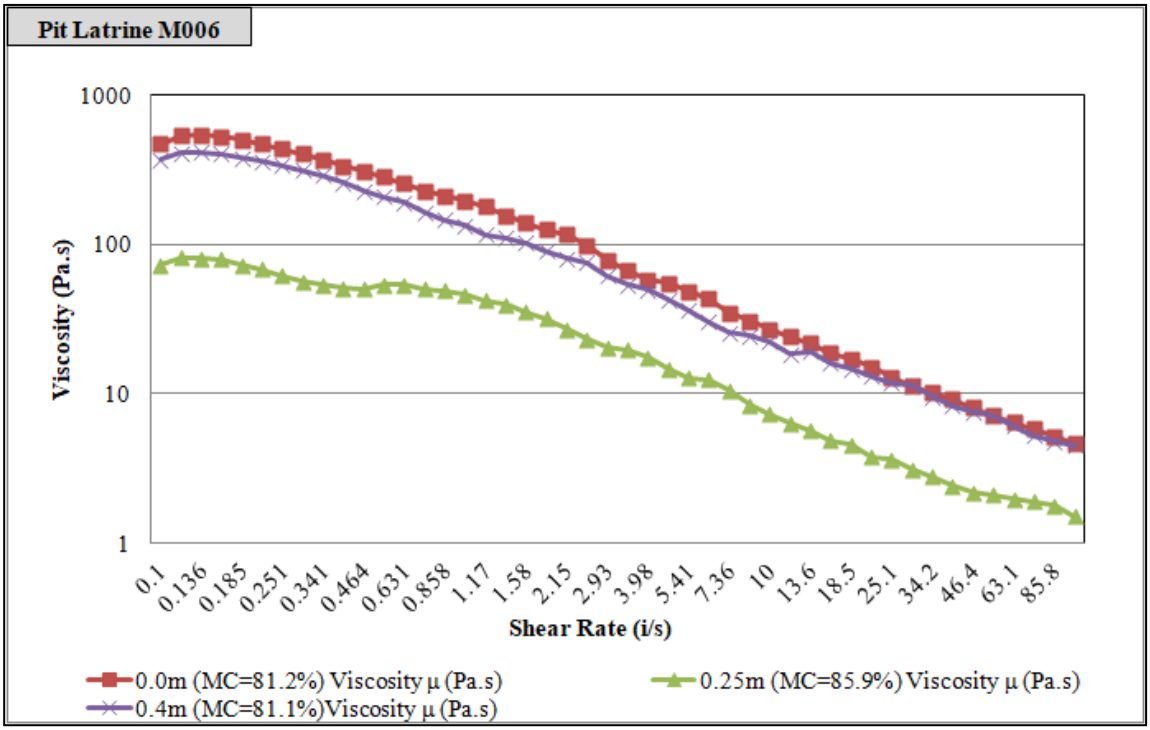

Figure F2-6: Graph of Viscosity against Shear Rate for samples 21, 22 and 23 from Latrine M006

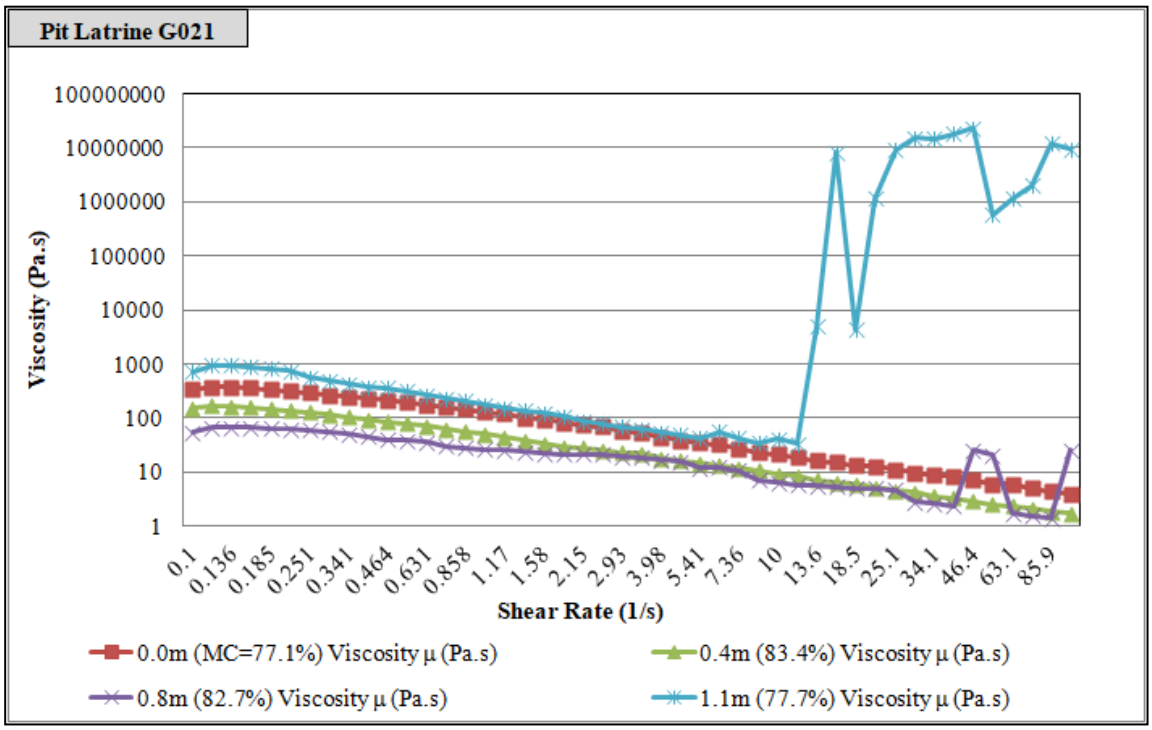

Figure F2-7: Graph of Viscosity against Shear Rate for samples 24, 25, 26 and 27 from Latrine G021

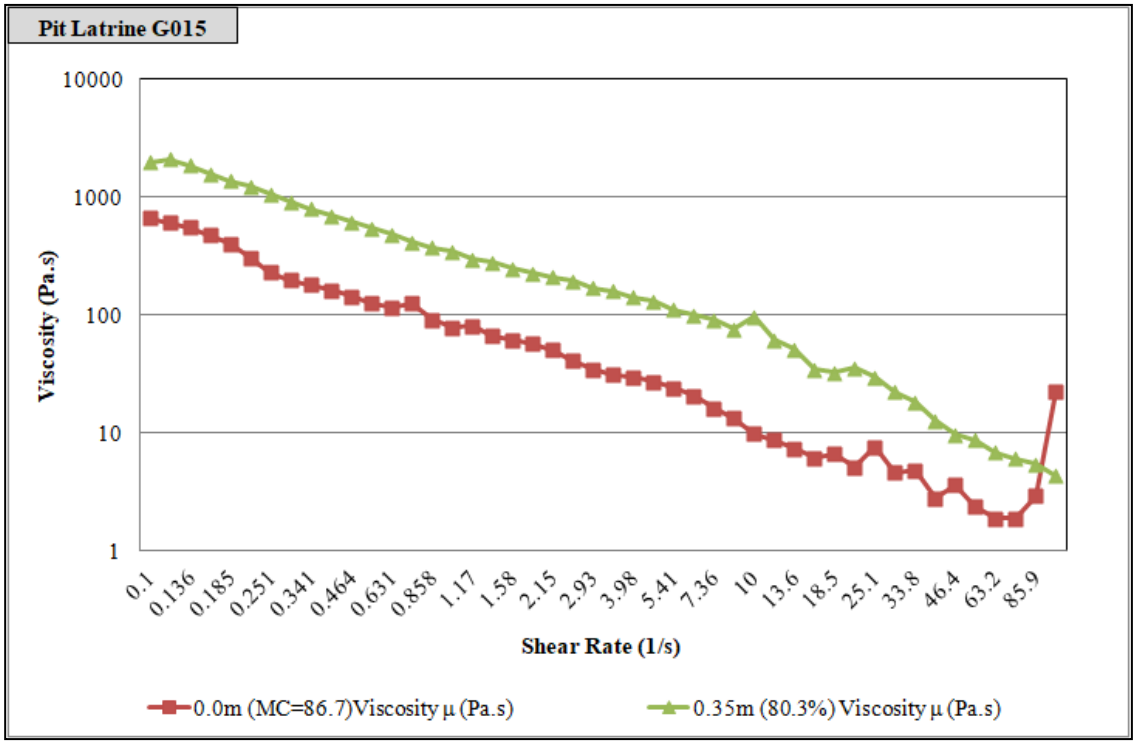

Figure F2-8: Graph of Viscosity against Shear Rate for samples 28 and 29 from Latrine G015

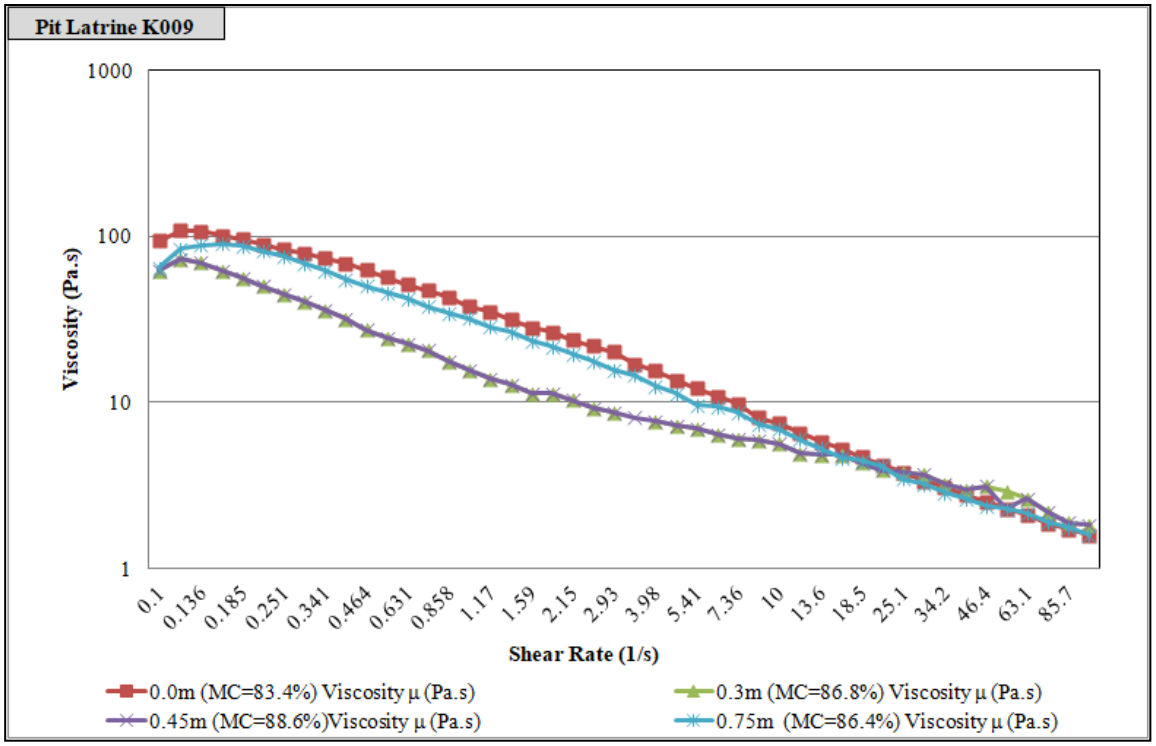

Figure F2-9: Graph of Viscosity against Shear Rate for samples 30, 31, 32 and 33 from Latrine K009

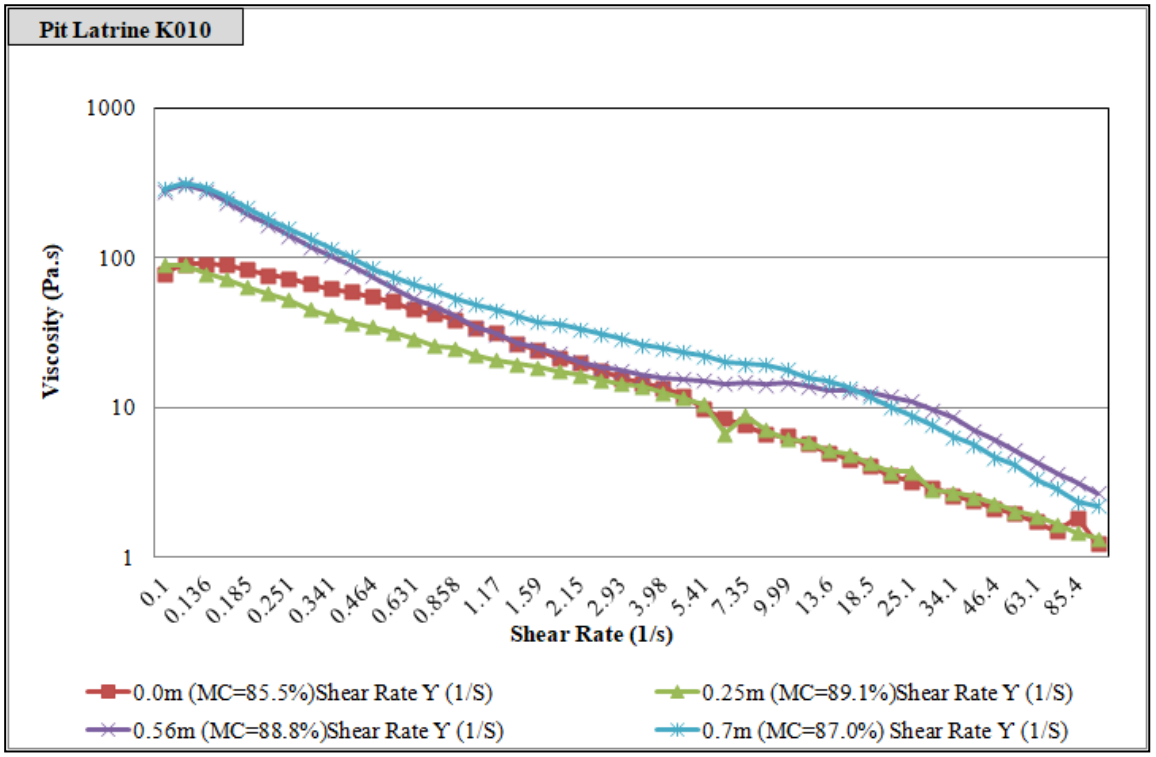

Figure F2-10: Graph of Viscosity against Shear Rate for samples 34, 35, 36 and 37 from Latrine K010

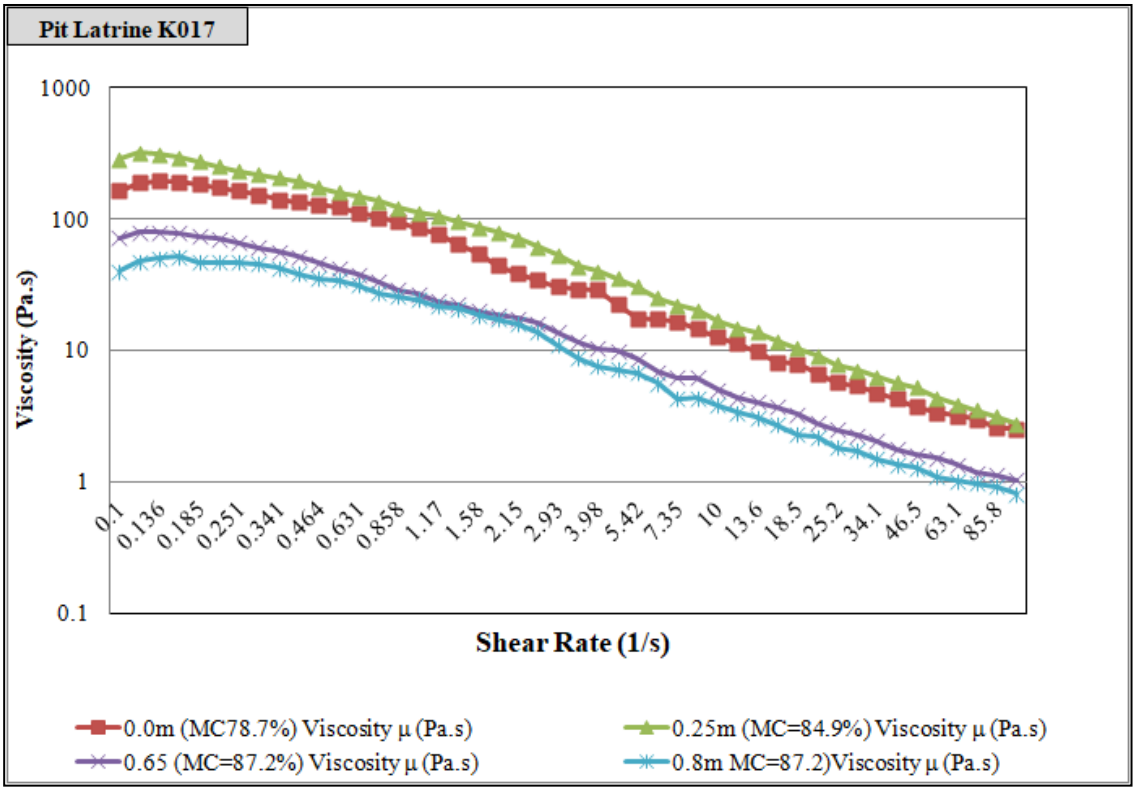

Figure F2-11: Graph of Viscosity against Shear Rate for samples 38, 39, 40 and 41 from Latrine K017

APPENDIX F3: Graphs for the relationship between Shear stress and Shear rate

Appendix F3:

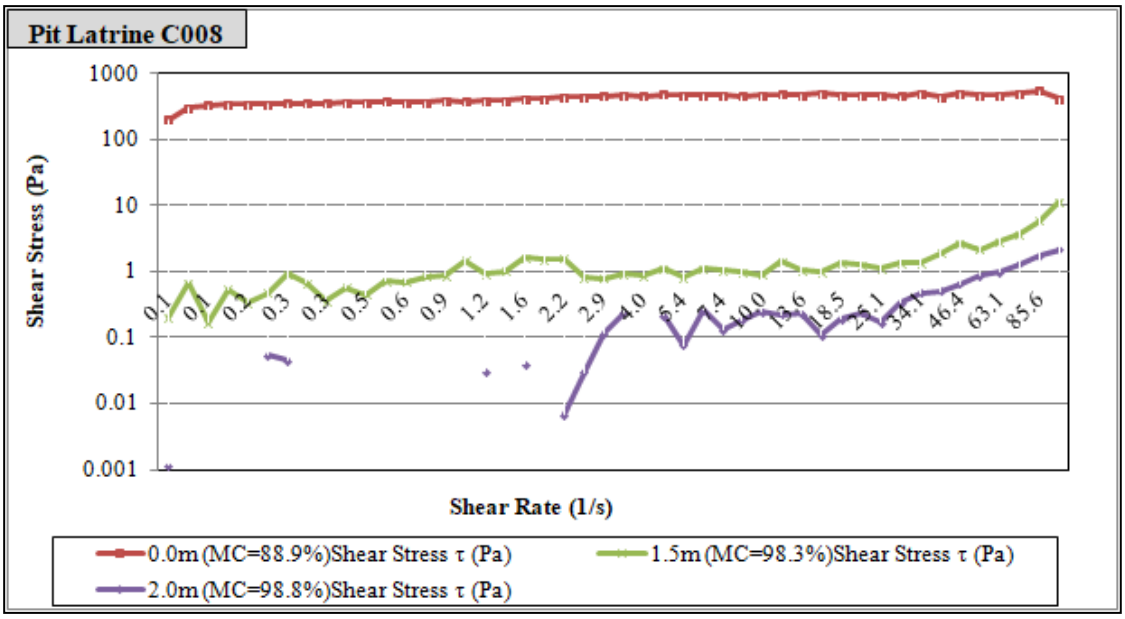

Figure F3-1: Graph of Shear Stress against Shear Rate for samples 1,4 and 5 from Latrine C008

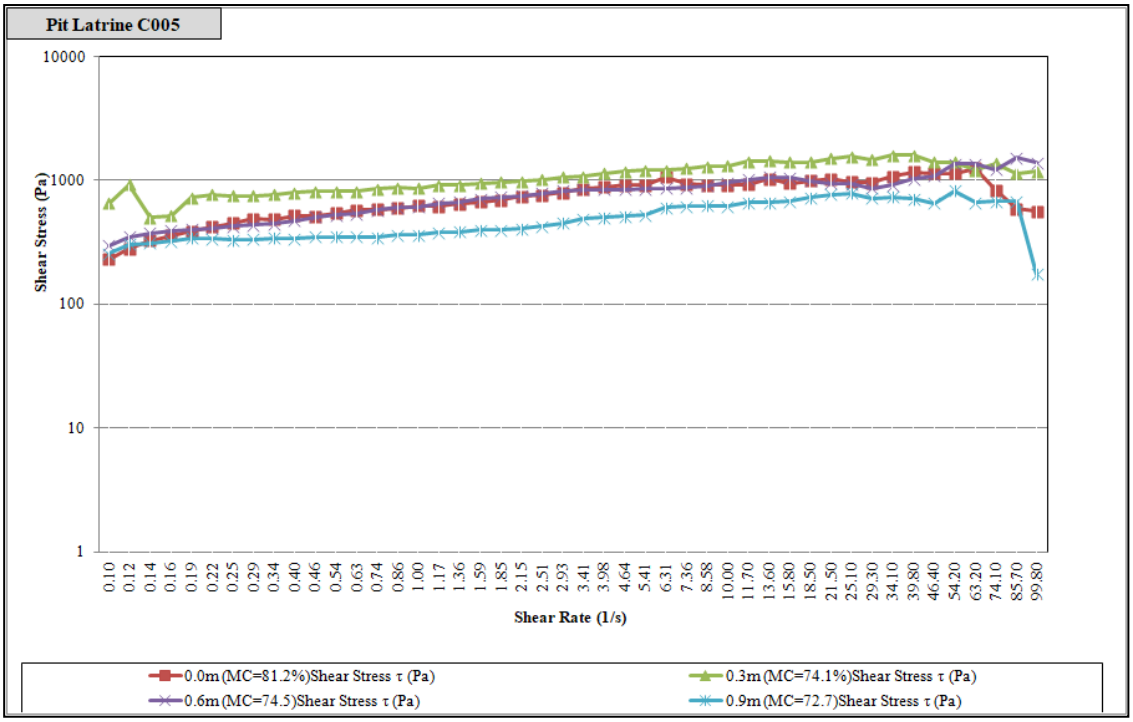

Figure F3-2: Graph of Shear Stress against Shear Rate for samples 6, 7, 8 and 9 from Latrine C005

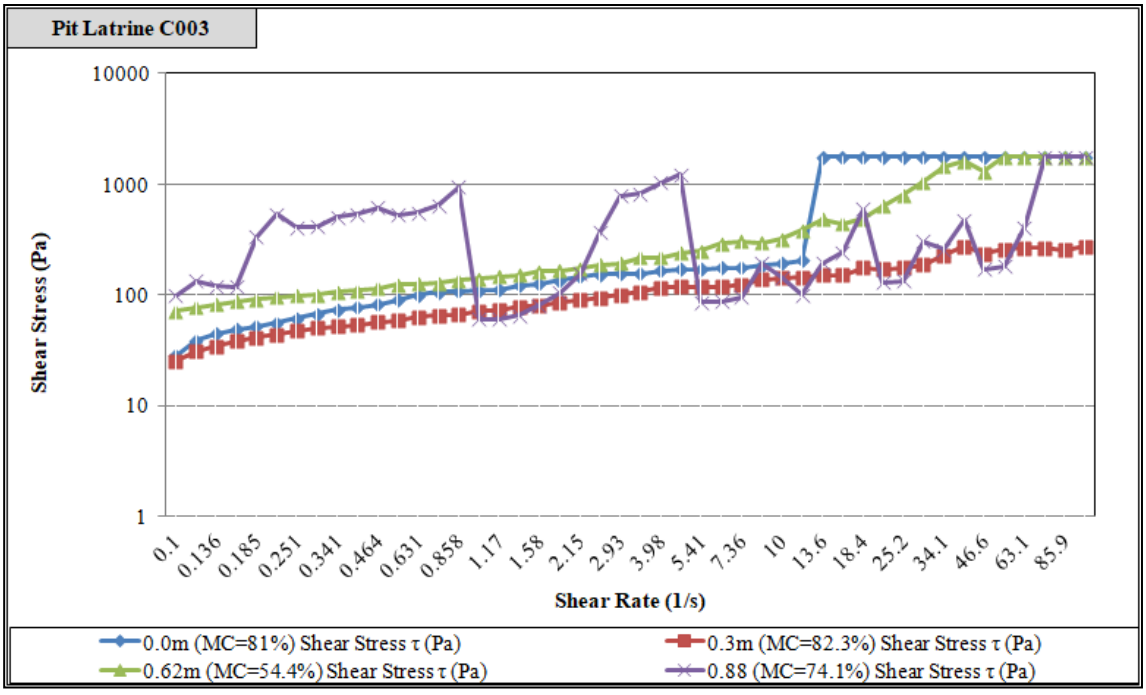

Figure F3-3: Graph of Shear Stress against Shear Rate for samples 10, 11, 12 and 13 from Latrine C003

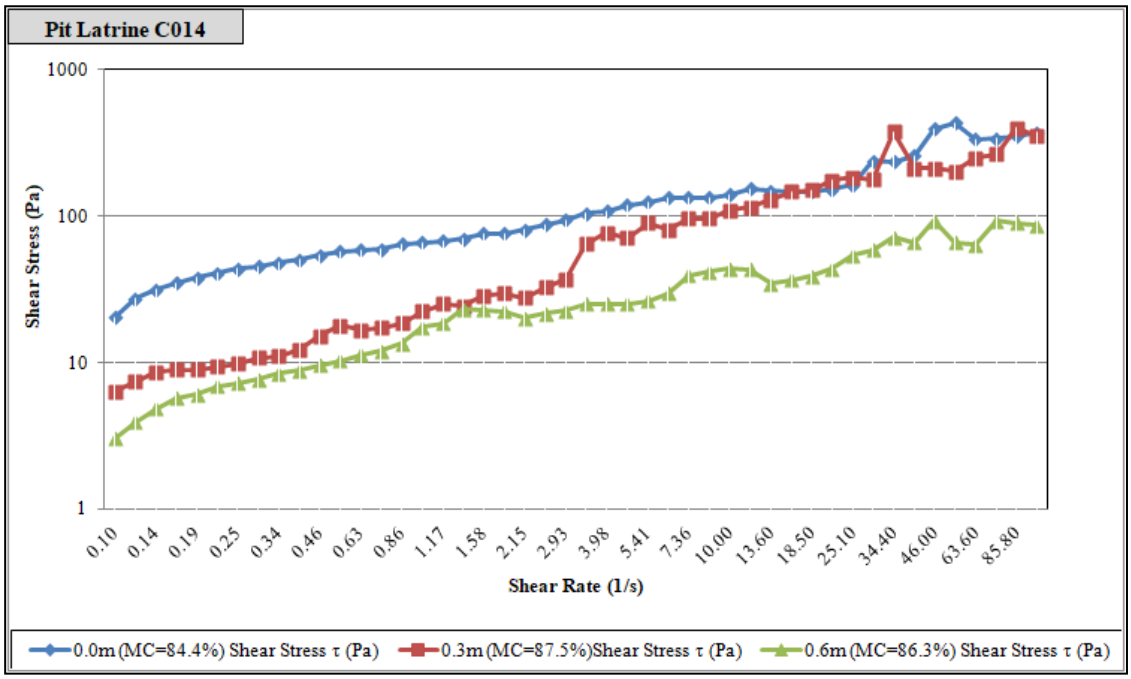

Figure F3-4: Graph of Shear Stress against Shear Rate for samples 14, 15, and 16 from Latrine C014

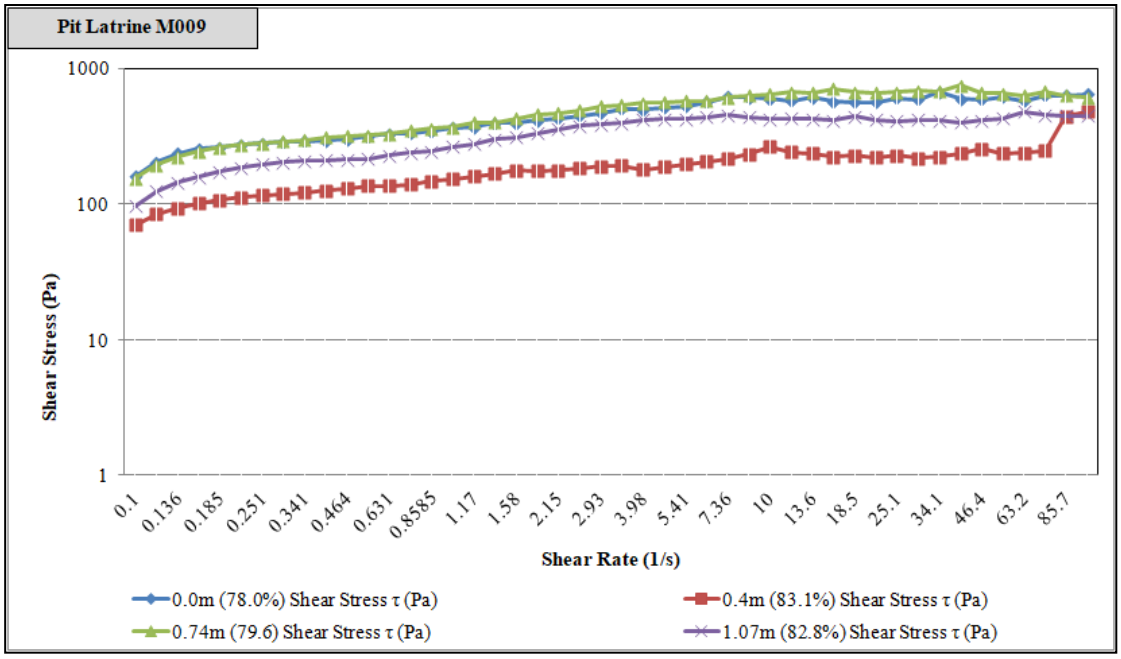

Figure F3-5: Graph of Shear Stress against Shear Rate for samples 17, 18, 19 and 20 from Latrine M009

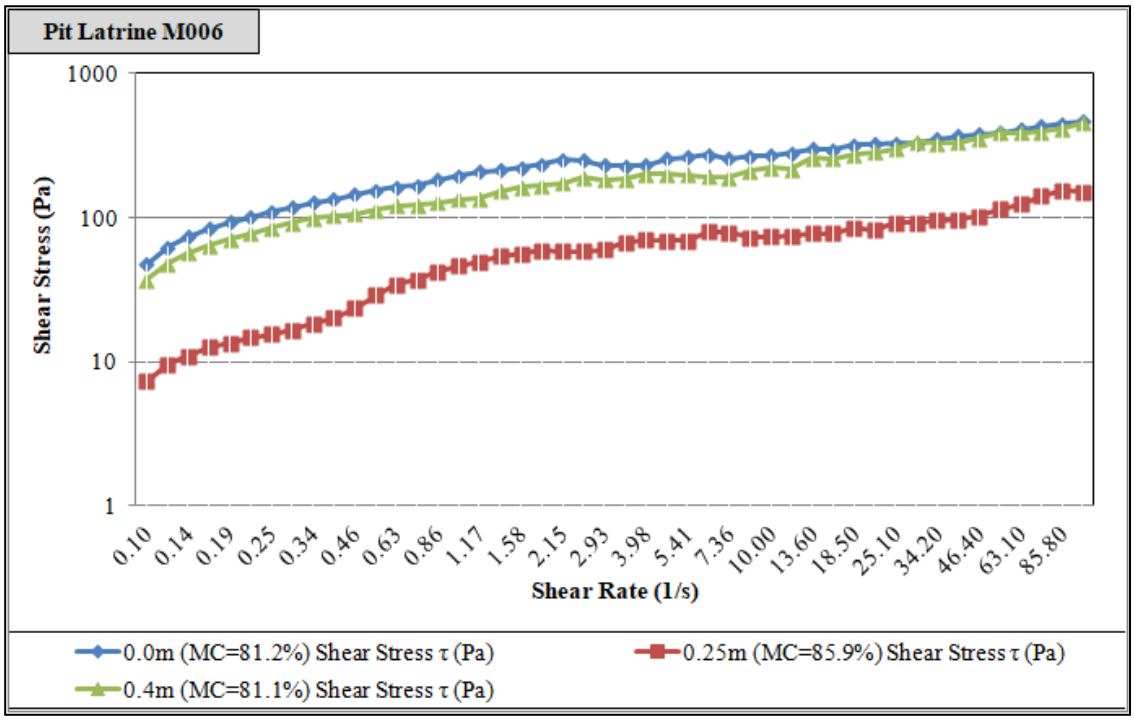

Figure F3-6: Graph of Shear Stress against Shear Rate for samples 21, 22 and 23 from Latrine M006

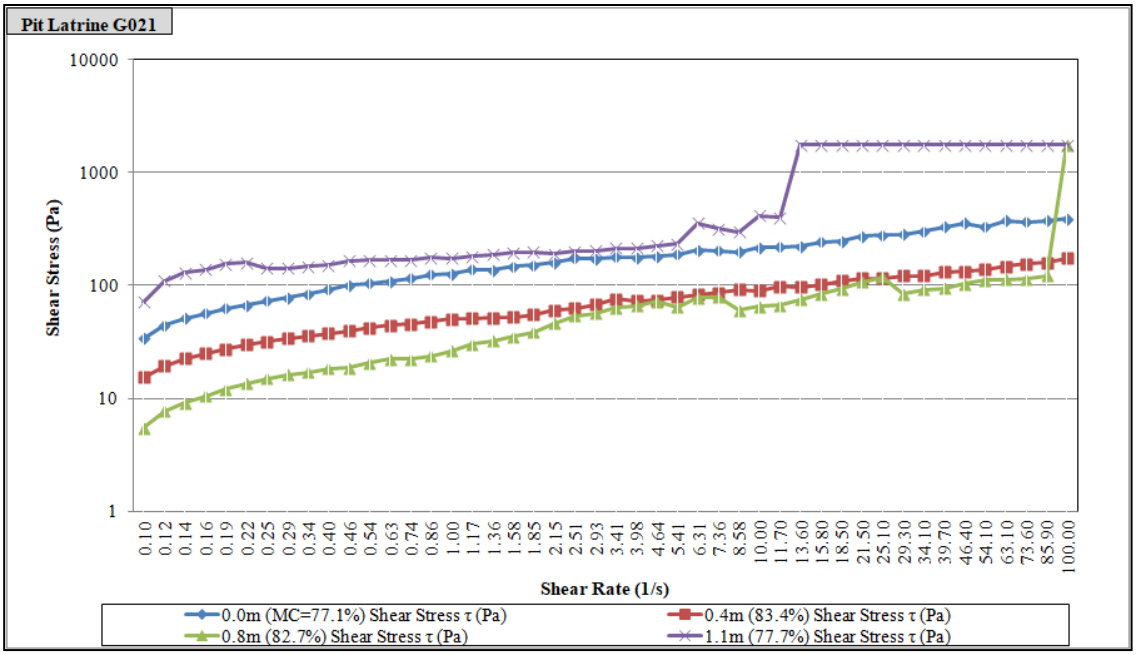

Figure F3-7: Graph of Shear Stress against Shear Rate for samples 24, 25, 26 and 27 from Latrine G021

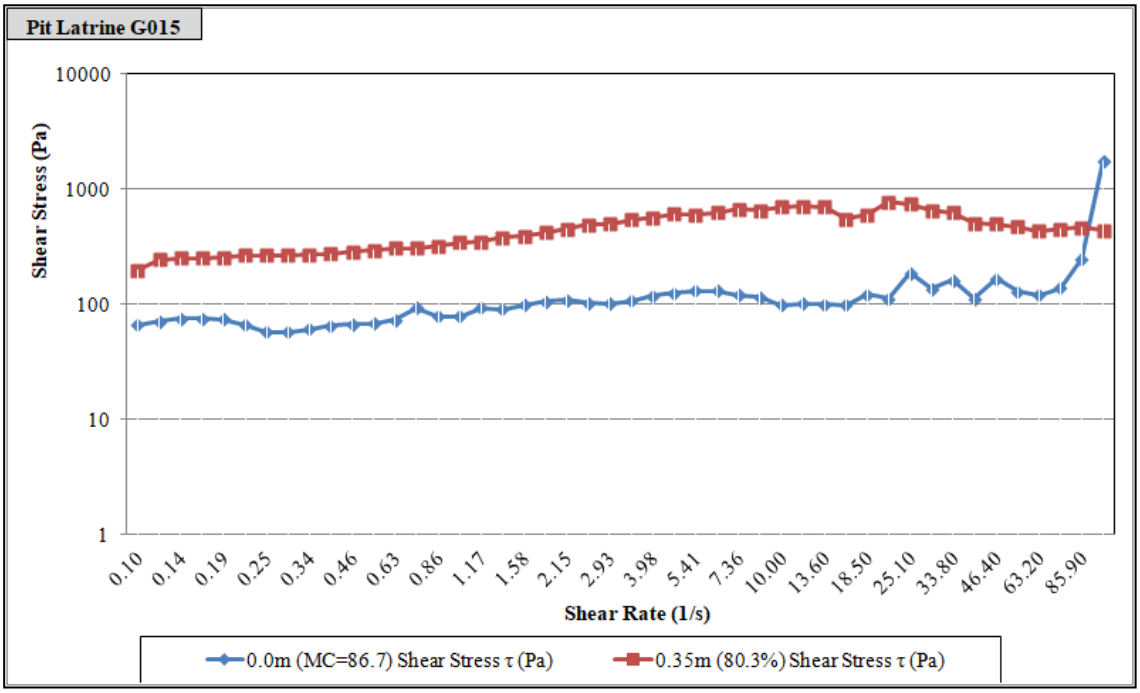

Figure F3-8: Graph of Shear Stress against Shear Rate for samples 28 and 29 from Latrine G015

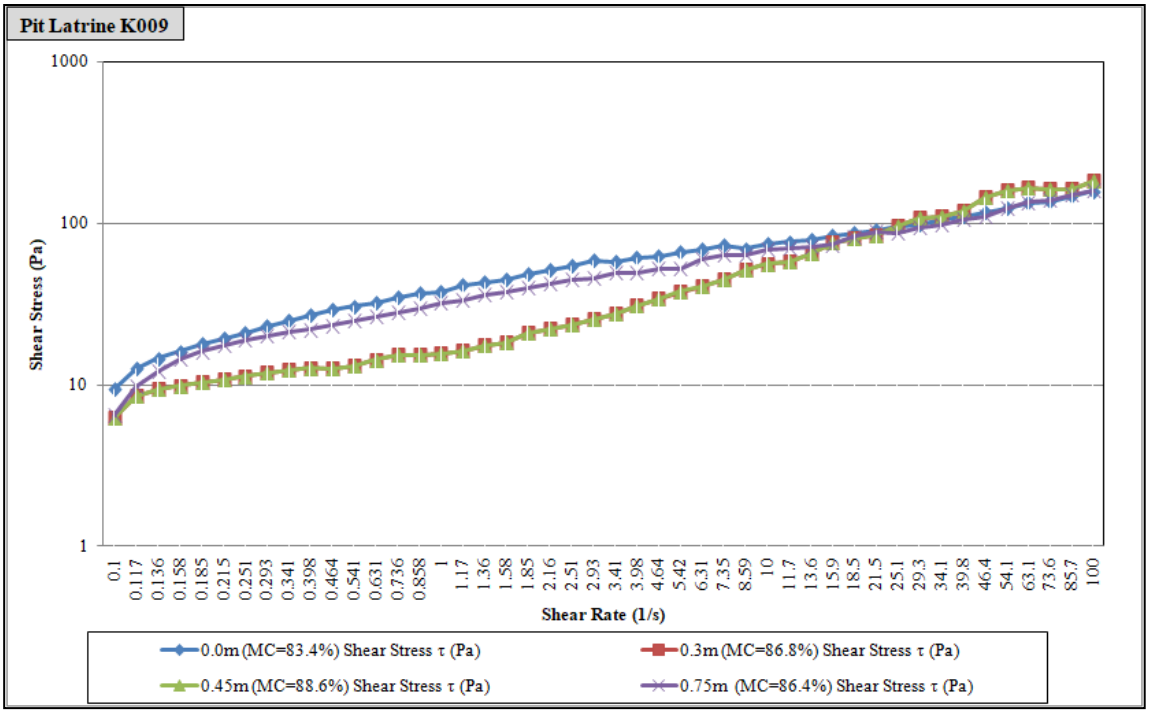

Figure F3-9: Graph of Shear Stress against Shear Rate for samples 30, 31, 32 and 33 from Latrine K009

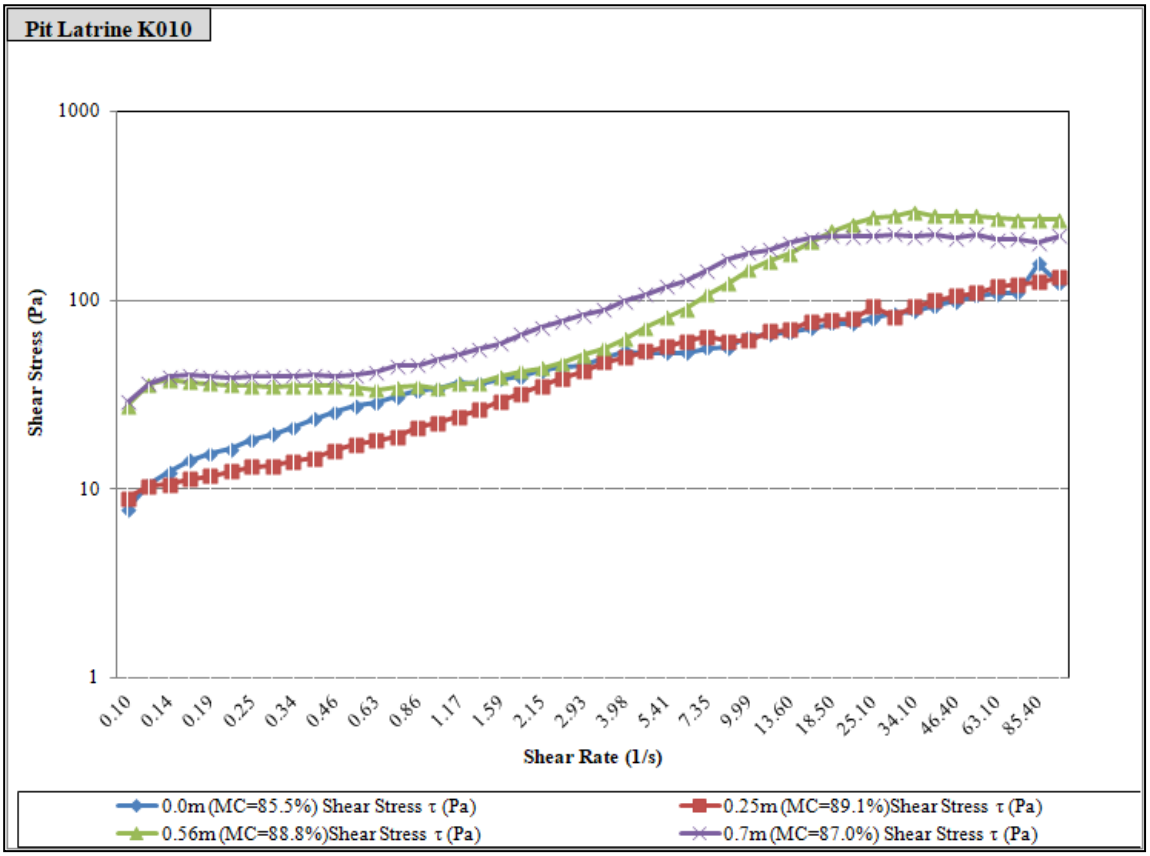

Figure F3-10: Graph of Shear Stress against Shear Rate for samples 34, 35, 36 and 37 from Latrine K010

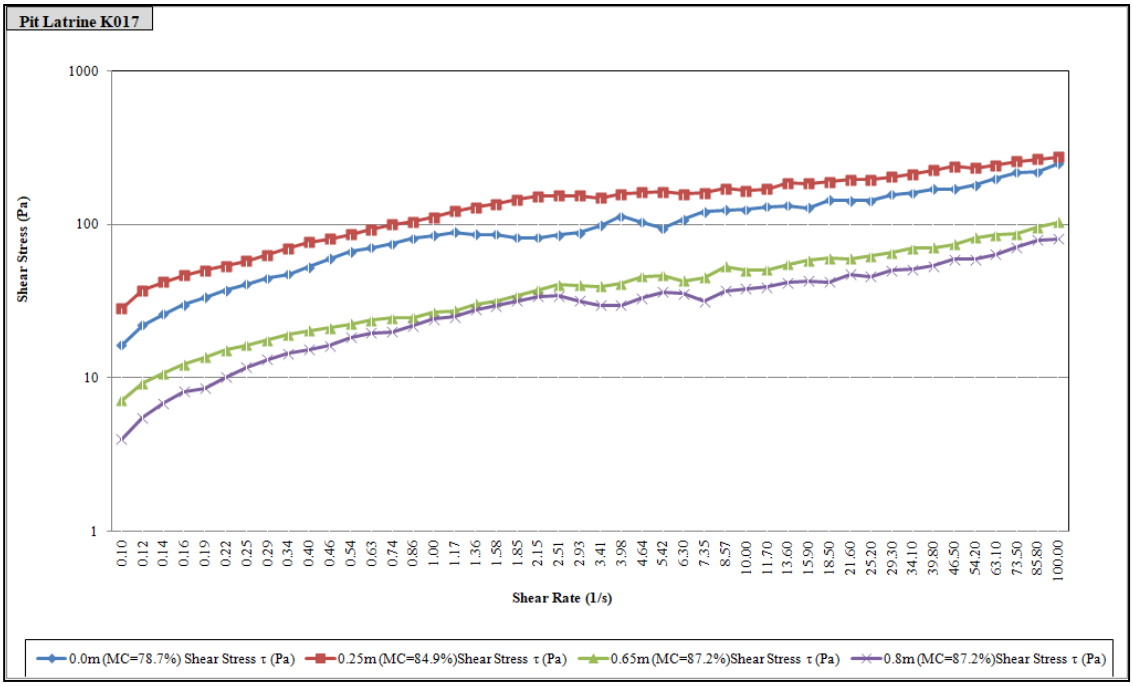

Figure F3-11: Graph of Shear Stress against Shear Rate for samples 38, 39, 40 and 41 from Latrine K017

APPENDIX G: RESULTS FOR THE ANALYSED CHEMICAL PARAMETERS

Table G-1: Results for pH

PIT ID	Mean Top Sludge (-)	STD Dev. Top Sludge	Mean Bottom Sludge (-)	STD Dev. Bottom Sludge
C001	7.3	0.02	7.3	0.02
C002	6.3	0.16	6.9	0.70
C003	6.9	0.06	7.5	0.06
C004	6.6	0.04	6.7	0.07
C005	7.4	0.04	7.8	0.02
C007	6.4	0.08	7.2	0.04
C008	7.2	0.05	7.3	0.03
C011	6.4	0.04	6.6	0.07
C012	7.1	0.04	7.4	0.05
C014	7.4	0.02	7.4	0.26
C015	7.0	0.06	7.4	0.06
C017	6.5	0.06	6.6	0.06
C019	7.0	0.06	7.5	0.11
C020	7.2	0.02	6.9	0.11
C024	7.2	0.03	7.1	0.02
G001	6.5	0.41	7.1	0.30
G002	6.8	0.28	6.5	0.72
G003	6.2	0.07	7.4	0.12
G004	6.5	0.18	6.9	0.17
G012	7.2	0.05	7.1	0.06
G013	6.9	0.07	7.1	0.09
G013	7.0	0.03	7.5	0.19
G014	7.1	0.22	7.0	0.18
G015	6.3	0.17	7.5	0.10
G016	7.4	0.04	7.5	0.05
G017	7.1	0.05	7.7	0.06
G018	6.9	0.05	7.4	0.18
G021	7.3	0.09	7.3	0.13
G023	6.9	0.02	7.3	0.02
G024	7.8	0.05	7.9	0.02
K004	7.5	0.07	7.9	0.10
K005	7.5	0.08	7.7	0.19
K008	7.6	0.24	7.7	0.58
K009	6.4	0.04	7.8	0.07
K010	7.5	0.02	7.5	0.01
K011	8.3	0.27	8.1	0.03
K013	7.1	0.05	7.2	0.06

Table G-1: Continued

PIT ID	Mean Top Sludge (-)	STD Dev. Top Sludge	Mean Bottom Sludge (-)	STD Dev. Bottom Sludge
K014	7.0	0.15	7.6	0.13
K016	7.2	0.06	7.5	0.07
K017	7.4	0.08	8.0	0.04
K019	7.9	0.03	8.1	0.06
K020	7.6	0.15	7.9	0.04
K021	7.9	0.09	7.9	0.06
K023	7.3	0.05	7.5	0.06
K025	6.9	0.06	6.9	0.03
M001	6.7	0.08	7.6	0.14
M004	6.4	0.18	7.1	0.09
M005	7.0	0.02	7.0	0.04
M006	6.9	0.05	7.4	0.10
M007	7.3	0.11	7.7	0.16
M008	7.1	0.08	7.8	0.13
M009	7.8	0.02	7.9	0.07
M010	7.8	0.02	7.9	0.04
M011	7.0	0.02	8.0	0.01
M013	7.2	0.08	7.2	0.07
M014	7.2	0.03	7.8	0.01
M020	7.5	0.49	7.8	0.03
M021	7.6	0.03	7.8	0.08

Table G-2: Results for Total COD

PIT ID	Mean Top Sludge (g/g dry Sample)	STD Dev. Top Sludge	Mean Bottom Sludge (g/g dry Sample)	STD Dev. Bottom Sludge
C001	216,747	37,457	244,480	44,580
C002	192,000	20,955	224,000	69,262
C003	131,413	30,245	50,773	7,278
C004	187,307	20,573	152,747	21,584
C005	84,480	22,318	47,787	8,523
C007	80,640	41,417	74,667	27,163
C008	87,893	35,248	107,093	18,207
C011	74,453	41,798	36,907	19,214
C012	112,853	29,809	122,240	39,056
C014	61,013	18,652	73,813	14,557
C015	176,213	16,106	144,640	42,818
C017	101,973	16,706	145,493	93,976
C019	106,027	11,544	115,413	19,257
C020	152,107	4,115	152,107	5,329
C024	124,160	8,960	134,400	13,845
G001	123,307	19,257	103,253	57,676
G002	99,413	33,484	112,213	10,735
G003	144,640	55,750	81,920	26,635
G004	73,387	14,157	78,080	15,729
G013	119,893	42,556	154,453	74,607
G014	111,787	22,981	143,787	25,643
G015	126,720	15,091	72,533	20,252
G016	77,227	37,325	76,373	19,426
G024	178,347	54,911	169,387	22,549
GO12	85,547	34,018	77,867	14,557
GO13	123,947	27,612	83,413	27,936
GO17	169,600	90,120	105,600	22,207
GO18	114,987	23,752	79,573	16,106
GO21	54,827	19,426	100,480	40,416
GO23	180,267	28,315	134,187	25,992
K004	171,947	52,235	141,653	38,193
K005	121,173	75,121	151,467	41,464
K008	89,600	74,339	77,227	26,890
K009	179,627	49,248	91,307	76,204
K010	158,080	45,273	152,107	67,250
K011	221,227	61,711	213,973	33,922
K013	181,760	18,856	105,387	45,098
K014	100,693	13,074	26,453	14,557

Table G-2: Continued

PIT ID	Mean Top Sludge (g/g dry Sample)	STD Dev. Top Sludge	Mean Bottom Sludge (g/g dry Sample)	STD Dev. Bottom Sludge
K016	148,907	46,931	106,667	55,740
K017	136,107	46,862	55,893	4,846
K019	76,800	10,160	101,973	36,075
K020	240,853	21,659	221,653	89,877
K021	89,387	31,880	141,867	75,621
K023	233,173	87,681	181,120	91,955
K025	314,667	67,006	246,400	84,867
M001	177,920	26,450	69,547	51,269
M004	113,920	16,640	98,560	7,127
M005	156,160	28,247	139,520	12,210
M006	149,760	78,863	97,707	17,752
M007	162,987	81,683	113,067	57,676
M008	89,173	36,324	85,333	10,346
M009	41,813	22,034	68,693	10,425
M010	73,813	41,384	37,973	5,912
M011	22,613	8,229	123,307	19,552
M013	98,133	61,551	55,040	22,500
M014	99,072	21,160	53,333	30,729
M020	134,400	25,213	69,547	50,432
M021	48,640	31,432	72,533	41,146

Table G-3: Results for Soluble COD

PIT ID	Mean Top Sludge (mg/L)	STD Dev Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev Bottom Sludge
C001	116,053	29,149	90,043	5,947
C002	106,027	17,924	56,107	9,713
C003	30,507	2,423	15,573	10,207
C004	136,320	16,454	134,187	14,794
C005	39,467	22,945	14,507	7,821
C007	101,547	17,129	96,853	6,661
C008	36,693	5,367	26,667	4,065
C011	18,453	9,500	16,107	6,216
C012	24,000	10,690	21,440	7,760
C014	31,573	12,216	30,080	10,652
C015	30,933	13,338	16,853	18,989
C017	106,027	10,792	102,827	13,338
C019	24,640	3,200	21,867	4,261
C020	36,800	6,105	34,240	13,069
C024	32,640	19,232	30,720	12,344
G013	119,253	27,604	134,827	36,734
G014	143,573	66,647	88,320	67,395
G015	135,893	32,774	139,947	32,542
G016	96,427	17,554	99,627	17,378
G024	127,360	16,342	133,760	2,308
GO12	37,547	17,717	53,333	16,004
GO13	41,813	23,958	52,267	7,021
GO17	75,947	30,468	49,707	11,128
GO18	56,747	11,128	36,267	6,537
GO21	26,453	10,346	53,333	27,470
GO23	82,773	12,885	40,960	31,685
K004	71,680	14,968	30,293	6,083
K005	54,827	7,021	48,853	17,578
K008	62,507	8,523	29,013	6,083
K009	78,293	57,835	32,640	10,240
K010	44,480	7,994	45,973	8,830
K011	158,400	43,109	111,467	6,843
K013	89,600	8,394	115,840	51,284
K014	48,853	19,054	60,587	5,173
K016	66,773	12,821	26,453	4,261
K017	62,507	9,607	34,347	38,561
K019	27,520	7,127	27,733	7,193
K020	165,653	47,482	129,387	21,441

Table G-3: Continued

PIT ID	Mean Top Sludge (mg/L)	STD Dev Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev Bottom Sludge
K021	24,427	10,886	21,653	8,968
K023	85,440	39,850	58,347	16,706
K025	138,133	24,599	128,747	14,780
M001	80,000	7,864	50,560	17,422
M004	85,547	22,366	56,960	14,664
M005	53,973	16,458	56,320	11,853
M006	43,733	21,123	24,533	5,736
M007	17,280	11,853	18,987	10,886
M008	40,107	5,329	25,387	8,053
M009	31,573	4,261	29,653	1,332
M010	25,173	5,212	5,333	2,587
M011	58,453	5,133	58,453	11,807
M013	65,493	3,695	47,787	8,328
M014	36,693	6,843	26,880	5,866
M020	31,147	5,736	27,307	4,356
M021	35,840	3,893	32,640	1,920

Table G-4: Results for Total BOD

PIT ID	Mean Top Sludge (mg/L)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev. Bottom Sludge
C003	1,600	799	840	662
C004	627	467	773	185
C005	3,573	711	3,107	711
C007	733	220	520	200
C008	2,333	1,329	1,333	1,204
C011	800	106	680	80
C012	773	227	720	400
C014	2,187	323	2,013	911
C015	1,507	711	2,227	1,125
C017	747	335	693	189
C019	680	144	693	201
C020	653	411	973	300
C024	1,467	757	1,667	945
G001	933	260	1,040	120
G002	1,013	205	1,093	197
G003	987	234	800	223
G004	373	284	347	272
G013	853	401	707	295
G014	1,147	300	1,280	243
G015	880	240	907	101
G016	640	356	347	180
G024	387	220	560	349
GO12	827	151	853	115
GO13	987	83	773	167
GO17	667	122	987	361
GO18	827	92	800	240
GO21	613	92	960	174
GO23	853	227	840	139
K004	1,187	172	900	243
K005	946	31	1,053	160
K008	1,193	220	1,000	322
K009	600	53	533	136
K010	840	346	1,187	306
K011	880	144	653	500
K013	580	122	827	232
K014	600	87	540	60
K016	773	436	780	445
K017	533	280	547	162

Table G-4: Continued

PIT ID	Mean Top Sludge (mg/L)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev. Bottom Sludge
K019	1,160	106	687	192
K020	1,240	106	1,147	428
K021	800	320	1,000	139
K023	1,013	260	867	201
K025	1,213	122	813	129
M001	540	72	607	61
M004	1,693	241	1,493	61
M005	1,453	326	1,293	115
M006	1,493	180	1,320	106
M007	1,227	122	1,493	482
M008	1,587	197	960	262
M009	987	162	1,307	227
M010	1,347	244	1,213	244
M011	907	241	907	503
M013	1,053	205	1,227	129
M014	920	183	1,227	189
M020	1,173	23	1,040	69
M021	933	23	1,187	101

Table G-5: Results for Ammonia

PIT ID	Mean Top Sludge (mg/L)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev. Bottom Sludge
C001	2,433	293	1,717	520
C002	2,637	550	2,446	407
C003	1,303	236	1,417	386
C004	287	193	1,167	510
C005	2,423	176	1,564	267
C007	603	526	880	193
C008	1,933	225	1,513	304
C011	420	121	203	35
C012	1,323	75	1,807	258
C014	1,210	560	940	390
C015	1,197	258	2,493	624
C017	630	410	407	60
C019	2,400	1,100	1,863	350
C020	803	278	967	425
C024	1,233	264	1,010	461
G001	2,090	585	3,150	1,843
G002	2,313	1,261	2,180	678
G003	4,067	455	6,810	2,763
G004	2,983	989	2,467	346
G013	673	283	1,363	420
G014	4,703	1,973	5,500	1,210
G015	3,887	257	3,773	781
G016	1,517	585	50	30
G024	1,430	171	1,423	626
GO12	330	87	77	15
GO13	623	254	437	174
GO17	1,527	976	3,027	696
GO18	303	234	803	429
GO21	547	384	1,123	904
GO23	1,357	599	3,457	1,732
K004	6,943	631	6,537	745
K005	3,870	867	6,327	1,378
K008	5,863	929	7,577	2,100
K009	2,283	392	3,903	1,750
K010	1,370	147	1,573	525
K011	1,180	613	1,387	257
K013	4,063	1,690	4,780	696
K014	1,497	441	1,197	519
K016	5,077	1,320	2,797	1,350

Table G-5: Continued

PIT ID	Mean Top Sludge (mg/L)	STD Dev Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev Bottom Sludge
K017	2,380	1,035	2,693	470
K019	3,470	534	3,830	652
K020	1,043	361	1,457	800
K021	1,383	326	1,230	17
K023	1,760	397	2,167	256
K025	1,263	200	1,560	173
M001	833	636	543	127
M004	377	216	643	471
M005	840	494	1,587	716
M006	137	110	847	422
M007	517	359	1,477	687
M008	503	317	820	151
M009	3,513	1,536	2,850	615
M010	450	62	560	553
M011	4,840	429	3,687	881
M013	1,730	538	2,260	1,001
M014	343	247	1,363	725
M020	5,393	3,236	4,307	860
M021	3,673	1,478	3,387	589

Table G-6: Results for Sulphates

PIT ID	Mean Top Sludge (mg/L)	STD Dev Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev Bottom Sludge
C001	4,761	265	4,923	1,189
C002	3,199	1,485	3,997	1,265
C003	10,044	1,918	5,628	2,039
C004	9,339	1,594	8,110	2,057
C005	13,201	5,635	5,653	718
C007	6,328	944	969	411
C008	16,396	5,764	12,035	2,869
C011	7,890	1,083	3,279	1,155
C012	3,843	2,298	14,500	4,479
C014	9,801	1,312	10,915	3,496
C015	19,349	3,437	14,730	1,698
C017	4,613	1,701	5,573	938
C019	4,347	1,558	6,573	2,196
C020	8,893	2,219	7,075	1,118
C024	15,537	586	14,259	3,710
G001	4,071	2,059	2,867	638
G002	6,325	849	2,796	1,704
G003	3,353	475	2,071	1,336
G004	3,184	1,053	2,678	867
G013	5,955	1,053	6,769	503
G014	3,925	1,730	3,641	785
G015	5,509	827	4,713	732
G016	3,491	1,394	1,408	394
G024	5,716	336	8,442	5,033
GO12	9,383	4,144	10,128	1,864
GO13	8,719	2,507	5,115	1,815
GO17	11,262	1,990	7,053	3,354
GO18	11,913	2,658	7,711	506
GO21	7,379	755	8,086	4,451
GO23	14,999	1,808	11,964	2,801
K004	9,768	1,951	2,860	1,102
K005	5,369	916	2,655	406
K008	6,242	2,523	1,928	1,043
K009	5,678	300	2,879	899
K010	7,597	3,823	3,437	1,939
K011	6,323	753	3,944	1,727
K013	11,041	2,758	10,596	1,604
K014	4,297	2,114	1,571	242

Table G-6: Continued

PIT ID	**Mean Top Sludge (mg/L)**	**STD Dev Top Sludge**	**Mean Bottom Sludge (mg/L)**	**STD Dev Bottom Sludge**
K016	8,719	1,429	5,938	841
K017	6,851	1,032	1,622	92
K019	302	46	3,656	1,243
K020	8,810	251	6,429	2,427
K021	1,945	210	1,637	222
K023	13,739	3,385	5,971	1,968
K025	7,005	119	10,845	4,612
M001	13,369	6,792	1,034	835
M004	14,845	1,818	9,025	2,567
M005	16,219	2,476	19,057	581
M006	12,693	2,558	3,967	561
M007	6,515	2,963	2,637	131
M008	18,980	938	5,592	1,431
M009	10,893	4,874	4,730	799
M010	9,335	3,677	4,392	1,561
M011	12,471	2,925	15,758	2,971
M013	13,590	2,806	9,001	1,780
M014	8,197	2,128	2,522	1,020
M020	10,553	3,075	18,776	1,138
M021	8,748	3,434	1,826	598

Table G-7: Results for Phosphates

PIT ID	Mean Top Sludge (mg/L)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev. Bottom Sludge
C001	1,433	183	1,089	342
C002	786	423	1,671	768
C003	1,865	392	373	215
C004	2,290	282	999	375
C005	1,238	289	1,205	44
C007	827	469	207	39
C008	755	62	170	101
C011	812	250	722	438
C012	1,623	240	1,553	828
C014	1,489	554	374	134
C015	1,476	163	1,211	288
C017	1,164	81	976	22
C019	3,292	296	2,639	168
C020	1,850	64	2,166	981
C024	1,280	205	1,449	87
G001	1,407	777	1,289	693
G002	1,283	400	394	122
G003	2,059	495	1,336	83
G004	968	378	755	497
G013	1,054	263	1,551	682
G014	1,016	530	1,164	166
G015	3,261	482	642	485
G016	61	8	980	393
G024	1,569	195	1,701	379
GO12	677	339	623	365
GO13	963	415	656	209
GO17	2,407	416	2,179	258
GO18	2,904	622	2,263	502
GO21	1,850	121	1,957	1,110
GO23	3,448	313	2,638	208
K004	2,489	620	967	666
K005	889	411	1,132	220
K008	1,919	954	570	333
K009	3,780	469	1,405	240
K010	613	193	413	164
K011	2,443	226	2,545	189
K013	3,366	476	4,241	1,710
K014	2,099	202	1,175	353
K016	3,909	189	2,851	55

Table G-7: Continued

PIT ID	Mean Top Sludge (mg/L)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/L)	STD Dev. Bottom Sludge
K017	2,554	244	1,053	59
K019	1,379	629	981	217
K020	2,730	181	2,605	593
K021	658	51	1,348	755
K023	1,375	630	796	334
K025	2,700	486	2,479	575
M001	4,049	432	1,455	293
M004	2,923	356	822	208
M005	2,518	651	1,612	410
M006	1,629	560	656	268
M007	624	108	473	249
M008	708	8	248	16
M009	951	326	820	375
M010	1,015	93	211	16
M011	621	122	582	191
M013	1,628	562	406	264
M014	667	545	606	100
M020	1,981	1,192	852	415
M021	1,617	946	1,398	308

APPENDIX H: RESULTS FOR LIGHT METALS

Table H-1: Results for Potassium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	7,722	4,686	3,257	1,485
C002	9,896	844	9,646	779
C003	16,717	964	17,303	2,632
C004	13,429	2,611	13,820	3,045
C005	11,263	445	15,256	4,176
C007	9,875	3,110	7,281	686
C012	114,573	35,692	115,118	2,068
C014	1,897	141	18,900	4,037
C015	2,368	988	6,658	564
C017	1,166	96	7,968	2,122
C019	40,728	18,180	22,828	6,075
C023	43,484	21,150	10,903	1,627
C024	6,832	2,057	3,831	1,481
G001	23,800	6,243	28,734	9,857
G002	8,050	6,972	8,949	7,814
G003	12,367	4,369	13,316	3,686
G004	7,617	2,076	3,911	878
G012	24,589	6,820	32,125	11,644
G013	9,608	3,583	26,900	12,199
G014	4,779	1,037	46	3
G015	33,967	7,057	9,399	994
G016	12,779	2,381	3,610	1,845
G017	13,011	3,490	42,287	10,903
G018	16,172	5,466	12,610	5,188
G021	4,091	397	9,851	4,311
G024	54,208	29,139	50,379	18,849
K004	1,764	391	12,767	7,700
K005	59,806	16,213	22,752	6,965
K008	15,376	1,591	16,913	6,326
K009	11,717	895	10,018	979
K010	16,955	9,946	11,694	1,037
K011	1,912	160	1,350	268
K013	21,376	3,169	10,671	2,615
K016	10,616	1,417	8,003	576
K017	12,183	1,685	11,097	1,052
K019	6,657	2,222	7,733	1,924
K020	7,451	751	6,717	1,261

Table H-1: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K021	6,366	4,692	10,015	282
K023	7,274	1,648	2,907	498
K025	22,025	8,622	10,228	2,093
M001	24,036	4,397	7,538	804
M004	195,179	132,232	76,747	33,928
M005	14,348	1,027	14,615	5,915
M006	71,274	7,574	23,356	8,584
M007	37,688	10,535	8,791	1,025
M008	96,961	42,942	77,417	22,574
M009	14,956	3,651	74,545	32,006
M010	16,432	2,873	94,657	37,822
M011	7,434	533	10,130	3,361
M013	5,879	956	10,827	5,041
M014	15,199	2,566	15,452	7,666
M020	8,302	2,822	6,029	1,061
M021	18,067	4,929	5,984	1,761

Table H-2: Results for Sodium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	4,667	1,414	2,568	981
C002	2,375	305	1,992	87
C003	3,879	1,245	2,793	634
C004	8,827	2,294	8,174	803
C005	9,919	3,313	12,012	3,437
C007	3,207	1,121	2,556	276
C012	95,600	27,658	92,832	2,145
C014	7,919	5,923	12,095	3,043
C015	7,791	3,668	2,146	423
C017	5,747	883	3,393	222
C019	13,029	5,261	7,875	1,902
C023	40,947	9,117	10,509	2,434
C024	3,073	830	1,723	551
G001	12,387	5,900	13,344	4,256
G002	2,741	2,374	3,017	2,646
G003	8,585	1,733	7,199	2,134
G004	12,978	5,121	5,076	4,322
G012	13,952	11,510	31,148	10,711
G013	6,056	1,624	10,682	8,272
G014	6,794	7,972	691	196
G015	12,201	1,992	3,487	269
G016	4,504	1,112	1,059	277
G017	4,642	1,292	15,257	3,972
G018	5,752	1,645	4,416	1,941
G021	4,232	1,267	8,500	2,355
G024	42,196	21,996	35,051	10,890
K004	4,996	670	4,650	2,265
K005	21,486	4,209	7,515	2,106
K008	8,575	2,435	11,958	1,129
K009	5,832	261	6,778	473
K010	12,525	321	15,388	1,174
K011	7,633	432	6,113	908
K013	7,746	890	3,661	1,171
K016	8,861	697	8,139	173
K017	8,456	1,543	6,361	777
K019	7,270	2,176	6,754	1,573
K020	4,236	599	3,194	362
K021	2,940	639	3,717	58

Table H-2: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	5,731	1,146	2,069	609
K025	8,996	3,943	4,077	587
M001	7,127	1,027	8,303	937
M004	68,067	38,208	36,187	19,367
M005	19,281	3,766	17,317	2,025
M006	49,436	12,006	34,809	12,573
M007	84,122	11,119	15,582	971
M008	164,275	98,267	182,368	143,297
M009	14,888	4,054	91,936	28,971
M010	21,554	7,128	126,087	46,578
M011	3,733	290	4,911	1,403
M013	5,406	1,042	10,699	4,423
M014	9,679	2,046	10,784	9,589
M020	6,189	2,621	9,960	2,060
M021	15,499	2,257	12,599	4,675

Table H-3: Results for Calcium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	5,522	1,900	28,528	8,825
C002	2,405	1,132	2,912	942
C003	4,007	973	3,716	618
C004	5,903	1,307	5,223	2,084
C005	14,323	6,282	7,020	2,676
C007	3,634	2,010	2,335	1,186
C012	160,884	37,881	135,729	10,371
C014	9,347	2,680	10,831	3,221
C015	10,989	1,997	5,127	2,437
C017	7,564	1,438	5,193	1,850
C019	3,347	2,622	2,637	2,130
C023	28,636	7,579	8,960	4,192
C024	1,945	1,133	1,607	1,390
G001	12,347	3,936	11,058	3,097
G002	4,249	994	5,142	3,055
G003	8,429	3,251	5,586	1,622
G004	15,973	7,055	7,325	571
G012	3,037	1,367	5,607	2,497
G013	9,160	5,301	8,345	4,656
G014	10,508	4,496	8,512	1,537
G015	15,750	8,742	3,654	335
G016	2,200	912	1,508	117
G017	1,370	804	5,737	2,898
G018	2,085	195	1,951	986
G021	3,571	1,736	4,838	1,942
G024	10,236	4,454	11,396	4,508
K004	5,923	1,352	14,300	5,961
K005	18,976	9,093	10,642	4,844
K008	4,884	1,426	6,014	1,825
K009	2,449	1,054	2,317	604
K010	8,483	456	3,626	294
K011	1,910	655	6,438	2,994
K013	6,266	4,008	3,264	2,112
K016	3,030	1,303	2,459	1,169
K017	19,518	10,765	12,120	3,998
K019	7,456	2,922	8,102	1,761
K020	2,830	1,382	2,406	529
K021	4,629	3,099	12,388	5,527

Table H-3: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	8,830	3,536	1,956	1,772
K025	2,926	2,075	5,243	3,185
M001	7,196	2,360	8,093	2,174
M004	46,176	23,411	28,675	7,695
M005	19,795	10,601	12,143	1,572
M006	41,972	7,878	22,726	10,204
M007	86,958	20,840	10,948	990
M008	111,290	61,518	124,494	66,085
M009	13,751	4,360	64,826	14,864
M010	11,705	9,071	130,982	29,019
M011	15,021	5,715	9,383	1,994
M013	12,382	1,244	24,996	12,013
M014	3,730	1,222	4,600	2,596
M020	6,305	2,703	5,233	1,975
M021	16,324	2,470	9,070	2,378

Table H-4: Results for Magnesium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	7,214	5,288	274	279
C002	3,121	1,548	4,056	1,125
C003	28,958	2,802	19,455	9,777
C004	4,004	328	5,150	1,816
C005	10,367	2,990	10,186	1,653
C007	3,168	1,067	3,549	974
C012	8,025	8,479	18,140	7,308
C014	7,698	3,284	5,472	580
C015	7,509	1,233	3,280	730
C017	3,447	485	2,670	711
C019	14,864	4,460	9,470	5,152
C023	24,204	4,543	8,322	2,554
C024	6,419	1,543	3,101	1,128
G001	5,702	1,561	6,829	713
G002	2,632	1,869	2,542	1,813
G003	6,414	632	9,312	2,371
G004	7,925	751	6,727	1,467
G012	4,399	3,725	3,782	871
G013	2,964	2,089	8,213	5,156
G014	6,173	2,108	2,280	2,945
G015	17,949	5,385	8,956	2,882
G016	3,829	2,098	1,714	405
G017	7,547	1,206	17,850	1,723
G018	8,051	2,114	6,890	6,329
G021	3,391	2,647	5,309	2,842
G024	17,484	6,629	15,134	3,226
K004	10,558	753	24,107	7,581
K005	29,324	3,781	12,922	11,176
K008	5,138	996	5,374	1,565
K009	4,254	417	4,069	1,203
K010	6,583	265	5,470	1,248
K011	13,771	2,155	14,663	3,624
K013	3,969	1,179	3,583	465
K016	4,402	632	2,988	830
K017	13,504	4,284	6,129	711
K019	4,731	960	6,582	1,024
K020	15,839	1,532	11,969	2,083
K021	7,117	4,687	11,709	1,121

Table H-4: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	5,101	798	1,815	1,390
K025	9,423	2,004	5,574	4,651
M001	10,023	4,181	6,802	2,061
M004	117,394	63,585	40,126	13,279
M005	42,436	41,098	3,211	1,110
M006	38,733	10,063	15,957	6,298
M007	60,287	18,649	5,189	364
M008	33,040	12,465	29,000	22,689
M009	9,588	3,448	67,710	22,641
M010	11,326	2,929	70,065	30,735
M011	12,589	1,688	8,076	5,149
M013	3,052	1,145	5,533	2,972
M014	7,379	515	11,936	11,714
M020	4,108	2,751	1,167	29
M021	7,416	1,576	23,320	29,862

APPENDIX I: RESULTS FOR HEAVY METALS

Table I-1: Results for zinc

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	12.3	10.80	0.0	0.00
C002	3.7	6.48	3.3	3.79
C003	1.3	1.52	6.4	1.40
C004	8.7	3.99	9.8	8.78
C005	0.3	0.51	0.4	0.66
C007	0.0	0.00	0.0	0.00
C012	0.0	0.00	0.0	0.00
C014	0.0	0.00	0.0	0.00
C015	0.0	0.00	0.0	0.00
C017	0.0	0.00	0.0	0.00
C019	0.0	0.00	0.0	0.00
C023	3.3	5.67	3.0	5.24
C024	3.0	5.13	5.4	4.75
G001	26.5	34.15	4.7	4.28
G002	0.0	0.00	0.0	0.00
G003	4.5	5.30	1.4	2.22
G004	1.8	3.19	0.0	0.00
G012	3.0	2.95	6.1	4.02
G013	2.5	4.33	0.0	0.00
G014	0.0	0.00	0.0	0.00
G015	0.0	0.00	0.0	0.00
G016	0.0	0.00	0.0	0.00
G017	0.0	0.00	0.0	0.00
G018	0.0	0.00	0.0	0.00
G021	0.9	1.53	4.0	6.86
G024	0.0	0.00	0.0	0.00
K004	0.0	0.00	0.0	0.00
K005	0.0	0.00	0.0	0.00
K008	32.0	7.31	38.1	12.31
K009	20.1	5.46	17.8	7.97
K010	45.7	7.67	30.4	5.08
K011	0.0	0.00	0.0	0.00
K013	0.0	0.00	0.0	0.00
K016	35.9	19.22	28.4	20.87
K017	0.0	0.00	0.4	0.75
K019	0.0	0.00	8.0	7.10

Table I-1: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K020	0.0	0.00	0.0	0.00
K021	0.0	0.00	0.0	0.00
K023	8.8	15.29	0.0	0.00
K025	0.0	0.00	0.0	0.00
M001	0.0	0.00	8.6	3.19
M004	0.0	0.00	2.4	2.08
M005	6.0	10.36	20.9	17.15
M006	0.0	0.00	4.7	4.31
M007	65.0	21.28	3.2	2.78
M008	134.4	93.28	88.4	83.39
M009	6.8	6.18	13.4	12.48
M010	3.1	3.13	95.9	110.79
M011	0.0	0.00	0.0	0.00
M013	13.4	1.91	12.8	22.18
M014	0.0	0.00	0.0	0.00
M020	12.3	6.65	9.6	6.35
M021	11.7	5.42	5.8	6.02

Table I-2: Results for cadmium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	13.9	19.62	2.8	4.03
C002	1.1	1.55	0.0	0.00
C003	0.3	0.42	3.2	0.86
C004	6.7	5.46	4.1	3.46
C005	3.0	2.27	1.6	2.27
C007	0.0	0.00	0.0	0.00
C012	0.0	0.00	0.0	0.00
C014	0.0	0.00	0.0	0.00
C015	0.0	0.00	0.0	0.00
C017	0.0	0.00	0.7	0.94
C019	0.0	0.00	1.5	2.15
C023	3.0	2.17	1.2	1.75
C024	0.0	0.00	0.9	1.29
G001	1.7	2.08	1.2	1.67
G002	0.0	0.00	0.0	0.00
G003	0.7	0.96	0.8	1.13
G004	0.0	0.00	2.9	4.15
G012	0.0	0.00	2.0	2.87
G013	0.0	0.00	4.7	3.65
G014	1.8	2.58	0.0	0.00
G015	0.0	0.00	0.0	0.00
G016	0.0	0.00	0.0	0.00
G017	0.0	0.00	0.0	0.00
G018	0.0	0.00	0.0	0.00
G021	1.1	1.58	6.9	3.38
G024	2.3	3.19	2.8	3.99
K004	0.0	0.00	0.0	0.00
K005	3.6	5.15	0.0	0.00
K008	0.0	0.00	0.0	0.00
K009	0.0	0.00	0.0	0.00
K010	0.0	0.00	0.0	0.00
K011	0.0	0.00	0.0	0.00
K013	0.0	0.00	3.9	5.53
K016	0.0	0.00	0.0	0.00
K017	4.6	3.57	0.0	0.00
K019	0.6	0.42	1.5	1.93
K020	0.0	0.00	0.0	0.00
K021	1.8	2.48	0.0	0.00

Table I-2: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	2.9	4.15	0.0	0.00
K025	3.1	4.43	4.2	5.96
M001	0.0	0.00	0.0	0.00
M004	23.4	16.56	16.5	14.10
M005	1.1	1.62	0.0	0.00
M006	12.5	11.85	1.4	1.99
M007	0.0	0.00	4.8	3.71
M008	0.0	0.00	120.6	67.56
M009	3.7	5.28	4.4	6.17
M010	1.5	2.15	54.9	39.09
M011	0.0	0.00	0.0	0.00
M013	0.0	0.00	10.7	8.00
M014	1.1	1.53	0.5	0.69
M020	1.9	1.62	0.1	0.19
M021	2.4	1.85	5.6	4.33

Table I-3: Results for cobalt

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	9.3	9.68	4.0	2.85
C002	0.0	0.00	0.0	0.00
C003	0.0	0.00	0.0	0.00
C004	0.0	0.00	0.0	0.00
C005	0.0	0.00	0.0	0.00
C007	1.9	1.88	0.4	0.62
C012	124.3	102.43	44.2	2.07
C014	3.4	2.40	15.4	6.85
C015	5.2	3.79	4.9	2.20
C017	9.0	1.49	2.3	2.23
C019	11.2	15.86	1.7	2.39
C023	0.0	0.00	0.0	0.00
C024	3.9	4.34	1.2	1.66
G001	0.0	0.00	0.0	0.00
G002	4.2	5.87	0.0	0.00
G003	0.0	0.00	0.0	0.00
G004	0.0	0.00	0.9	1.22
G012	0.0	0.00	0.0	0.00
G013	0.0	0.00	0.0	0.00
G014	0.0	0.00	2.5	3.56
G015	0.0	0.00	0.0	0.00
G016	6.4	6.94	1.2	1.71
G017	7.3	4.34	44.6	27.74
G018	1.0	1.35	4.7	4.62
G021	0.0	0.00	0.0	0.00
G024	0.0	0.00	0.0	0.00
K004	10.0	7.59	8.6	2.85
K005	17.9	13.24	0.0	0.00
K008	0.0	0.00	0.0	0.00
K009	0.0	0.00	0.0	0.00
K010	0.0	0.00	0.0	0.00
K011	3.7	1.07	6.6	6.20
K013	3.3	4.67	0.8	1.20
K016	0.0	0.00	0.0	0.00
K017	0.0	0.00	0.0	0.00
K019	0.0	0.00	0.0	0.00
K020	2.2	2.28	1.4	2.03
K021	10.6	3.07	240.3	334.21

Table I-3: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	0.0	0.00	1.4	1.15
K025	27.4	10.02	10.3	5.93
M001	0.0	0.00	0.0	0.00
M004	0.0	0.00	0.0	0.00
M005	0.0	0.00	0.0	0.00
M006	0.0	0.00	0.0	0.00
M007	0.0	0.00	0.0	0.00
M008	0.0	0.00	0.0	0.00
M009	0.0	0.00	0.0	0.00
M010	0.0	0.00	0.0	0.00
M011	27.1	9.67	22.3	23.38
M013	0.0	0.00	0.0	0.00
M014	0.0	0.00	0.0	0.00
M020	0.0	0.00	0.0	0.00
M021	0.0	0.00	0.0	0.00

Table I-4: Results for copper

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	0.00	0.000	0.00	0.000
C002	2.09	1.546	3.69	0.290
C003	8.18	2.918	7.19	0.963
C004	7.00	0.922	7.59	2.693
C005	7.60	3.577	4.30	1.816
C007	0.00	0.000	0.00	0.000
C012	0.00	0.000	0.00	0.000
C014	0.00	0.000	0.00	0.000
C015	0.00	0.000	0.00	0.000
C017	0.00	0.000	0.00	0.000
C019	0.00	0.000	0.00	0.000
C023	0.00	0.000	0.00	0.000
C024	0.00	0.000	0.00	0.000
G001	0.77	1.091	0.00	0.000
G002	0.00	0.000	0.00	0.000
G003	0.00	0.000	0.00	0.000
G004	0.00	0.000	0.00	0.000
G012	0.00	0.000	0.00	0.000
G013	0.00	0.000	0.00	0.000
G014	2.05	2.904	0.00	0.000
G015	0.00	0.000	0.00	0.000
G016	0.00	0.000	0.00	0.000
G017	0.00	0.000	0.00	0.000
G018	0.00	0.000	0.00	0.000
G021	0.00	0.000	0.00	0.000
G024	0.00	0.000	0.00	0.000
K004	0.00	0.000	0.00	0.000
K005	0.00	0.000	0.00	0.000
K008	210.30	7.926	249.60	24.488
K009	115.19	1.398	155.45	5.019
K010	299.81	12.441	345.27	25.544
K011	0.00	0.000	0.00	0.000
K013	0.00	0.000	0.00	0.000
K016	183.34	8.754	182.15	7.387
K017	0.00	0.000	0.00	0.000
K019	0.00	0.000	0.00	0.000
K020	0.00	0.000	0.00	0.000
K021	0.00	0.000	0.00	0.000

Table I-4: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	2.61	3.688	0.00	0.000
K025	0.00	0.000	0.00	0.000
M001	55.78	11.388	10.46	5.958
M004	0.00	0.000	0.00	0.000
M005	0.00	0.000	0.00	0.000
M006	0.00	0.000	0.00	0.000
M007	0.00	0.000	0.00	0.000
M008	0.00	0.000	0.00	0.000
M009	0.00	0.000	0.00	0.000
M010	8.75	12.368	0.00	0.000
M011	0.00	0.000	0.00	0.000
M013	0.00	0.000	0.00	0.000
M014	0.00	0.000	16.67	23.568
M020	4.03	1.002	5.74	4.758
M021	4.00	0.679	6.21	4.493

Table I-5: Results for Iron

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	44.6	13.9	0.0	0.0
C002	39.3	4.4	48.5	2.7
C003	77.8	21.5	106.7	16.6
C004	56.0	4.4	46.3	9.1
C005	48.1	5.2	80.9	7.0
C007	25.5	8.2	21.9	7.2
C012	0.0	0.0	0.0	0.0
C014	0.0	0.0	0.0	0.0
C015	0.0	0.0	0.0	0.0
C017	107.5	14.5	33.6	14.8
C019	100.4	31.1	53.1	24.7
C023	123.0	36.4	44.2	7.0
C024	31.3	19.7	5.1	2.7
G001	75.1	15.5	38.6	22.1
G002	25.4	5.2	51.2	9.1
G003	56.1	25.6	45.4	13.3
G004	142.9	19.8	46.2	7.6
G012	74.8	37.9	74.1	17.3
G013	47.4	6.6	81.7	32.7
G014	74.4	12.0	44.4	11.4
G015	19.9	3.6	24.7	14.0
G016	28.1	14.7	18.3	3.0
G017	17.2	4.4	190.1	18.1
G018	66.4	30.3	31.6	14.9
G021	91.8	27.4	109.1	26.6
G024	94.1	47.3	121.9	53.9
K004	0.0	0.0	0.0	0.0
K005	193.4	94.2	46.1	9.5
K008	498.9	18.8	579.7	76.2
K009	391.3	37.1	417.6	37.0
K010	599.8	7.2	667.3	47.9
K011	0.0	0.0	0.0	0.0
K013	57.5	41.0	0.0	0.0
K016	378.5	18.9	360.2	33.5
K017	90.3	19.0	64.7	10.3
K019	48.4	27.5	16.4	1.3
K020	0.0	0.0	0.0	0.0
K021	0.0	0.0	0.0	0.0

Table I-5: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	15.5	4.9	10.5	4.8
K025	51.3	19.5	39.7	16.3
M001	9.3	2.2	53.1	1.8
M004	1634.2	812.3	636.8	186.7
M005	132.8	11.2	230.0	33.5
M006	708.0	57.1	473.5	168.1
M007	938.7	85.0	280.0	35.8
M008	1603.3	434.1	2710.9	392.9
M009	292.9	53.3	1302.9	410.1
M010	296.3	57.0	1713.0	957.5
M011	0.0	0.0	0.0	0.0
M013	166.1	13.0	434.3	64.8
M014	62.9	9.2	86.9	31.4
M020	37.5	9.7	51.2	7.8
M021	153.0	21.7	106.5	2.3

Table I-6: Results for chromium

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	0.0	0.0	0.0	0.0
C002	0.0	0.0	0.0	0.0
C003	0.0	0.0	0.0	0.0
C004	0.0	0.0	0.0	0.0
C005	0.0	0.0	0.0	0.0
C007	0.0	0.0	0.0	0.0
C012	0.0	0.0	0.0	0.0
C014	0.0	0.0	0.0	0.0
C015	0.0	0.0	0.0	0.0
C017	0.0	0.0	0.0	0.0
C019	0.0	0.0	0.0	0.0
C023	0.0	0.0	0.0	0.0
C024	0.0	0.0	0.0	0.0
G001	0.0	0.0	0.0	0.0
G002	0.0	0.0	0.0	0.0
G003	0.0	0.0	0.0	0.0
G004	0.0	0.0	0.0	0.0
G012	0.0	0.0	0.0	0.0
G013	0.0	0.0	0.0	0.0
G014	0.0	0.0	0.0	0.0
G015	0.0	0.0	0.0	0.0
G016	0.0	0.0	0.0	0.0
G017	0.0	0.0	0.0	0.0
G018	0.0	0.0	0.0	0.0
G021	0.0	0.0	0.0	0.0
G024	0.0	0.0	0.0	0.0
K004	0.0	0.0	0.0	0.0
K005	0.0	0.0	0.0	0.0
K008	0.0	0.0	0.0	0.0
K009	0.0	0.0	0.0	0.0
K010	0.0	0.0	0.0	0.0
K011	0.0	0.0	0.0	0.0
K013	0.0	0.0	0.0	0.0
K016	0.0	0.0	0.0	0.0
K017	0.0	0.0	0.0	0.0
K019	0.0	0.0	0.0	0.0
K020	0.0	0.0	0.0	0.0
K021	0.0	0.0	0.0	0.0

Table I-6: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	0.0	0.0	0.0	0.0
K025	0.0	0.0	0.0	0.0
M001	0.0	0.0	0.0	0.0
M004	0.0	0.0	0.0	0.0
M005	0.0	0.0	0.0	0.0
M006	0.0	0.0	0.0	0.0
M007	0.0	0.0	0.0	0.0
M008	0.0	0.0	0.0	0.0
M009	0.0	0.0	0.0	0.0
M010	0.0	0.0	0.0	0.0
M011	0.0	0.0	0.0	0.0
M013	0.0	0.0	0.0	0.0
M014	0.0	0.0	0.0	0.0
M020	0.0	0.0	0.0	0.0
M021	0.0	0.0	0.0	0.0

Table I-7: Results for Lead

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
C001	0.000	0.000	0.000	0.000
C002	0.000	0.000	0.000	0.000
C003	0.000	0.000	0.000	0.000
C004	0.000	0.000	0.000	0.000
C005	0.000	0.000	0.000	0.000
C007	0.000	0.000	0.000	0.000
C012	0.000	0.000	0.000	0.000
C014	0.000	0.000	0.000	0.000
C015	0.000	0.000	0.000	0.000
C017	0.000	0.000	0.000	0.000
C019	0.000	0.000	0.000	0.000
C023	0.000	0.000	0.000	0.000
C024	0.000	0.000	0.000	0.000
G001	0.000	0.000	0.000	0.000
G002	0.000	0.000	0.000	0.000
G003	0.000	0.000	0.000	0.000
G004	0.000	0.000	0.000	0.000
G012	0.000	0.000	0.000	0.000
G013	0.000	0.000	0.000	0.000
G014	0.000	0.000	0.000	0.000
G015	0.000	0.000	0.000	0.000
G016	0.000	0.000	0.000	0.000
G017	0.000	0.000	0.000	0.000
G018	0.000	0.000	0.000	0.000
G021	0.000	0.000	0.000	0.000
G024	0.000	0.000	0.000	0.000
K004	0.000	0.000	0.000	0.000
K005	0.000	0.000	0.000	0.000
K008	0.000	0.000	0.000	0.000
K009	0.000	0.000	0.000	0.000
K010	0.000	0.000	0.000	0.000
K011	0.006	0.008	0.000	0.000
K013	0.000	0.000	0.000	0.000
K016	0.000	0.000	0.000	0.000
K017	0.000	0.000	0.000	0.000
K019	0.000	0.000	0.000	0.000
K020	0.000	0.000	0.000	0.000
K021	0.000	0.000	0.000	0.000

Table I-7: Continued

PIT ID	Mean Top Sludge (mg/Kg)	STD Dev. Top Sludge	Mean Bottom Sludge (mg/Kg)	STD Dev. Bottom Sludge
K023	0.000	0.000	0.000	0.000
K025	0.000	0.000	0.000	0.000
M001	0.000	0.000	0.000	0.000
M004	0.000	0.000	0.000	0.000
M005	0.000	0.000	0.000	0.000
M006	0.000	0.000	0.000	0.000
M007	0.000	0.000	0.000	0.000
M008	0.000	0.000	0.000	0.000
M009	0.000	0.000	0.000	0.000
M010	0.000	0.000	0.000	0.000
M011	0.000	0.000	0.013	0.018
M013	0.000	0.000	0.000	0.000
M014	0.000	0.000	0.000	0.000
M020	0.000	0.000	0.000	0.000
M021	0.000	0.000	0.000	0.000

APPENDIX J: RESULTS FOR ANALYSED MICROBIOLOGICAL PARAMETERS

Table J-1: Faecal Coliform Results with associated standard deviations

Pit Latrine ID	Top sludge- Mean CFU /100 mL ($x10^9$)	Top sludge STD Dev ($x10^9$)	Bottom sludge, Mean CFU/100 mL ($x10^9$)	Bottom sludge STD Dev ($x10^9$)
C001	8.6	4.4	19.3	2.9
C002	77.5	27.2	79.4	8.8
C003	343.2	31.1	98.4	18.5
C004	1111.8	12.1	146.0	33.3
C005	226.0	5.8	33.7	15.0
C006	455.8	11.3	127.7	21.3
C007	20.9	13.2	175.0	4.6
C008	65.7	9.3	86.2	8.1
C009	148.5	9.1	82.9	12.2
C010	10.7	6.0	36.3	3.3
C011	124.9	11.7	136.7	11.2
C012	80.9	8.4	70.2	9.0
C013	133.6	10.5	110.1	11.6
C014	78.5	2.5	6.2	8.9
C015	0.2	7.3	52.9	0.5
C016	335.6	9.7	94.8	18.3
C017	305.4	21.5	42.5	17.5
C018	9.7	18.4	38.7	3.1
C019	158.5	3.1	9.8	12.6
C020	111.4	8.5	71.9	10.6
C021	205.0	7.8	61.5	14.3
C022	122.9	16.9	284.4	11.1
C023	11.6	11.6	135.0	3.4
C024	9.7	13.1	171.3	3.1
C025	80.2	3.5	12.5	9.0
G001	20.9	3.9	15.4	4.6
G002	56.6	7.5	56.6	7.5
G003	540.6	9.0	81.5	23.3
G004	40.4	6.9	48.0	6.4
G005	17.4	6.5	42.8	4.2
G006	117.4	4.3	18.2	10.8
G007	130.9	13.9	192.3	11.4
G008	149.8	13.3	177.4	12.2
G009	70.1	3.9	15.4	8.4
G010	1.1	0.7	0.4	1.0
G011	5.2	8.5	72.7	2.3
G012	2.6	2.5	6.1	1.6

Table J-1: Continued

Pit Latrine ID	Top sludge- Mean CFU /100 mL ($x10^9$)	Top sludge STD Dev ($x10^9$)	Bottom sludge, Mean CFU/100 mL ($x10^9$)	Bottom sludge STD Dev ($x10^9$)
G013	8.6	1.8	3.2	2.9
G014	13.3	7.2	52.5	3.6
G015	26.1	6.2	38.5	5.1
G016	11.8	3.2	10.4	3.4
G017	257.8	26.7	713.2	16.1
G018	11.8	4.8	23.1	3.4
G019	48.3	3.4	11.8	7.0
G020	40.4	9.4	89.3	6.4
G021	134.0	18.2	329.5	11.6
G022	414.1	11.8	138.3	20.3
G023	974.1	8.7	74.9	31.2
G024	9.7	4.4	19.2	3.1
G025	1095.1	18.9	356.9	33.1
K001	0.0	0.0	0.0	0.0
K002	0.0	0.0	0.0	0.0
K003	0.0	0.0	0.0	0.0
K004	5.8	1.2	1.4	2.4
K005	0.1	1.0	1.0	0.3
K006	0.7	2.1	4.4	0.9
K007	288.1	9.9	97.8	17.0
K008	3.0	2.4	5.8	1.7
K009	0.1	14.2	201.7	0.3
K010	861.9	2.6	6.5	29.4
K011	11.6	1.0	1.0	3.4
K012	0.5	2.6	7.0	0.7
K013	0.0	0.0	0.0	0.0
K014	1.1	4.1	17.2	1.0
K015	34.3	8.2	67.9	5.9
K016	16.7	4.3	18.9	4.1
K017	9.9	1.1	1.3	3.1
K018	3.2	0.9	0.7	1.8
K019	6.9	2.3	5.3	2.6
K020	20.9	2.0	3.9	4.6
K021	48.8	5.8	33.4	7.0
K023	0.0	0.0	0.0	0.0
K024	0.5	10.8	117.6	0.7
K025	9.2	3.8	14.2	3.0
M001	380.8	14.7	216.4	19.5
M002	60.4	3.5	12.2	7.8

Table J-1: Continued

Pit Latrine ID	Top sludge- Mean CFU /100 mL ($x10^9$)	Top sludge STD Dev ($x10^9$)	Bottom sludge, Mean CFU/100 mL ($x10^9$)	Bottom sludge STD Dev ($x10^9$)
M003	462.1	6.6	43.9	21.5
M004	71.1	10.6	112.8	8.4
M005	203.8	4.4	19.5	14.3
M006	82.9	6.2	38.2	9.1
M007	24.6	8.9	79.1	5.0
M008	120.1	9.3	86.5	11.0
M009	96.9	9.3	85.8	9.8
M010	33.1	8.1	65.7	5.8
M011	0.0	4.5	20.6	0.0
M012	63.6	2.6	6.8	8.0
M013	55.1	11.0	121.7	7.4
M014	61.5	10.8	115.9	7.8
M015	67.2	10.3	106.6	8.2
M016	11.2	4.3	18.7	3.4
M017	42.1	3.8	14.6	6.5
M018	135.0	2.9	8.7	11.6
M019	202.3	11.1	123.3	14.2
M020	200.1	8.5	73.0	14.1
M021	608.7	12.8	163.3	24.7

Table J-2: Total Ascaris Results with associated standard deviations

Pit ID	Top sludge- Mean Total Ascaris (No./g)	Top sludge STD Dev	Top sludge- Mean Total Ascaris (No./g)	Bottom sludge STD Dev
C001	0	0	0	0
C002	14	20	0	0
C003	0	0	0	0
C004	0	0	0	0
C005	79	87	41	34
C006	100	141	0	0
C007	471	112	683	85
C008	60	61	85	39
C009	0	0	0	0
C010	14	20	138	116
C011	224	36	50	48
C012	0	0	13	18
C013	0	0	0	0
C014	0	0	0	0
C015	30	43	0	0
C016	417	232	167	73
C017	0	0	0	0
C018	0	0	0	0
C019	26	18	72	70
C020	106	69	56	79
C021	42	59	89	47
C022	449	99	263	112
C023	0	0	0	0
C024	0	0	0	0
C025	0	0	0	0
G001	98	93	214	138
G002	0	0	0	0
G003	0	0	0	0
G004	0	0	0	0
G005	0	0	0	0
G006	36	29	14	20
G007	45	64	58	51
G008	0	0	0	0
G009	0	0	0	0
G010	301	72	128	96
G011	26	36	260	104
G012	97	89	154	218
G013	54	45	46	5
G014	0	0	0	0
G015	88	41	0	0
G016	62	56	0	0
G017	0	0	0	0
G018	126	91	69	52
G019	0	0	0	0
G020	121	171	59	57
G021	0	0	14	20
G022	130	69	112	44
G023	169	169	93	55

Table J-2: Continued

Pit ID	Top sludge- Mean Total Ascaris (No./g)	Top sludge STD Dev	Top sludge- Mean Total Ascaris (No./g)	Bottom sludge STD Dev
G024	83	62	0	0
G025	0	0	47	37
K001	14	20	0	0
K002	0	0	0	0
K003	0	0	0	0
K004	57	19	17	24
K005	51	73	75	54
K006	13	18	31	22
K007	57	19	14	20
K008	14	20	17	24
K009	0	0	383	542
K010	33	47	34	24
K011	14	20	24	34
K012	0	0	0	0
K013	0	0	0	0
K014	0	0	0	0
K015	185	262	0	0
K016	14	20	39	5
K017	0	0	43	9
K018	168	103	117	87
K019	0	0	0	0
K020	0	0	0	0
K021	0	0	0	0
K022	69	71	33	47
K023	0	0	0	0
K024	13	18	30	43
K025	0	0	33	47
M001	0	0	130	37
M002	61	86	12	17
M003	181	227	222	157
M004	0	0	0	0
M005	340	210	67	62
M006	52	44	67	94
M007	297	225	128	181
M008	0	0	0	0
M009	30	43	17	24
M010	0	0	0	0
M011	0	0	0	0
M012	0	0	0	0
M013	0	0	0	0
M014	0	0	0	0
M015	0	0	0	0
M016	0	0	0	0
M017	0	0	0	0
M018	0	0	0	0
M019	90	127	30	43
M020	126	89	378	95
M021	76	107	0	0

Table J-2: Continued

Pit ID	Top sludge- Mean Total Ascaris (No./g)	Top sludge STD Dev	Top sludge- Mean Total Ascaris (No./g)	Bottom sludge STD Dev
M022	0	0	0	0
M023	0	0	0	0
M024	0	0	0	0
M025	0	0	0	0

Table J-3: Cryptosporidium Results with associated standard deviations

Pit ID	Top Sludge Mean *Cryptosporidium* Count No./g	Top STD Dev	Bottom Sludge Mean *Cryptosporidium* Count No./g	Bottom STD Dev
C001	1065	193	600	121
C002	161	8	48	45
C003	2958	326	1323	447
C004	190	86	40	34
C005	248	145	124	91
C006	645	168	249	114
C007	4810	365	4417	514
C008	533	236	138	51
C009	0	0	0	0
C010	581	213	184	114
C011	481	26	240	83
C012	1476	417	955	131
C013	428	70	270	136
C014	15	21	0	0
C015	725	124	218	117
C016	1367	347	530	102
C017	0	0	14	20
C018	77	63	0	0
C019	859	244	552	41
C020	897	208	66	49
C021	572	122	442	91
C022	3287	337	2295	336
C023	15	21	0	0
C024	618	86	121	69
C025	988	258	265	60
G001	2693	784	2139	307
G002	694	143	136	73
G003	826	286	911	204
G004	909	303	542	59
G005	4077	505	3318	724
G006	1595	110	968	168
G007	1312	203	1449	74
G008	882	177	622	79
G009	1399	308	478	91
G010	0	0	0	0
G011	1853	141	260	104
G012	570	136	205	78
G013	288	159	0	0
G014	97	71	13	18
G015	1989	222	1306	191
G016	721	109	0	0
G017	2521	206	757	155
G018	605	174	173	125
G019	82	63	0	0
G020	619	143	132	94
G021	6542	1405	3808	191
G022	139	111	17	24

Table J-3: Continued

Pit ID	Top Sludge Mean *Cryptosporidium* Count No./g	Top STD Dev	Bottom Sludge Mean *Cryptosporidium* Count No./g	Bottom STD Dev
G023	495	389	388	127
G024	0	0	0	0
G025	2557	14	1808	66
K001	678	195	244	78
K002	464	469	374	295
K003	122	102	273	223
K004	28	39	83	62
K005	282	48	322	165
K006	92	79	183	94
K007	265	257	147	88
K008	286	204	557	168
K009	371	149	225	162
K010	67	94	129	112
K011	79	63	15	21
K012	0	0	0	0
K013	50	48	167	143
K014	991	271	445	316
K015	139	31	119	88
K016	275	134	378	70
K017	878	116	666	82
K018	300	424	333	471
K019	226	66	125	59
K020	200	75	61	46
K021	82	63	50	71
K022	463	94	159	50
K023	479	161	178	66
K024	267	88	205	152
K025	11987	1459	10000	14142
M001	736	473	534	188
M002	441	93	60	33
M003	15	21	0	0
M004	472	171	359	176
M005	407	206	467	103
M006	0	0	3056	2187
M007	308	59	440	311
M008	581	415	192	94
M009	1647	1908	603	455
M010	434	227	190	197
M011	221	102	379	121
M012	5538	565	2784	874
M013	1003	171	772	165
M014	417	231	432	341
M015	1522	450	1235	199
M016	950	71	287	170
M017	583	181	317	266
M018	774	225	183	131
M019	389	104	191	71

Table J-3: Continued

Pit ID	Top Sludge Mean *Cryptosporidium* Count No./g	Top STD Dev	Bottom Sludge Mean *Cryptosporidium* Count No./g	Bottom STD Dev
M020	926	278	896	277
M021	361	312	0	0
M022	0	0	0	0
M023	0	0	0	0
M024	712	103	350	178
M025	28	39	0	0

APPENDIX K: GRAPHICAL PRESENTATION FOR PHYSICAL AND CHEMICAL PARAMETERS

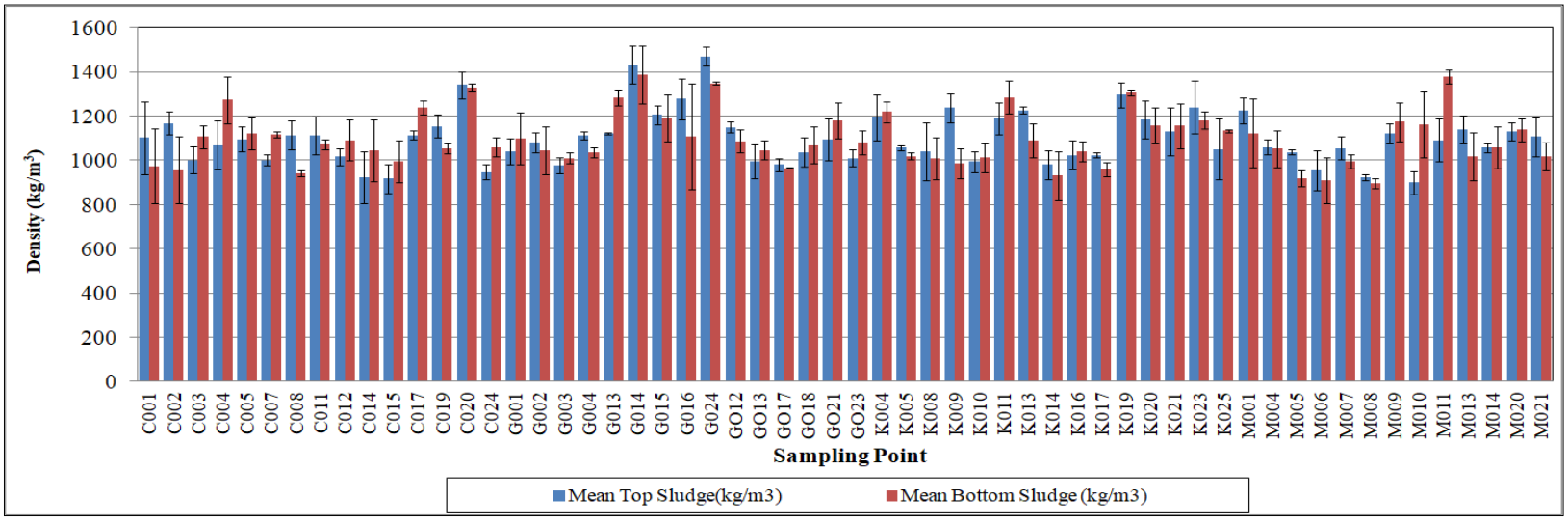

Figure K-1: Density results for the sludge from the top and bottom layers of respective pit latrines.

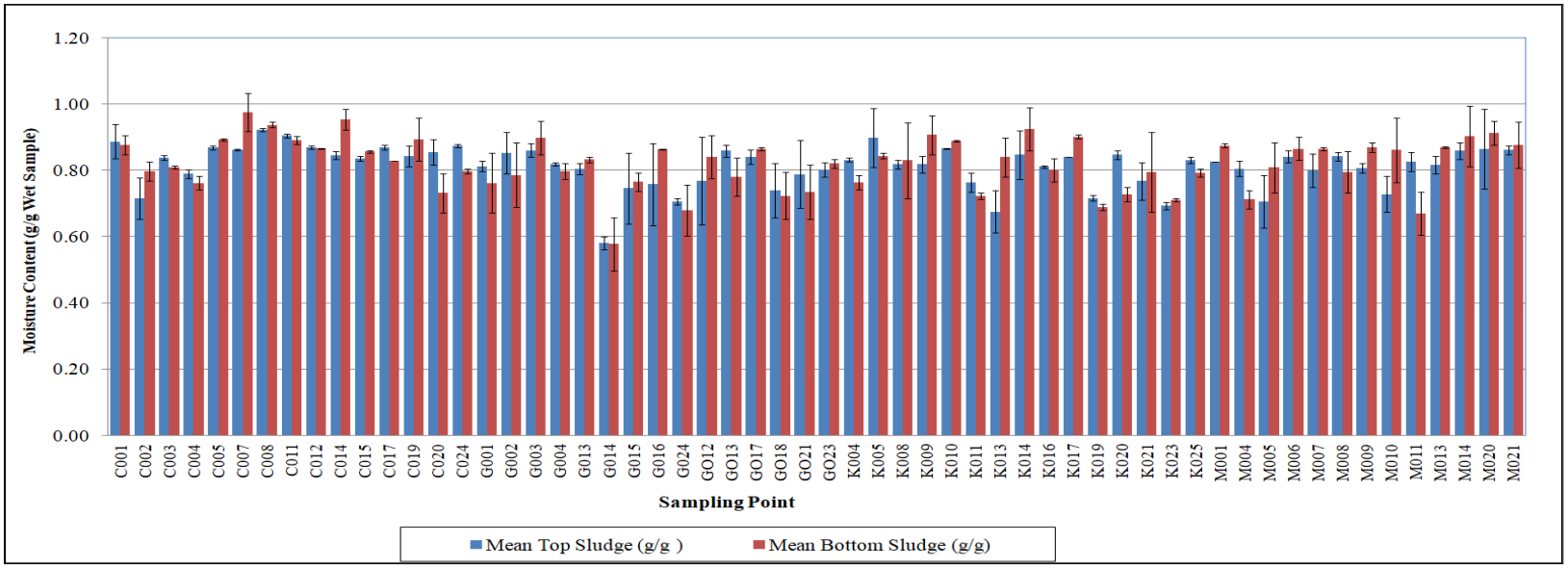

Figure K-2: Moisture Content results for the sludge from the top and bottom layers of respective pit latrines.

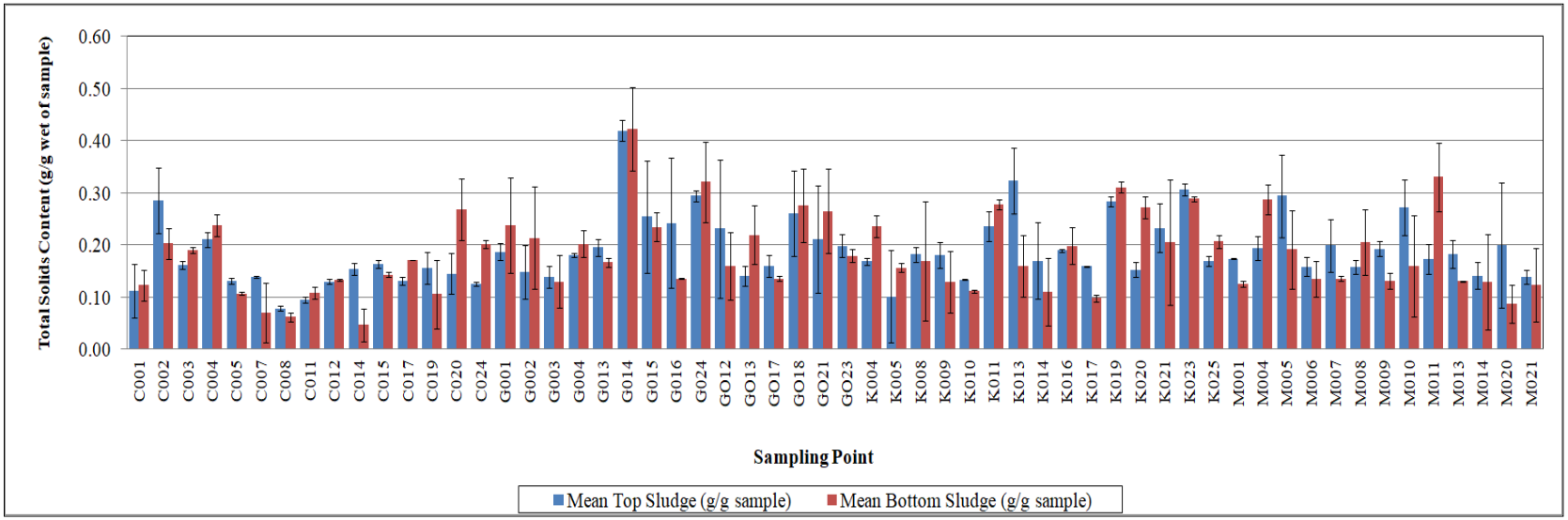

Figure K-3: Total Solids results for the sludge from the top and bottom layers of respective pit latrines.

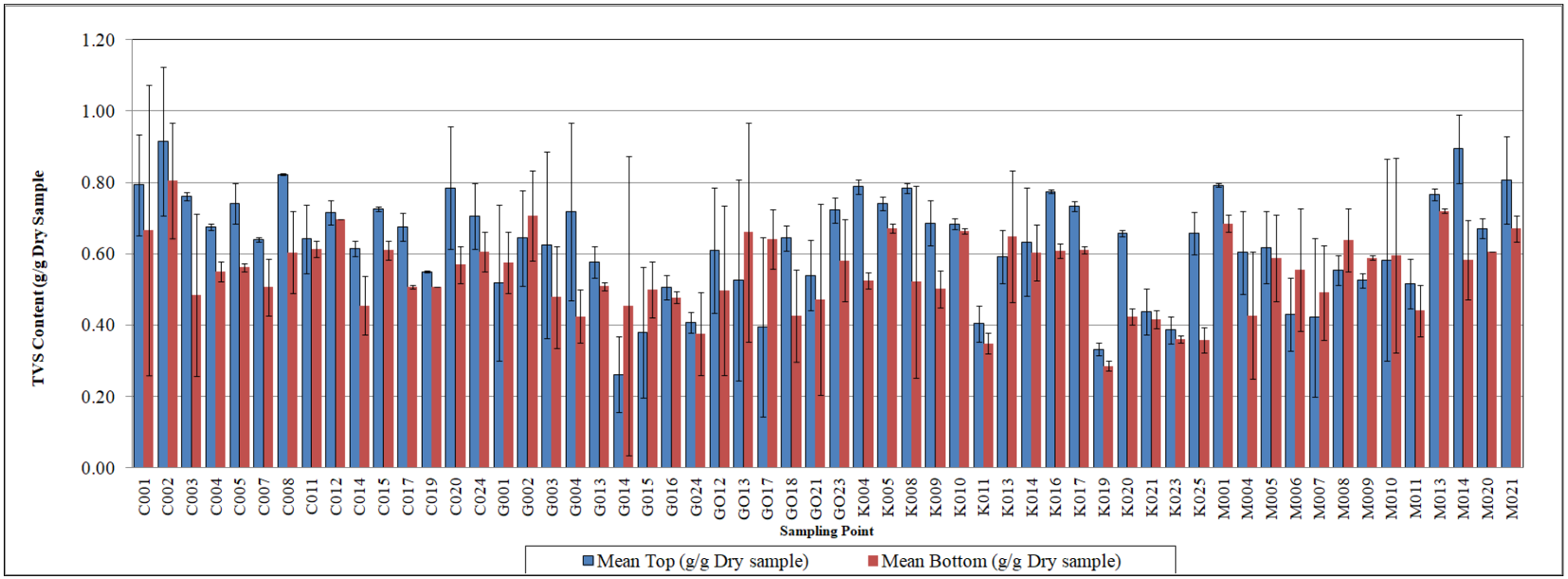

Figure K-4: Total Volatile Solids results for the sludge from the top and bottom layers of respective pit latrines.

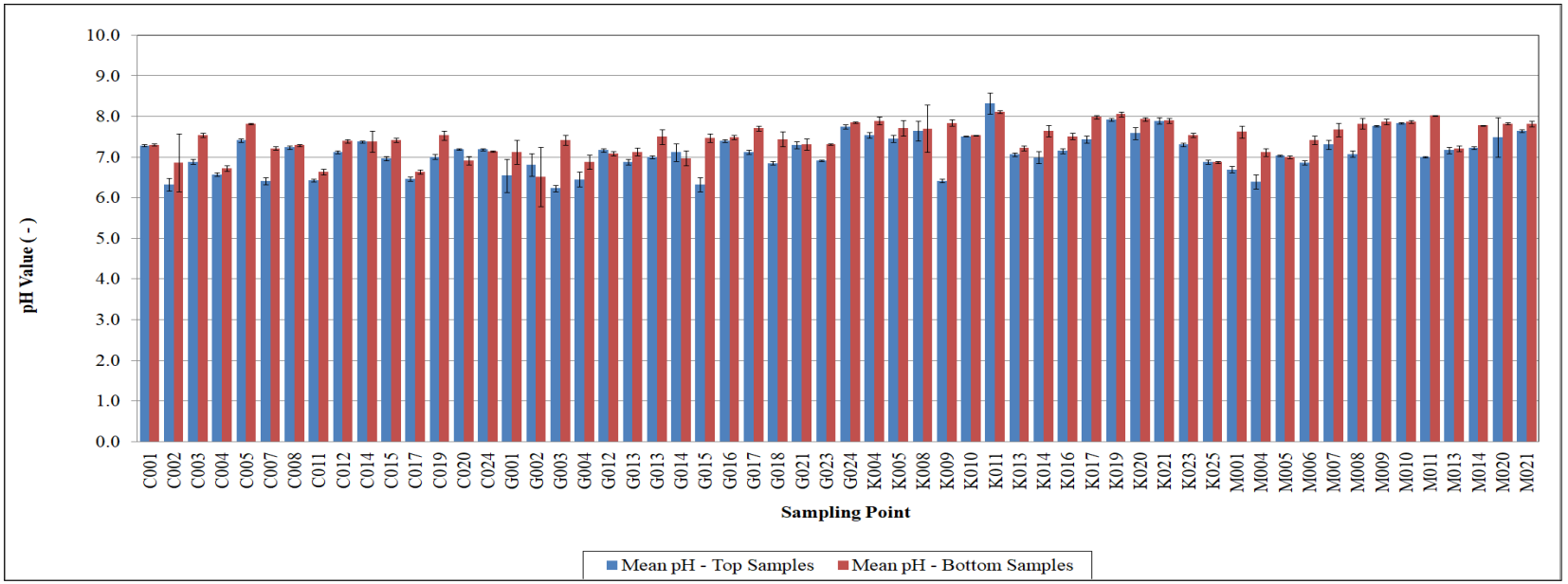

Figure K-5: pH results for the sludge from the top and bottom layers of respective pit latrines.

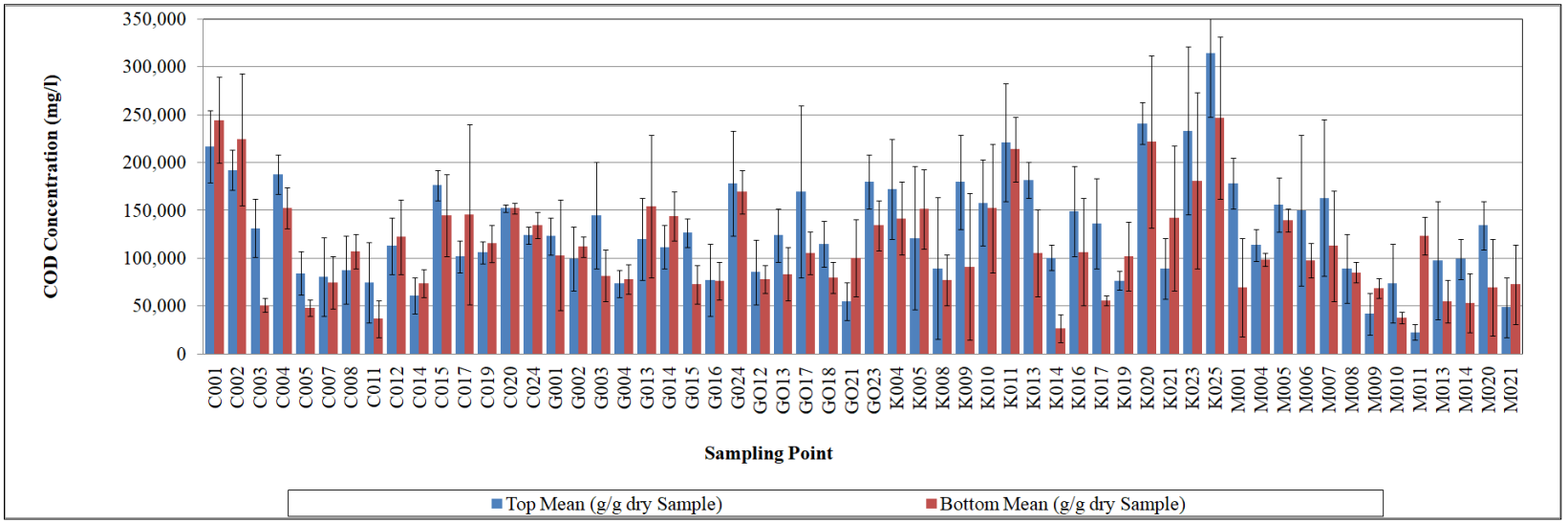

Figure K-6: Total COD results for the sludge from the top and bottom layers of respective pit latrines.

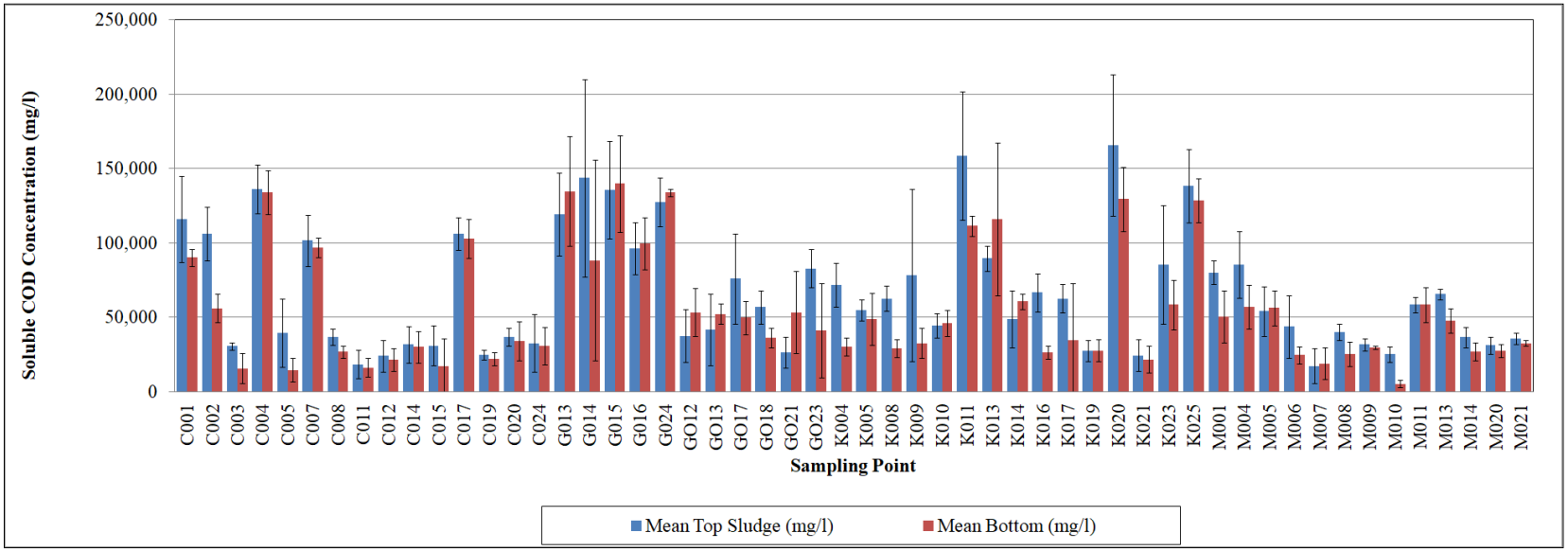

Figure K-7: Soluble COD results for the sludge from the top and bottom layers of respective pit latrines.

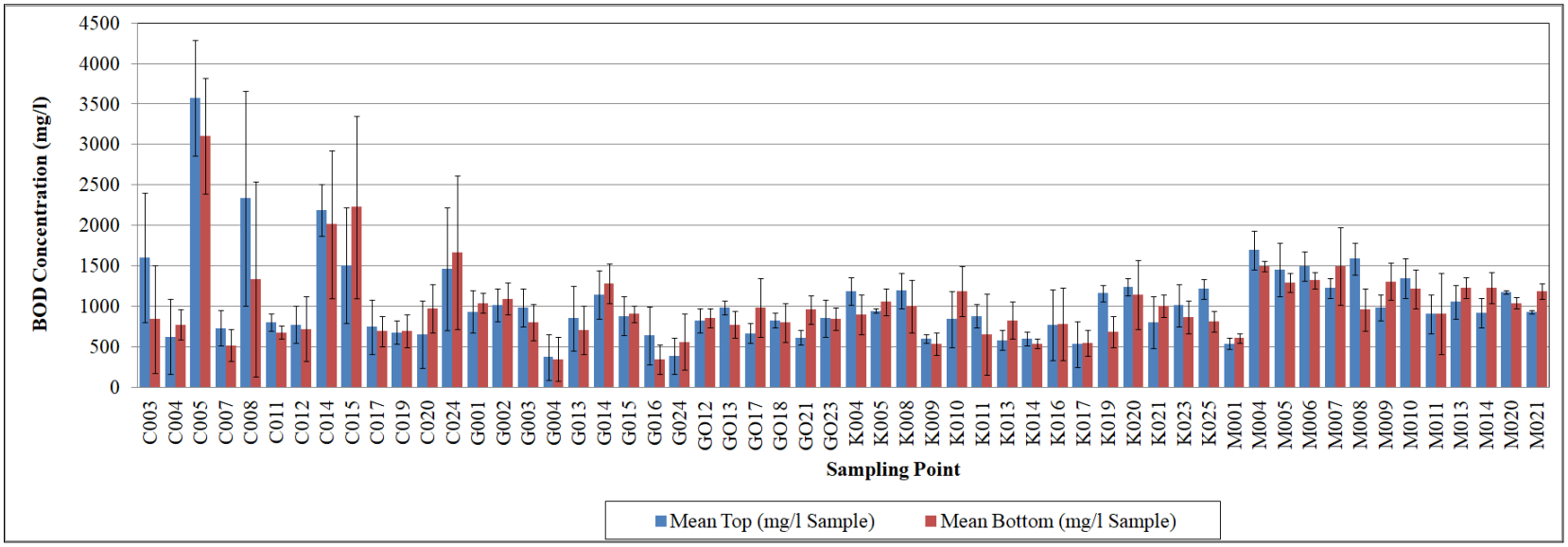

Figure K-8: Total BOD results for the sludge from the top and bottom layers of respective pit latrines.

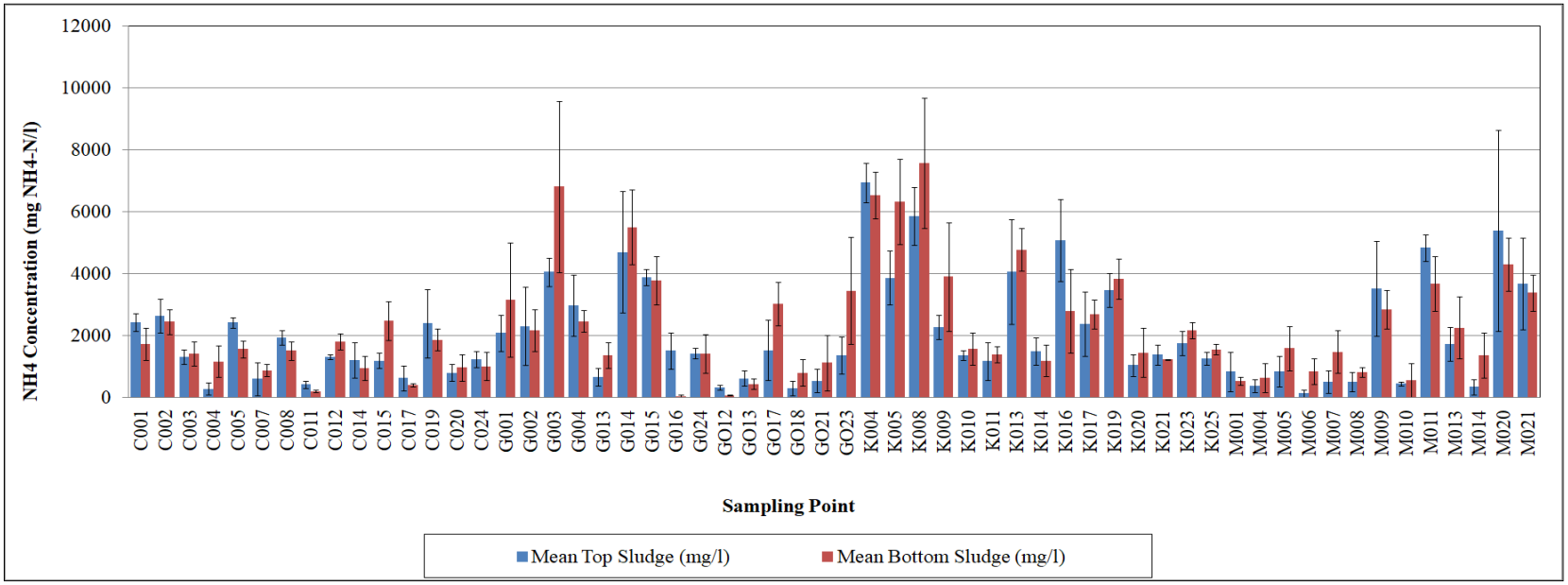

Figure K-9: Ammonia results for the sludge from the top and bottom layers of respective pit latrines.

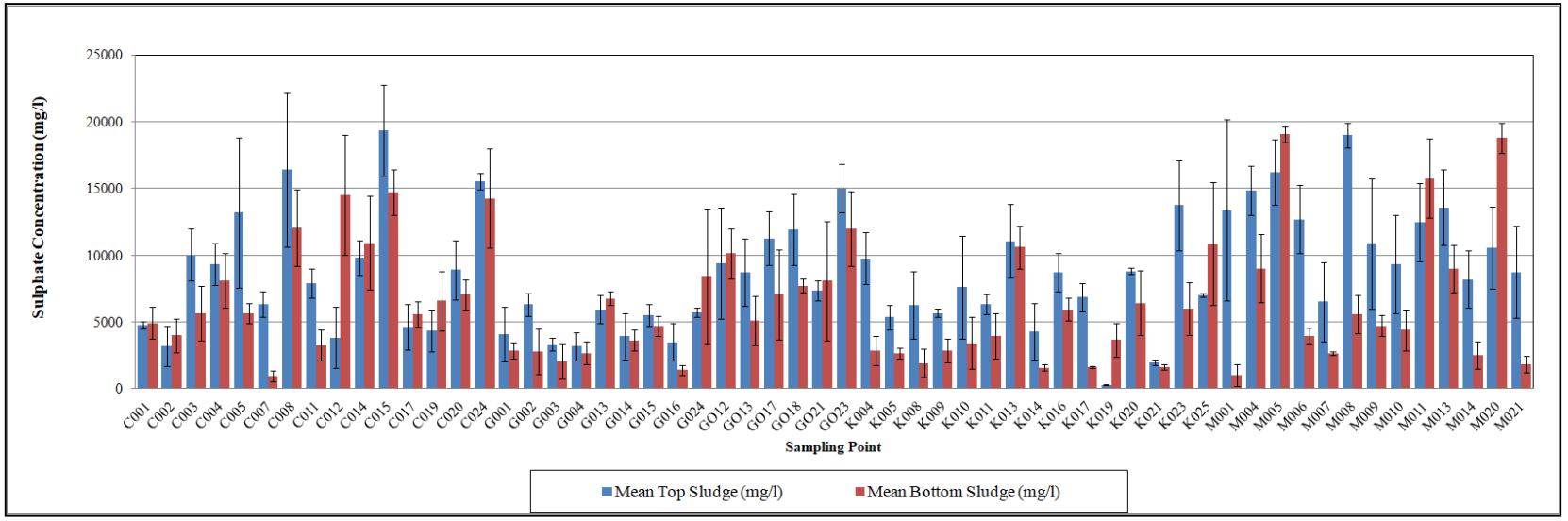

Figure K-10: Sulphate results for the sludge from the top and bottom layers of respective pit latrines.

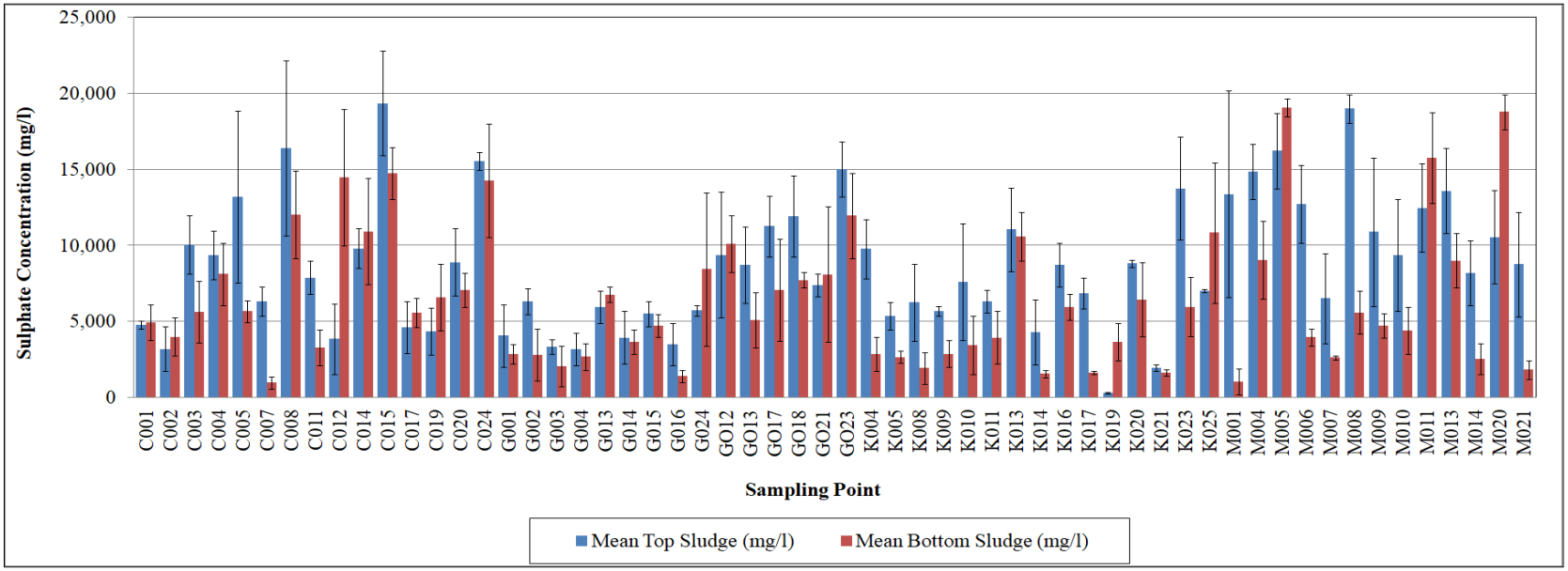

Figure K-11: Phosphate results for the sludge from the top and bottom layers of respective pit latrines.

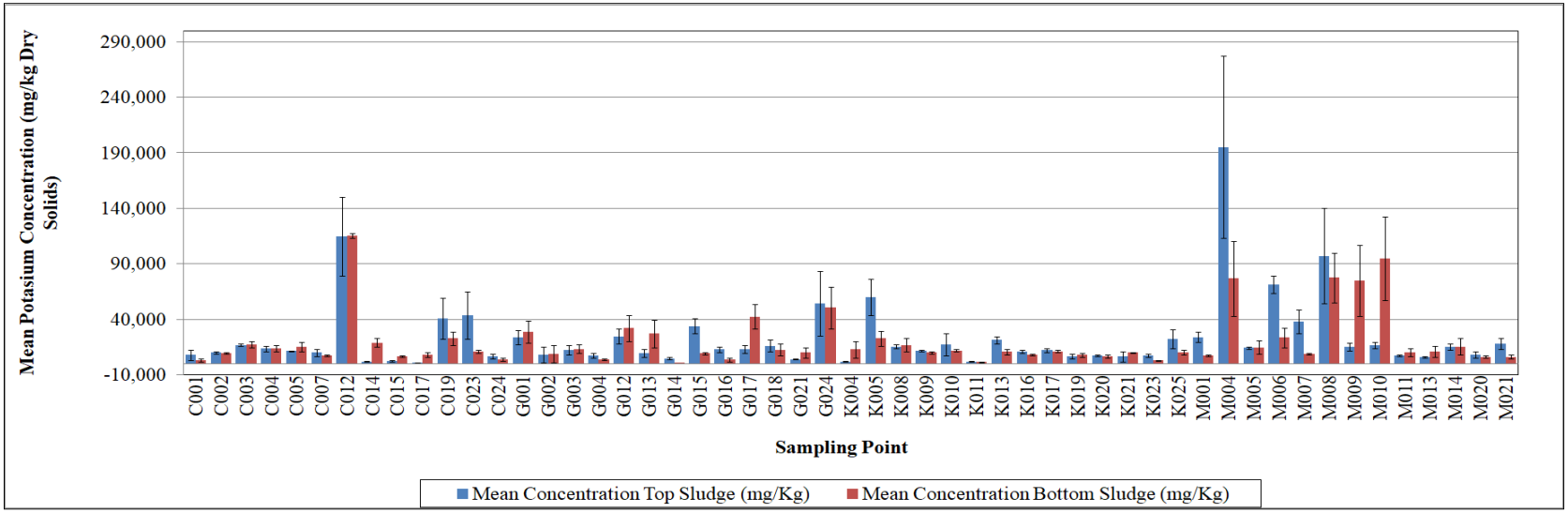

Figure K-12: Potassium results for the sludge from the top and bottom layers of respective pit latrines.

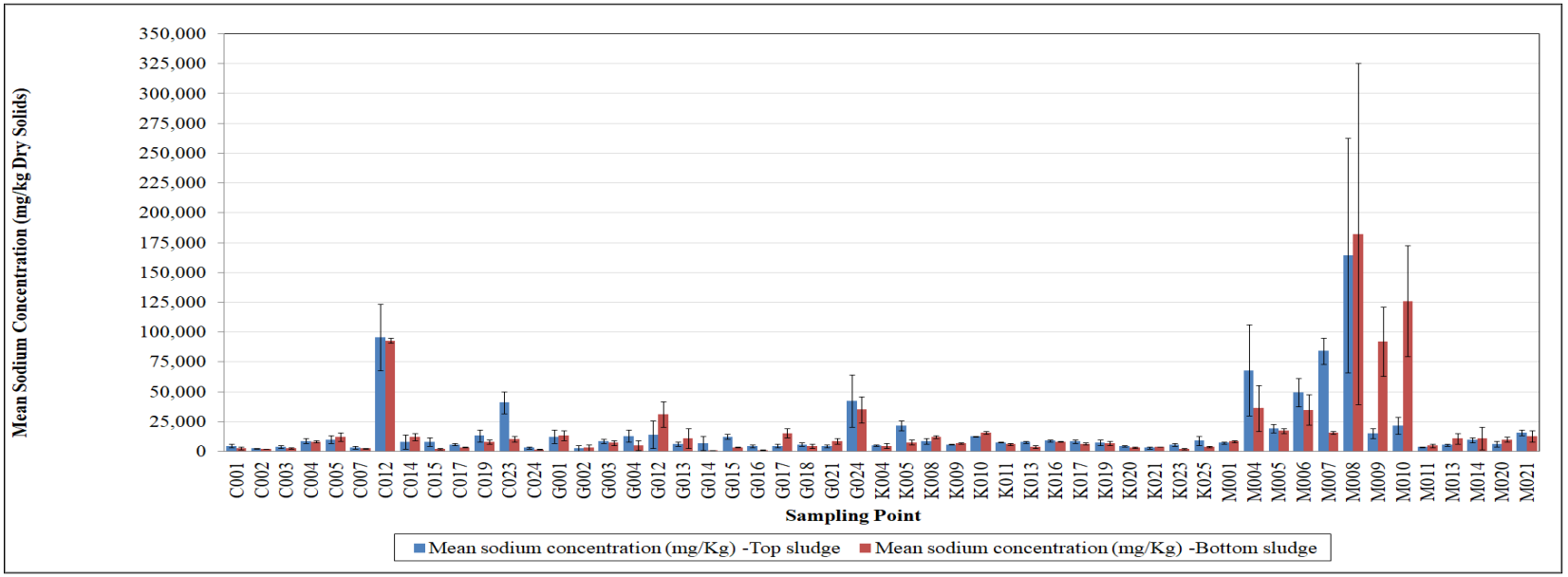

Figure K-13: Sodium results for the sludge from the top and bottom layers of respective pit latrines.

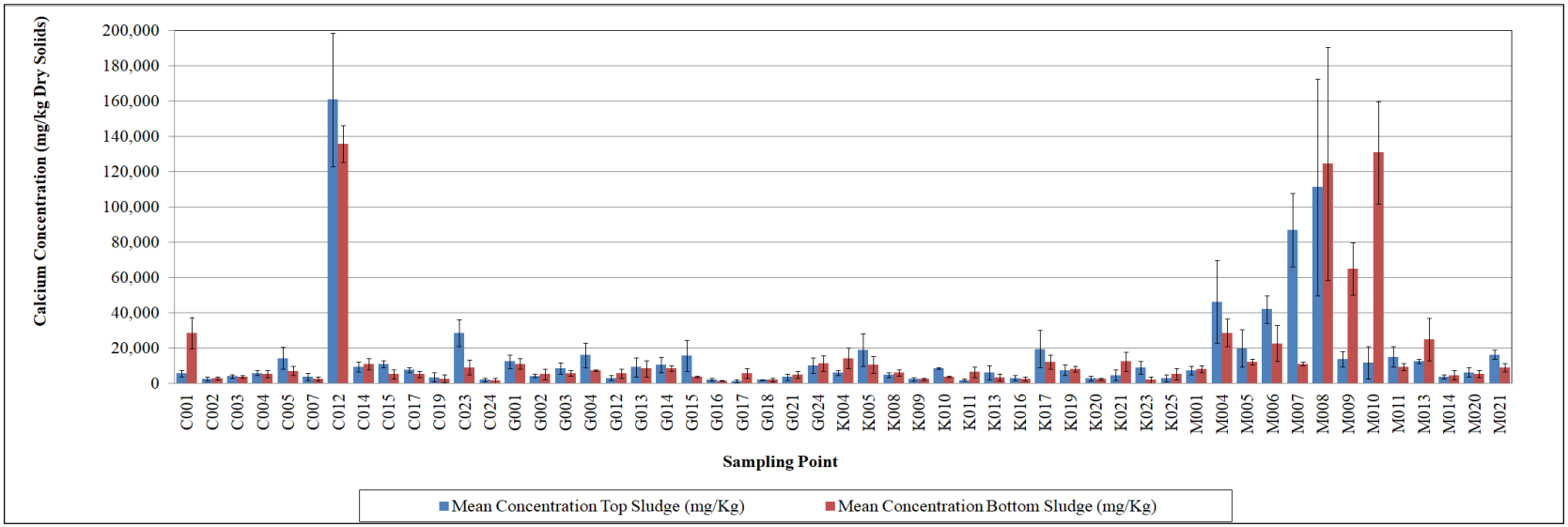

Figure K-14: Calcium results for the sludge from the top and bottom layers of respective pit latrines.

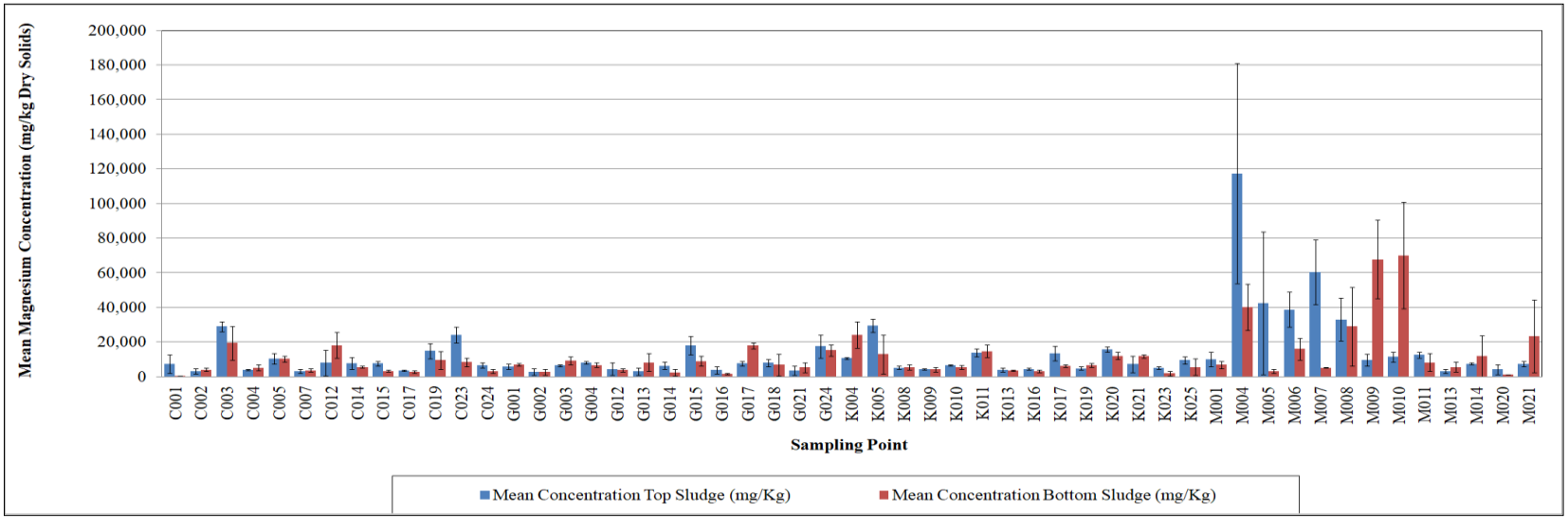

Figure K-15: Magnesium results for the sludge from the top and bottom layers of respective pit latrines.

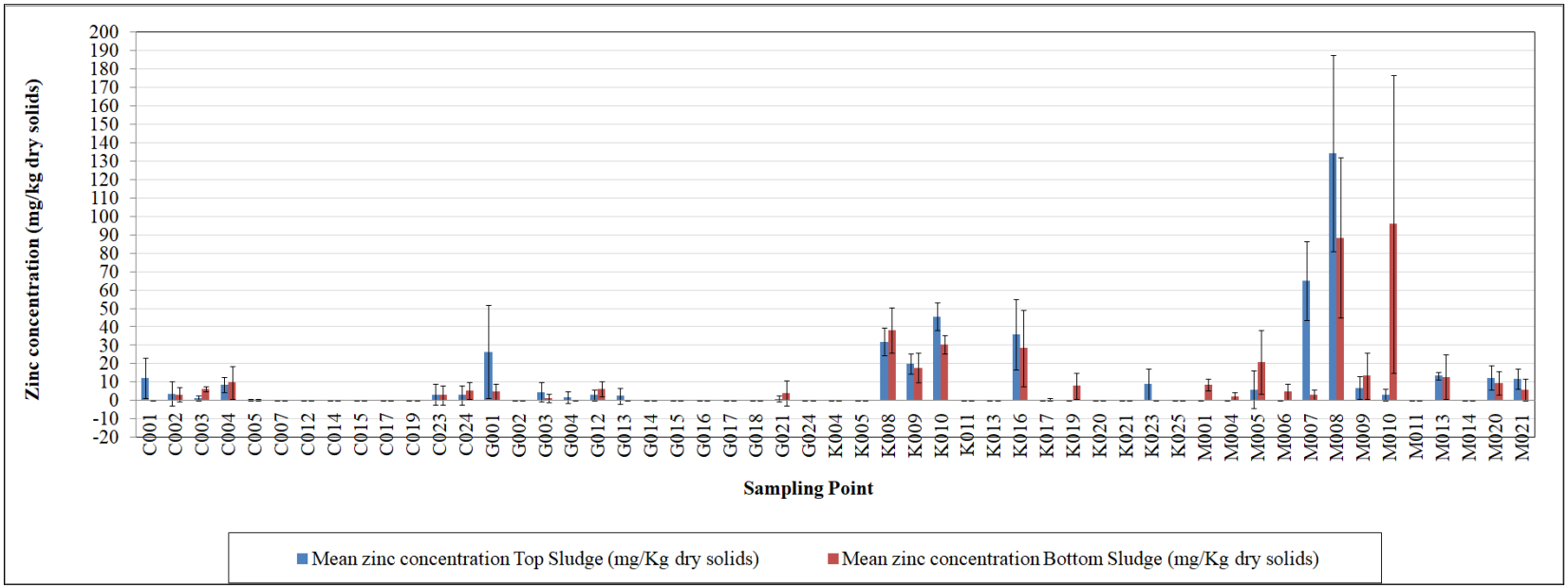

Figure K-16: Zinc results for the sludge from the top and bottom layers of respective pit latrines.

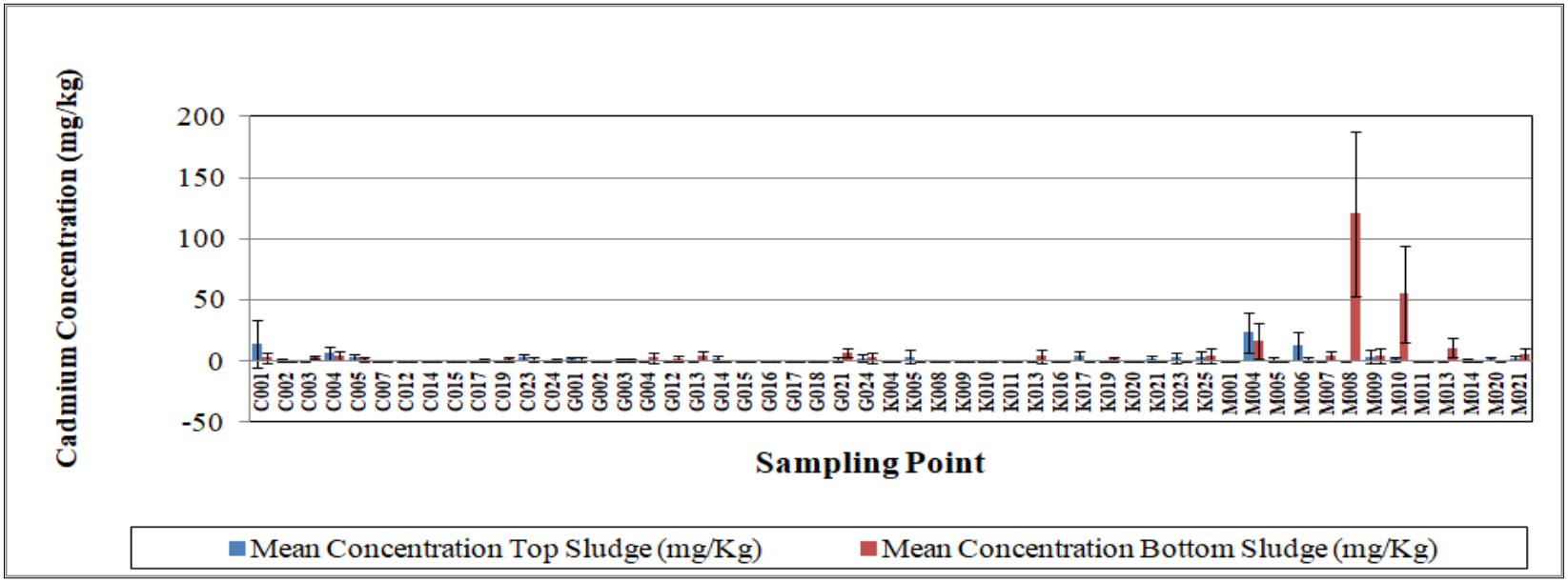

Figure K-17: Cadmium results for the sludge from the top and bottom layers of respective pit latrines.

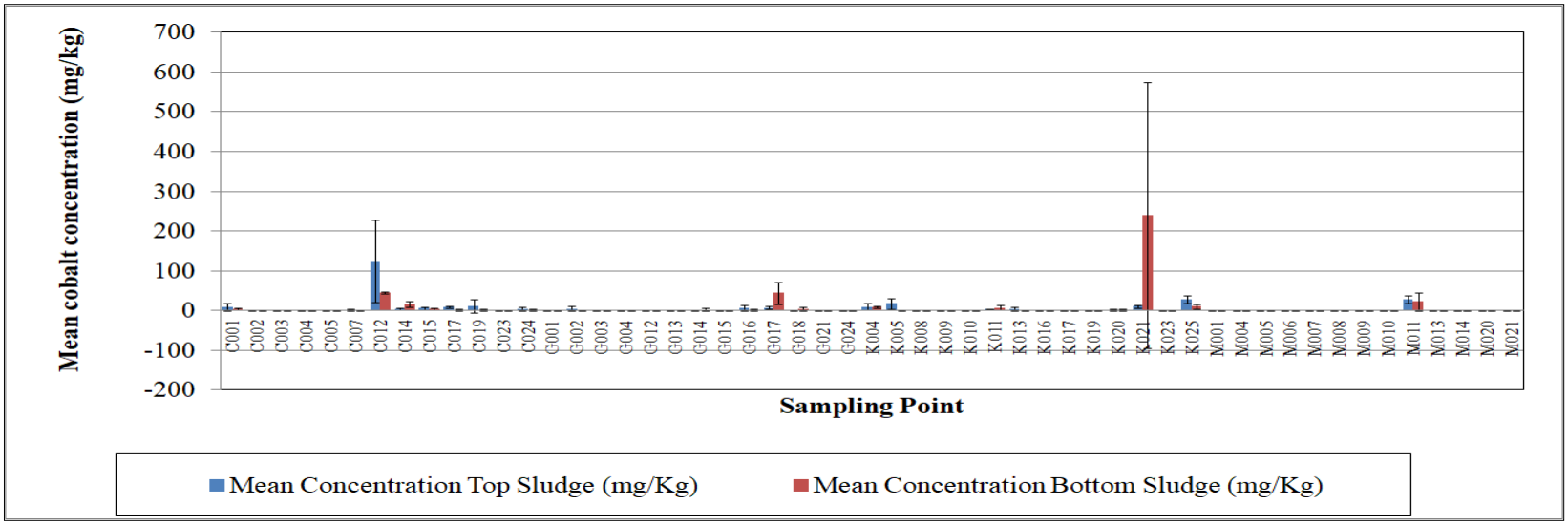

Figure K-18: Cobalt results for the sludge from the top and bottom layers of respective pit latrines.

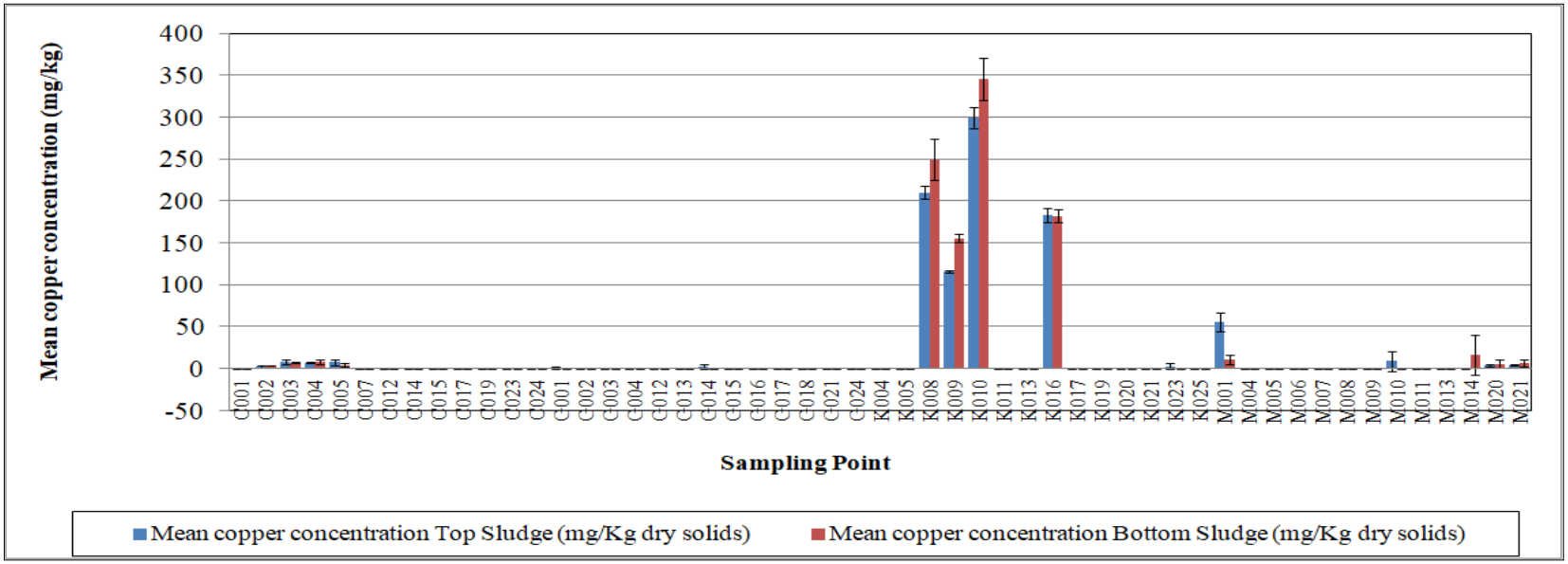

Figure K-19: Copper results for the sludge from the top and bottom layers of respective pit latrines.

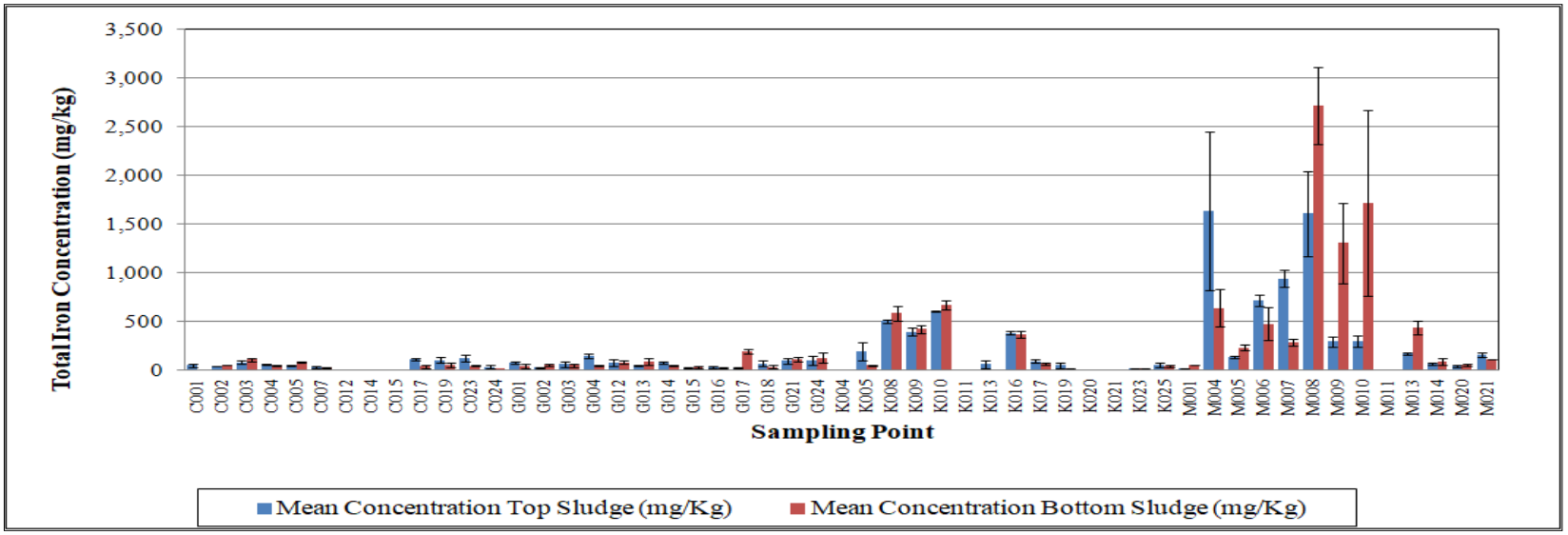

Figure K-20: Total Iron results for the sludge from the top and bottom layers of respective pit latrines.

APPENDIX L: RESULTS ON SELECTED PARAMETERS USED TO COMPARE SIGNIFICANCE OF ADDITION OF CHEMICALS TO PIT LATRINE CONTENTS

Table L-1: Comparative analysis of faecal sludge variability with addition of chemicals to pit latrines

Parameter	**Mean for latrines where chemicals were added**		**Mean for latrines where chemicals were not added**		**Mann-Whitney U test results**					
	Top Sludge	**Bottom Sludge**	**Top Sludge**	**Bottom Sludge**	**n_1**	**n_2**	**U**	**Z**	**P**	**Conclusion**
pH (-)	7.18±0.42	7.45±0.36	7.05±0.49	7.43±0.43	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	31	27	329.5	-1.3796	0.1676	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	31	27	398.5	-0.3040	0.7642	Not Significantly different
Faecal Coliforms (No. CFU/100 mL)	129±219	79±121	140±236	66±64	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	45	50	1091.5	0.2460	0.8026	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	45	50	1116	0.0634	0.9522	Not Significantly different
COD (mg O_2/L)	132,894± 50,386	116,804± 59,541	126,369± 54,913	107,912± 48,500	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	31	27	390	-0.4365	0.6599	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	31	27	371	-0.7327	0.4654	Not Significantly different
BOD (mg O_2/L)	983±418	991±410	1,099±605	1,019±512	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	30	26	357	0.5339	0.5961	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	30	26	368.5	-0.3450	0.7263	Not Significantly different

APPENDIX M: RESULTS ON SELECTED PARAMETERS USED TO COMPARE SIGNIFICANCE OF DESLUDGING PIT LATRINE CONTENTS

Table M-1: Comparative analysis of faecal sludge quality between latrines reportedly never desludged and those desludge not more than a year from time of sampling

Parameter	**Mean for latrines never desludged**		**Mean for latrines desludged within a year from sampling date**		**Mann-Whitney U test results**					
	Top Sludge	**Bottom Sludge**	**Top Sludge**	**Bottom Sludge**	**n_1**	**n_2**	**U**	**Z**	**P**	**Conclusion**
Faecal Coliforms (No. CFU/100 mL)	136±202	101±126	139±269	33±39	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	46	14	280	0.7253	0.4654	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	46	14	169	2.6653	0.0076	Significantly different
COD (mg O_2/L)	120,827± 34,538	102,693± 53,919	122,944± 69,535	120,827± 34,538	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	24	10	101	0.6992	0.4839	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	24	10	103.5	-0.6047	0.5485	Not Significantly different
BOD (mg O_2/L)	984±412	994±452	1,141±540	1,027±284	-	-	-	-	-	-
Mann-Whitney U test between top sludge samples	-	-	-	-	24	8	68.5	-1.1750	0.2380	Not Significantly different
Mann-Whitney U test between bottom sludge samples	-	-	-	-	24	8	75.5	-0.8704	0.3843	Not Significantly different

APPENDIX N: PUBLICATIONS ARISING FROM THIS RESEARCH

1. Holm, R., Tembo, J.M. and Thole, B. (2015). *A comparative study of faecal sludge management in Malawi and Zambia: Status, challenges and opportunities in pit latrine emptying.* African Journal of Environmental Science and Technology. Vol. 9(11), pp. 783-792.
2. Tembo, J.M., Nyirenda, E. and Nyambe, I. (2016). *Enhancing faecal sludge management in peri-urban areas of Lusaka through faecal sludge valorisation: challenges and opportunities.* International Conference on Recent Trends in Physics 2016 (ICRTP2016), IOP Conf. Series: Earth and Environmental Science 60 (2017) 012025
3. Tembo, J.M., Matanda, R., Banda, N.I., Mwanaumo, E., Nyirenda, E., Mambwe, M., and Nyambe, I.A (2019). *Pit latrine faecal sludge solid waste quantification and characterization to inform the design of treatment facilities in peri-urban areas: A case study of Kanyama.* African Journal of Environmental Science and Technology.