MANAGEMENT PRACTICES OF WATER TREATMENT SLUDGE IN SRI LANKA

AND

RE-USE POTENTIAL OF SLUDGE AS A CONSTRUCTION MATERIAL

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Degree of Master of Science in Environmental Engineering & Management

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Thesis submitted in partial fulfillment of the requirements for the Degree Master of Science

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DECLARATION

"I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any University or other institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text"

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ABSTRACT

Sludge remaining at water treatment plants is an inescapable byproduct of the water treatment process. The nature of sludge depends on suspended solids of raw water, coagulant type and chemicals that are used in the treatment process. Direct discharge of sludge into water bodies result in the risk of contamination of surface and ground water that affects water quality and aquatic biota. According to existing legislation, water treatment sludge is classified under industrial waste. Therefore, it is anticipated that the water treatment process would be legislated as a licensable activity in the near future. The National Water Supply and Drainage Board (NWSDB) which is the main potable water supplier in Sri Lanka, has paid attention to identify disposal routes, sustainable practices, and potential applications of water treatment sludge. The objective of this research was to recognize disposal practices and cost effective methods that conform to environmental regulations. To fulfill the objectives, a questionnaire survey was conducted pertaining to chemical usage, sludge production, sludge handling and disposal methods. To introduce sustainable practices, a series of experiments were conducted by adding sludge into production of burnt clay brick, replacing cement by sludge as an adhesive fine material in cement mortar and replacing sand by sludge as fine aggregate in Concrete Paving Blocks (CPB). The questionnaire survey revealed that 50% of selected treatment plants that are operated by NWSDB directly discharge the sludge into inland surface waters with no treatment or dispose to bare lands. Experimental results showed that the required compressive strength of burnt brick could be achieved by adding sludge up to 10% for load bearing walls of single storey buildings. Further, replacement of cement by sludge up to 30% in cement mortar, achieved the required flow of 105% to 115% with the water cement ratio between 0.7 and 1.1. Required compressive strength of cement mortar could be achieved with the addition of 10% sludge with the water cement ratios of 0.7, 0.9 & 1.1, 20% sludge with the water cement ratios of 0.7 & 0.9 and 30% of sludge with the water cement ratio of 0.7. The suitability of a CPB depends on its compliance to the compressive strength requirements. The results showed, the addition of 10% sludge as fine aggregate and 10% bottom ash and sludge as fine aggregate satisfies the requirement specified in the SLS standards for class 1. Hence Concrete Paving Blocks can be successfully produced using 10% of water treatment plant sludge as supplement for sand.Sludge production is an inevitable outcome of potable water treatmentand hence sustainable reuse techniques and disposal methods need to be introduced as a policy for protecting the environment.

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LIST OF ABBREVIATIONS

Abbreviation	Description
Alum	Aluminum Sulfate
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BOD5	Biochemical Oxygen Demand
BS	British Standards
BS EN	British Standard European Norm
COD	Chemical Oxygen Demand
CPB	Concrete Paving Blocks
DAF	Dissolved Air Flotation
DBH	Diameter at Breast Height
DMP	Donan Membrane Process
EPA	Environmental Protection Agency
ESS	Egyptian Standard Specification
ICTAD	Institute of Construction Training and Development
LIE	Liquid Iron Exchange
LOI	Loss on Ignition
NWSDB	National Water Supply and Drainage Board
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
PAC	Powdered activated Carbon
PACl	Poly Aluminum Chloride
RDA	Road Development Authority

RHA	Rice Husk Ash
SF	Silica Fume
SLS	Sri Lankan Standard
SS	Suspended Solids
TDS	Total Dissolved Solid
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USRV	Unpolished Slip Resistance Value
VOC	Volatile Organic Content
WTP	Water Treatment Plant
WTS	Water Treatment Sludge

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CHAPTER ONE

INTRODUCTION

1.1 Background

The National Water Supply and Drainage Board (NWSDB) is the main potable water supplier in Sri Lanka so far, providing pipe borne (treated) water for 44% of the population. There are other forms of water supply through rural water schemes run by local government as well as consumer societies and hand pumps etc. as shown in fig 1.1 (http://www.waterboard.lk). Currently NWSDB has a consumer data base of more than 1.75 million and 100, 000 new consumers are added every year.

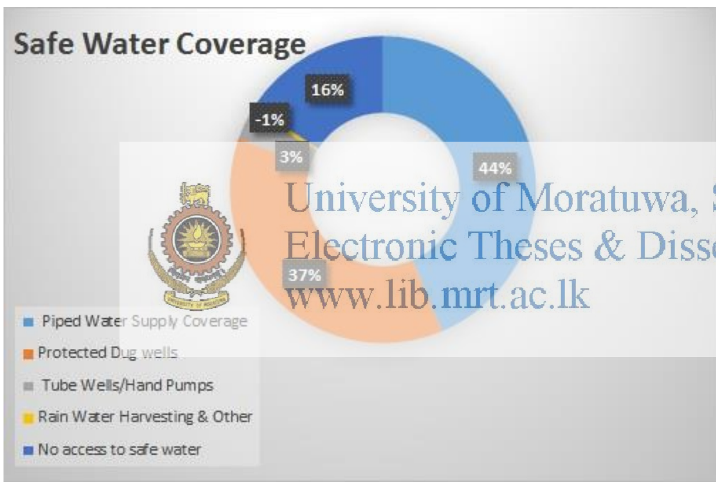

Figure1.1: Safe Water Coverage in Sri Lanka

Presently, NWSDB produces 590 million m³ of water annually which is distributed to various parts of the country. Normally 2% of water production is produced as waste (Sludge) during the water treatment. Eventually a majority of this waste is discharged to the rivers and streams, thereby polluting water in existing water resources. Therefore, it is essential to consider Waste Management System.

Raw water abstracted from surface water sources such as reservoirs, rivers and ground water sources (aquifers) may contain a wide variety of contaminants, including micro-organisms, inorganic and organic contaminants. These impurities may be present as dissolved constituents or suspended solid particles, or compounds bound to such suspended particles. Mostly the water is abstracted from surface water.

The provision of potable drinking water typically involves treatment processes to remove contaminants, which are distributed to consumers. Most of the surface Water Treatment Plants that employ the conventional treatment process such as Coagulation, Flocculation, Sedimentation and Filtration is typically followed by Aeration and preceded by Disinfection (Figure 1.2) produce large quantities of sludge by removing impurities from raw water and various water treatment chemicals which are used for relevant water treatment processes.

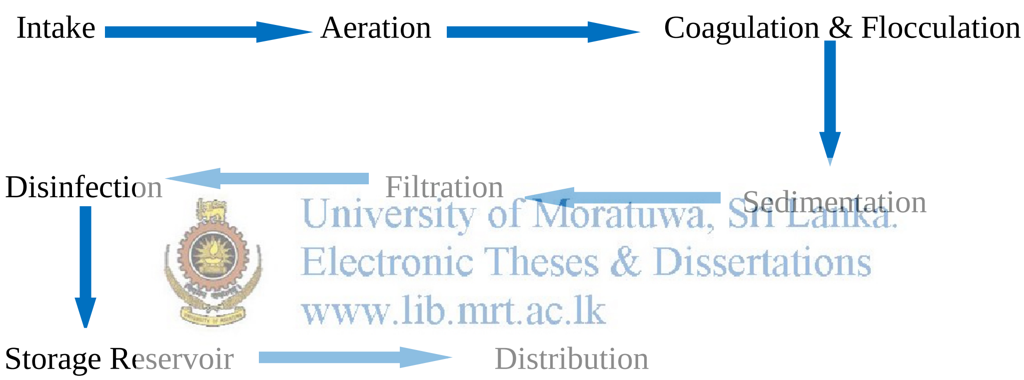

Figure 1.2: Conventional Water Treatment Process

The conventional water treatment process is well established and strong. It consists of dosing a ‘coagulant’ (chemical), which forms a precipitate in the water as it is neutralized upon addition of an alkali. In some raw waters sufficient quantity of natural ‘alkalinity’ is present to buffer the pH variation without alkali addition. The most commonly used coagulants are trivalent aluminum or iron salts. Aluminum sulfate (“Alum”) being the commonly used coagulant in Sri Lanka.

The precipitate is aggregated with the raw water contaminants, so that these are held together in a solid phase suspension within the purified liquid water. By separating these two phases a clear supernatant stream can be taken off for possible further processing and distribution to customers. The aggregates can be formed into larger ‘flocs’ by addition of a ‘flocculant’ (polymer) to aid the faster solid–liquid separation. The separation may be accomplished by gravity settling (‘sedimentation’), direct filtration (through a bed of granular media), or floatation (typically as ‘dissolved air floatation’).

Sludge of water treatment plant remains an inexorable by product of water treatment process and is normally directly discharged into the water courses downstream of the water intake point or disposed in a lagoon located at and around the plant in a short-term period. Questions have been raised in regard to the potential environmental impacts of the sludge when used. This research intends to identify cost effective and environmental friendly sludge management methods to dispose the sludge produced in NWSDB Water Treatment Plants.

The Sri Lankan Government targets to provide safe drinking water supply for all by 2025 with 60% piped borne water supply coverage by 2020 through the national authority, National Water Supply and Drainage Board (NWSDB) to provide safe drinking water, which will produce a huge amount of sludge. The management of the ever increasing sludge from Water Treatment Plants is a serious problem, due to environmental pollutions like surface/ground water, land pollution etc., high expenditure for cost of handling, transport and disposal of sludge and the risk on environment and human health.

Regulatory constraint on residual disposal has become an increasingly severe crisis in recent years. The use of water treatment plant sludge in various industrial and commercial manufacturing processes has been reported all over the world. The selection of an alternative should be based on economic as well as regulatory considerations. The type and characteristics of sludge are also important criteria to be used in developing disposal alternatives.

Therefore, it is necessary to identify appropriate methodologies and technologies for sludge management in the Water Treatment Plant that ensure required ecological and technological results.

1.2 Problem Statement

In order to satisfy the ever increasing demand for potable water, many new water treatment plants are being constructed and some of the existing water treatment plants are being enlarged and modernized. This will result in the production of an increased volume of sludge and wastewater.

The management of ever increasing sludge from Water Treatment Plants is a serious problem, due to its high treatment cost and the risk to environment and human health. The handling and disposal of sludge is one of the most significant challenges in water work management.

Generally Water Treatment Plants sludge is disposed as follows.

- Directly discharged into the water courses downstream of the water intake point as shown in Figure 1.3.

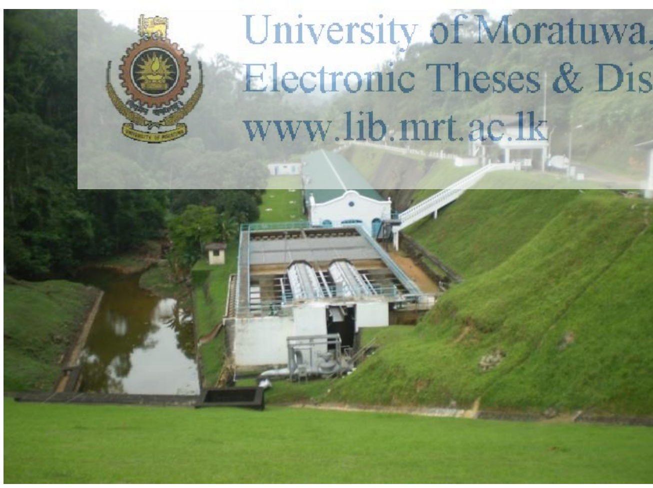

Figure 1.3: Direct Discharge of Water Treatment Sludge to Water Bodies (Kalatuwewa WTP)

- Dewatered and disposed within the water treatment plant site or open dumping as shown in Figure 1.4.

Figure 1.4: Dewatered and Disposed within the WTP Site or Open Dumping

Direct discharge of water treatment sludge to water bodies affects the water quality of downstream and aquatic biota and it is not acceptable in accordance with EPA recommendations. It will be a licensable activity in the near future, according to the environmental regulations. Large quantities of sludge are disposed off by land filling (Open dumping) also. The openly dumped sludge washed away with rain water, affects surface water quality. Ground water quality also affected due to leaching of sludge in to soil.

A key concern regarding the direct discharge of aluminum residuals to waterways is aluminum toxicity in the aquatic environment. When aluminum is mobilized intakes and streams, it may be toxic to aquatic life. The detailed review of existing legislation demonstrates that water treatment sludge is classified as an industrial waste. The management and disposal of which must be carried out in compliance with the environmental regulations.

Therefore extensive investigations are required for alternative reuse techniques and disposal routes for sludge produced in NWSDB water treatment plants to find the solution on sludge disposal issue and contributing towards the environmental sustainability by reduce the pollution. However those reuse techniques should be marketable and attractive to end users. So the most suitable proportion of sludge content that can be used in construction materials, to meet the stringent standards set by the regulatory bodies to be identified.

1.3 Objective of the Research

The objectives of this study are,

1. Identify the current sludge handling and disposal practices adopted in the NWSDB Water Treatment Plants in Sri Lanka by conducting a questionnaire survey.

2. Suggest sustainable practices to NWSDB on sludge handling and disposal.

3. Study the feasibility of using the sludge as an alternative material in the construction industry under local conditions for the following applications:

   - Re use of sludge in brick manufacturing as substitute for clay
   - Re use of sludge in cement mortar as substitute for cement
   - Re use of sludge in concrete paving block manufacturing as substitute for sand.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Treatment Plant and Sludge Production

Researches regarding the water treatment sludge have been carried out by different researchers around the world. This section of the report explains in detail about the sludge production in water treatment plant, nature / characteristic of sludge, sludge management, sludge disposal, minimizing sludge production, sludge treatment methods and reuse.

Clean water is vital for the survival of the world's population. Every living creature depends on water for survival. 98% of the water is saline water, 1.6 % is ice and only 0.4 % is ground and surface water, which is the simplest and common source of production of potable water. Due to increasing pollution more and more complex treatment technologies are required to raw water to meet the required quality potable drinking water.

Figure2.1 (Verlicchi & Masotti) depicts the general flow sheet of a surface Water Treatment Plant (WTP) and specifies where drinking sludge is produced and treatment and disposal routes in the "liquid" and "solid" forms; the sludge produced from the backwashing of sand filters, are normally sent in front of the settling compartment (just to recuperate water), but there is a tendency to treat them separately.

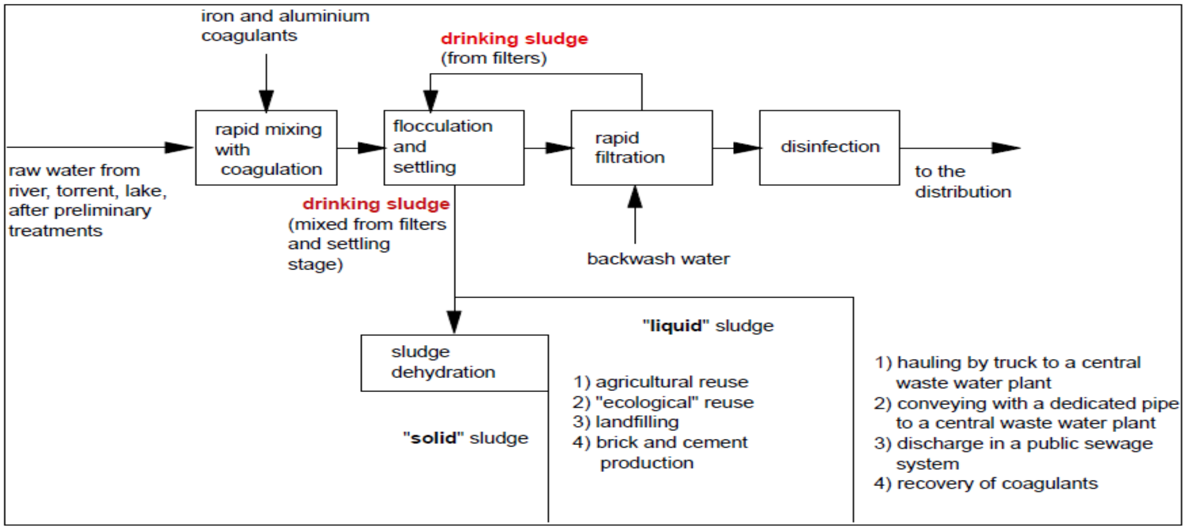

Figure 2.1: Production and Disposal of Solid and Liquid Drinking Sludge in a WTP

(*Source: Verlicchi &Masotti, 2000)*

2.2 Nature / Characteristics of Sludge

Sludge is the relatively concentrated suspension into which the residual solids fraction arising from water treatment is concentrated in the course of purification. Sludge is derived from the processes of chemical coagulation and softening at drinking water treatment plants. Most of the sludge is of an unstable organic nature and readily undergo active microbial decomposition with consequent generation of nuisance odours. They all have the common characteristics of high water content, usually greater than 95% by weight.

The composition and properties of the water treatment sludge depends typically on the quality of treated water, as well as on types and doses of chemicals used during the water treatment. Depending on the quality of the treated water, the water treatment sludge contains suspensions of inorganic and organic substances. Typically hydrated alumina oxides and iron oxides are present. This depends on the type of coagulants and other treatment chemical used for the water treatment. Sludge is in particulate or gelatinous form consisting of microorganisms, organic and suspended matter, coagulants and other chemical elements and the composition of sludge depends on the characteristics of the raw water, type of coagulant used and the dosage applied and plant operating conditions.

2.3 Sludge Management

Sludge of water treatment work remains an inescapable by product of water treatment process. The water treatment sludge is a liquid and solid and regarded as a waste. It must be handled in accordance with regulations in force.

In a conventional water treatment plant, the main source of sludge is the clarification stage. Some additional sludge may be generated from the settlement of filter backwash water. The nature of sludge depends on the type of coagulant and other treatment chemicals used for treatment. Sludge is in a particulate or gelatinous form consisting of varying concentrations of microorganisms, organic and suspended matter, coagulants and other chemical elements.

The composition of sludge depends on the characteristics of the raw water source, type of coagulant used and dosage applied during the water treatment, plant operation and maintenance practices.

The objective in sludge management is minimizing the amount of material that must be ultimately disposed. The basic technological step is reducing the water content (Dewatering).Without this step it would be difficult and uneconomical to handle and treat the sludge. Sludge produced in both the clarifiers and filter backwash water treatment processes need to be thickened.

The process that has shown the most successful and significant capabilities for dewatering sludge from water treatment plants are drying bed, vacuum filtration, Pressure filter press, Belt filter press, centrifugation and alum and lime recovery.

Regulatory constraints on residual disposal have become increasingly severe in recent years. Prior to this there was little concern for disposal of water treatment residuals. In most cases, they were simply returned to the nearest receiving water, usually the source of water supply. In the late 1960s some states began considering these residuals as pollutants and began establishing treatment or discharge standards.

2.4 Sludge Disposal

Several alternatives are available for the disposal of water treatment plant sludge. The selection of an alternative should be based on economic as well as regulatory considerations. The type and characteristics of sludge are also important criteria to be used in developing disposal alternatives.

Alternatives available for disposal of sludge are directly discharging into the water courses, dewatering and disposing within the water treatment plant site or landfill and disposing to sewer line.

2.4.1 Discharging into the water courses

The conventional method of disposing the sludge collected from water treatment processes is disposal to a natural water course. This had been the practice around the world for many years until the American Water Works Association Research Foundation started moving forward on the subject of water treatment plant residuals in the mid-1980s (American Water Works Association, 2007).

Now it is impossible to discharge the sludge or sludge water directly into rivers. When discharging the wastewater, it is necessary to comply with the National Environmental Act.

2.4.2 Dewatering

The basic technology step in the processing of the water treatment sludge is a decrease in water contents. Without this step, it would be difficult and considerably uneconomical to handle and treat the sludge. This is typically carried out in sludge drying beds or lagoons when natural dewatering processes take place for a rather long time. The dry weight of the sludge can be as much as 40% and final disposal is possible. As far as fully mechanized dewatering units for the treatment of the water treatment sludge are concerned, introduction of standard centrifuges and filter presses has been started recently.

2.4.3 Disposing within the water treatment plant site or landfill

It is possible to place the sludge in free spaces such as abandoned quarries, mines, gravel pits, sand quarries or artificial lakes. Of course, environment protection regulations and current legislative must be followed. In rare cases only, the suitable space is available close to the water processing plant. The placing of the water treatment sludge into free spaces can be regarded as an emergency solution that does not solve the issue forever, but moves the issue until the time when the storage space is used up.

2.5 Minimizing Sludge Production

The methods and costs for handling, treatment and disposal of sludge are influenced by the amount and characteristics of the sludge. The quantity and characteristics of sludge are affected by the raw water quality and the treatment chemicals used during the water treatment process. Little can be done to change the raw water quality. However, it is possible in many cases to change the water purification processes to minimize sludge production. The reduction of waste volumes results in operational cost savings at a plant.
Sludge generation can be minimized by the removal of water to reduce the sludge volume, the reduction of the solids content present in the sludge or some combination of the two. The methods for minimizing sludge production are reduction of chemical dosages (alum or lime), direct filtration of the water, recycling of filter wash water, substitution of coagulant and softening material, and chemical recovery (Westerhoff, 1978; AWWA, 1981).

2.5.1 Chemical Conservation

Stoichiometrically the reduction of each 1 mg/L of alum will result in a saving of about 1400 kg (3000 lb) of alum per year and will reduce the alum sludge by approximately

360 kg (800 lb) per year for a 3785-m /d (1-MGD) plant. At many water treatment plants excessive amounts of coagulants are used since it is difficult to continually determine the optimum coagulant dosage at a plant, especially with rapidly changing raw water characteristics. Small utilities may not have the know-how, manpower, or other resources to monitor and regulate coagulant dosing. Plant operators must be aware that the excessive use of coagulants results in increased costs, both for the coagulants and for handling, treatment, and disposal of the extra residues produced. (Thompson, 1987)

Optimization of lime feed systems can reduce solid loads by maximizing the efficiency of chemical dosages and by minimizing the amount of un reacted lime in the waste stream. Improved mixing in feeders, flash mixers, and flocculation zones reduce excess lime dosing. The well-mixed solids contact clarifiers use only 2 to 3% excess lime (AWWA, 1981).

By selective softening to remove only calcium hardness, waste volumes may be reduced and the dewatering characteristics of the softening sludge may be improved. However, this softening method may be a questionable practice for some plants because of incomplete removal of hardness. Another method, reducing the degree of softening, could reduce the chemical costs and also the amount of solid produced.

2.5.2 Direct Filtration

Direct filtration is a water treatment process in which filtration is not preceded by sedimentation. However, it may include rapid mixing with alum or other primary coagulants and the addition of a filter aid immediately ahead of the filter. Contact tanks may also be installed at some direct filtration facilities.

Direct filtration is most applicable to facilities with a relatively stable and high-quality (low-turbidity) raw water source. In the process of direct filtration coagulant dosages are generally low and virtually all residues are produced as filter backwash. This results in a significant cost saving for sludge handling, treatment, and disposal. Westerhoff (1978) reported a case history of direct filtration plants at the Niagara County Water District's plant in Lockport, New York.

The Metropolitan Water Board treatment plant, located in central New York State, has been successful in using direct filtration of Lake Ontario water to serve Syracuse and Onondaga County, New York, with a 94-ML/d (25-MGD). Capacity, Alum dosages were significantly reduced and sludge generation was lessened (Fitch and Elliott, 1986).

2.5.3 Recycling

Direct recycling of residues from the clarifiers and filters is generally not feasible. If sludge is concentrated, the recycling of filtrates from catch basins and clarified supernatant from the dewatering process will reduce solids loads, because these waters have a reduced TSS concentration and are softened. Clarification and filtration waste volumes represent 3 to 5% of the total plant pump age. The recycling of this water will reduce the waste volume by 3 to 5%.

It should be noted that conditioning alum sludge with lime as a preparatory step prior to filtration, may cause the re-solution of humic substances into the process stream. These dissolved organics are suspected of being precursors for the formation of possible cancer-producing trihalomethanes in the disinfection of water supplies with chlorine.

Recycling of concentrate or filtrate from lime-softening sludge is satisfactory. Recycling of lime sludge improves the efficiency of calcium carbonate precipitation and reduces lime usage. The use of a holding basin and limitation of the recycling rate to 10% of the total plant flow are desirable (Reh, 1978).

2.5.4 Chemical Substitution

Through the substitution of other treatment chemicals for all or part of the alum and lime, the quantities of sludge generated may be reduced and the dewatering characteristics may be improved. The substitution should not degrade the finished water quality, lessen the reliability of the sludge treatment, or increase the total cost.

Reh. (1980) described the use of magnesium carbonate ($MgCO_3$ 3H2O) as an alternate coagulant associated with chemical recovery and recycling. This method was developed by A. P. Black of the University of Florida and was successfully field-tested by the United States Environmental Protection Agency (USEPA). When magnesium carbonate dissolves in water at a high pH it forms magnesium hydroxide, $Mg(0H)_2$, which has the same coagulation power as aluminum hydroxide. In this process, coagulation of raw water is carried out by using $Mg(0H)_2$ at a pH of about 11. Magnesium hydroxide has about the same coagulation power as aluminum hydroxide (Reh, 1980). The sludge is then carbonated to convert $Mg(OH)_2$ to soluble magnesium bicarbonate, $Mg(HCO3)_2$. A thickener is used to separate $Mg(HCO3)_2$; it is then recycled back to the flocculation tank. Most heavy metals present in raw water can be removed because the coagulation process is carried out at a high pH. There is no acidification step to release the sludge back to the liquid phase.

Complete replacement for alum is achieved by the use of iron salts such as ferric chloride, ferric sulfate, and chlorinated copperas. Many facilities have used polymers for primary coagulants.

Partial substitution for alum has been obtained by decreasing the alum dosage and adding a polymer or other coagulant aid. This practice is widely used at the present time. New and improved coagulant aids continue to be developed. The advantages of this process are in reducing the alum dosage and the quantity of sludge produced.

Sodium hydroxide (caustic soda) has been used as a partial or complete substitute for soda ash or lime softening. Substituting sodium hydroxide is not widely accepted because it is more expensive. However, the higher cost of sodium hydroxide can be offset by lower solids generation and disposal costs.

When removal of high magnesium hardness is required, split treatment is justified because it eliminates the lime treatment for bypassed water and minimizes re-carbonation requirements and sludge generation.

2.5.5 Chemical Recovery

Chemical recovery is technically feasible for the reclamation of alum, iron, and magnesium carbonate and for the recalcination of lime sludge. In each case finished water quality, side stream discharge, and gaseous emission should be considered. Chemical recovery from water treatment plant sludge can provide the benefits of the reusable chemicals themselves, reduced sludge production, reduced costs for sludge disposal, and/or improvements in the treatability of the sludge.

2.5.5.1 Alum Recovery

Alum is recovered through acidification. When sulfuric acid is added to the thickened sludge the reaction of aluminum hydroxide with acid takes place almost instantaneously to form aluminum sulfate (alum) solution. Acidulation also hydrolyzes much of the organic matter. Re-dissolved organic matter is a source of concern with regard to public health (Fulton, 1978a), because some carcinogenic volatile organic compounds and toxic chemicals may also be present.

Cornwell and Susan (1979) reported that the optimum acid dose for almost all sludge occurred at a sulfuric acid to total aluminum molar ratio of 1.5:1. The optimal dissolution corresponded very closely to the theoretical acid requirements. The acid demand corresponded to approximately 0.5 kg sulfuric acid per kg of alum added to the raw water.

When sulfuric acid is added to alum sludge, between 70 and 80% recovery of alum can be achieved (Chandler, 1982; Westerhoff, 1978). The recovered alum can be reused for the water treatment process, or it can be employed as a source of alum for phosphate precipitation in wastewater treatment. The transportation of the recovered alum should be carefully considered. The residue has a low pH and the residue cake may require neutralization by lime prior to disposal on land. In case it is reused in the water treatment plant, consideration should be given to whether re-dissolved impurities might cause a possible degradation of the finished water. This is an expensive process and its economic viability depends upon the capital costs of acid-resistant equipment and the relative costs of sulfuric acid and fresh alum.

2.5.5.2 Recalcining

Lime recovery by recalcination is not a new process and is practiced at many facilities. The recalcination process is the burning of softening sludge at a high temperature of 1010°C (1850°F) as shown in the following reaction (AWWA, 1981):

The process generally includes sludge thickening from an initial 3 to 10% solids to 18 to 30%.Recalcination has the potential to recover even more lime than would be used in the softening process, while reducing the sludge weight by 80% (Westerhoff and Cline,1980). At the same time, the carbon dioxide produced can be used for re-carbonation.

Recovered lime can be sold for soil pH adjustment or re-used in the water treatment plant. However, the lighter hydroxides of metals such as magnesium, iron, and aluminum are undesirable contaminants in a lime recalcination process. Also the high cost of fresh lime along with the high cost of energy for lime recovery may make recalcination too expensive to adopt. Thompson and Mooney (1978) discussed lime and magnesium recoveries from water plant sludge.

$$CaCO_3 \xrightarrow[1700\text{–}2000^{\circ}F]{heat} CaO + CO_2$$

2.5.5.3 Magnesium Recovery

When magnesium carbonate, $MgCO_3$• 3H2O, is added to water as a coagulant at a high pH of about 11.0, magnesium hydroxide, $Mg(OH)_2$, is formed. The sludge then is carbonated to convert $Mg(OH)_2$ to the soluble magnesium bicarbonate $Mg(HCO3)_2$. A thickener or filter is used to separate $Mg(HCO3)_2$. The magnesium in the filtrate is recycled back to the flocculation tank for use and the solid portion is disposed of. This coagulant is particularly applicable in conjunction with lime recalcination because of the release of carbon dioxide in the recalcination process. This is used in turn to re-dissolve the magnesium hydrate.

2.6 Sludge Treatment

Treatment and disposal of waste from a water treatment plant depend on the types of waste and on local conditions. Treatment methods used for domestic wastewater sludge are most likely applicable to water plant wastes. However, further studies should be conducted to evaluate their feasibility.

Generally waste treatment processes for water plants consist of three elements: co-treatment, pre-treatment, and solids dewatering. There are several methods available for each of these elements.

2.6.1 Co-Treatment

Discharge of water plant wastes to a sewage system, either raw or after concentration, has been a common practice for many facilities. It is probably more cost-effective than using separated systems, especially for communities which own both the water and sewer systems. Definite advantages have been reported for" joint dewatering of alum and sewage sludge" (Fulton, 1978b).

Hsu (1976) claimed that joint treatment of alum sludge and wastewater plant sludge was the most promising off-site treatment method. Alum sludge can be discharged to the existing wastewater treatment plant, where it can be thickened and mixed with the wastewater sludge, followed by dewatering at a proper pH. Alum sludge can serve as a useful wastewater sludge conditioner, rather than a nuisance.

Lime sludge can be advantageous for increasing pH, as a bulking agent, for neutralizing acid wastes, and for pre-treatment of industrial wastes; and it can be incinerated to -produce high alkaline ash (AWWA, 1981). Water-softening sludge tends to settle well and to deposit in sewers. It needs a good velocity to prevent its settling in sanitary sewers.

Spent brines would not have a significant effect on sewage treatment (Reh, 1978). Flow equalization is needed to avoid abrupt changes of TDS and salt concentrations in the sewage.

2.6.2 Pre-Treatment

Some sort of pre-treatment is needed for effective and economical water plant sludge treatment. Pre-treatment includes flow equalization, solid separation, and solid concentration or sludge thickening (Fulton, 1978b). Pre-treatment facilities for particular water can use one of these methods or a combination of the three.

2.6.2.1 Flow Equalization

Flow equalization is used to provide storage volume for holding the quantity of waste discharge which exceeds the allowable amount being discharged to a sewer system. Storage requirements depend on the designed waste discharge schedule.

2.6.2.2 Solids Separation

Solids separation may be accomplished by detention in settling facilities with designed waste withdrawal rates or with adequate overflow. The settling facilities may include a simple settling tank, decant tank, or both decant and settling/thickening tanks. Flow equalization storage preceding settling facilities may be needed for filter wash wastewater because of relatively high discharge rates.

As a decant tank is filled it remains full for a sufficient time (about 2 hours) for the settling of solids without withdrawal. The solids are then removed by a mechanical collector for further treatment and the supernatant is drawn off.

2.6.2.3 Thickening

Thickening is used to reduce the volume of sludge and to improve sludge dewatering characteristics by concentrating the sludge in the bottom of a thickener or lagoon. It is an inexpensive and effective device. Although coagulant sludge thickens poorly, it can be gravity-thickened to a solids content of 2 to 10% (Westerhoff and Cline, 1980). Lime-softening sludge which primarily contains calcium carbonate can be thickened2 to 30% solids and more at a thickener loading rate of approximately 4.6 m /907 kg (50 sqft/ton)/d (AWWA, 1981; Westerhoff and Cline, 1980).

Unfortunately, the literature indicates that most water treatment plants make no effort to minimize sludge volume, although thickening can save on the costs for sludge discharge piping and for supernatant recycling.

One of the more efficient methods of sludge thickening is the use of a slow-stir rotating picket fence to enhance solids separation. The theory is that thickening occurs initially by gravity settling and is aided by the compressing action of the stirrer on the sludge. The use of inclined, parallel plates has also reportedly been successful in improving solids separation.

2.6.3 Solids Dewatering

2.6.3.1 Non-mechanical Dewatering

Following collection and thickening, the sludge can be further concentrated or dewatered either by co-disposal with sewage sludge or by mechanical or non-mechanical dewatering methods. Co-disposal was discussed previously. Non-mechanical sludge dewatering devices include lagooning, drying on sand beds, natural or artificial freezing and thawing (physical method), and chemical conditioning.

Lagooning - Lagoons have been used as an all-purpose treatment device. They may function as a flow equalizer, solids separator, sludge thickener, and sludge storage area all in one unit. Lagoons generally provide sufficient surface area and volume for treatment. They are usually equipped with under drains and decant facilities for sludge dewatering.

Design criteria for lagoons vary with each particular plant situation, depending on the waste received. Generally at least two lagoons are required. Liquid can be discharged by an under drain or through an overflow. The lagoon can be operated in a fill-and-draw pattern or in a continuous mode. Recovered water can be recycled to the plant. Sludge, cake or wet, may be removed by earth-moving equipment after it has been drained. Sludge can be withdrawn without draining by means of hydraulic equipment. It should be noted that settled alum sludge does not pump well even when it is wet.

Lagooning is the most inexpensive but perhaps the least effective dewatering method for alum sludge, usually resulting in 5% solids. Nevertheless, a successful example was reported by Fulton (1976). One filter plant of the Hackensack Water Company in New Jersey has been discharging alum sludge to settling basins for over 40 years. The sludge in the lagoon compacted to 10% solids with long-term storage. On the other hand, it has been reported that through lagooning, lime-softening sludge can be successfully dewatered to greater than 50% solids (AWWA, 1981).

Drying Beds - The sludge drying bed is an improvement over the sludge lagoon. It incorporates a permeable medium (such as sand and wedge wire) and a system of under drainage. In England a modified sand drying system using wedge wire was developed. The wedge wire system required a high capital expenditure although maintenance costs were low.

Where rainfall and humidity conditions permit and where large land tracts are available, sand drying beds are an effective and relatively inexpensive method of dewatering water plant waste solids. These beds usually consist of 15 to 30 cm (6 to 12 in.) of sand ranging in size up to 0.5 mm with graded gravel and drainpipes (AWWA, 1969a). Sludge is applied in 30- to 60-cm (1- to 2-ft) layers and allowed to dewater. The beds may be covered or open.

Rainfall is a major factor in the effectiveness of sludge drying beds. Poor dewatering of sludge occurs in cold or rainy climates. The costs of the large land area required and of the sand should be considered. Dewatered sludge can be removed manually if there is a lack of suitable equipment. The difficulty of sludge removal together with the labor-intensive operation makes this method uneconomical.

Sludge penetration through sands during the initial sludge application is a problem which requires frequent sand replacement. Polymer conditioning can prevent sludge penetration by increasing the gravity drainage rate by 100% and enhancing' evaporation, thereby preventing cake crust formation (AWWA, 1981).

Sand drying beds have been employed for dewatering coagulant sludge and, to a lesser extent, lime softening sludge. Use of these beds is a feasible method for dewatering mixed coagulation-softening sludge.

Freezing and Thawing - Freezing can be natural or artificial. The freezing and thawing process was developed for sewage sludge in 1950. In 1963 in the United Kingdom the process was first initiated successfully for the treatment of water plant sludge at Stocks, England (Doe et al., 1965).

Pre-treatment by thickening reduced the sludge volume. The sludge was thickened to 4% solids. The process consisted of two 45-min. freezing cycles and one 45-min. thaw cycle. In the freezing process, water hydration was removed from the gelatinous aluminum hydroxide, changing the sludge characteristics to small granular particles which settled rapidly. The final volume was reduced to one-sixth of the original volume. The capital costs and operational costs of this process are relatively high.

In cold-weather conditions with a large amount of available land, natural freezing on open beds is feasible for dewatering alum sludge. The process of freezing and thawing has no particular benefit for lime-softening waste. A holding facility with sufficient volume to store waste generated during non-freezing periods is required. Sludge is applied to the bed in successive layers to facilitate freezing.

Freezing and thawing of alum sludge will change sludge concentrations substantially. Recently a successful freeze-thaw process in central New York State was reported by Fitch and Elliott (1986). Alum sludge from a settling basin with 8% solids was concentrated to 25% by freezing, thawing, and decanting. The final sludge was found to be more granular in character. It was also observed that regardless of the pumped sludge concentration it separated quickly into settled sludge and clear decant. The settled sludge was easily handled by standard earth-moving machines for removal from the beds for land application. For the 72-MGD (272-ML/d) plant treating Lake Ontario water, the construction cost for permanent sludge-handling facilities including the freeze-dry beds was about $300,000 in 1981.

Randall (1978) claimed that liquid butane is an ideal refrigerant for direct slurry freezing of waste-activated sludge to promote settling, concentration, and dewatering. Because of the high recovery rate for butane, the process effectively and economically accomplishes wastewater sludge dewatering.

Chemical Conditioning - Conditioning of sludge may be accomplished by judicious use of organic polyelectrolytes, inorganic chemicals, and acidification. Anionic polymers (hydrolyzed polyacrylamides) have been reported to be particularly effective conditioning agents for coagulating sludge prior to gravity or vacuum filtration dewatering (King and Randall, 1968).

Ferric chloride, lime, or fly ash is possibly applicable for particular sludge conditioning. The use of chemicals, separately or in combination, should be evaluated for a particular sludge.

Acidification of sludge is a good conditioning method, particularly with the alum recovery process. The acidified sludge must be neutralized prior to its ultimate disposal.

2.6.3.2 Mechanical Dewatering

The most frequently used mechanical systems for dewatering water plant sludge are centrifugation, vacuum filtration, and pressure filtration. Belt filtration and dual cell gravity solids concentrators have been installed to a lesser extent. Pellet flocculation is relatively new and is used less often for sludge dewatering. For all mechanical dewatering systems pre-conditioning is generally required.

Centrifugation -Centrifugation is the settling of sludge by a centrifuge that uses the gravitational force created by high-speed rotation to separate the solids. Various types of centrifuges are commercially available. Generally, there are two categories: continuous scroll type and continuous bath bottom feed basket (bowl) type (Hagstrom and Mignone, 1978). Feed solids concentration to the centrifuge usually ranges from 2 to 6%, although alum sludge at a concentration of 0.4 to 1.0% has been successfully dewatered (Westerhoff, 1978). However, several full-scale installations have been found to be unacceptable (AWWA, 1969a). The centrifuges for alum sludge dewatering at Rock Island, Illinois, are an example of a failure. The expected cake dryness is affected by the centrifugal force, feed rate, rate of polymer dosage, raw water quality, floc size and density, and residence time. The water that is removed can be recycled to the plant or properly disposed of.

Lime-softening sludge is reported to be easily dewatered by centrifugation because of its high (80 to 85%) calcium carbonate content. Albertson and Guidi (1969) cited in Thompson 1978 reported that when a solid bowl centrifuge was used, a thickened lime sludge could be dewatered to a cake solids concentration of 55% with 78 to 93% solids capture. Data from plants using centrifugation showed that the lime cake solids concentrations were in the range of 55 to 70% solids by weight (AWWA, 1969b; Vesilind, 1979), while alum sludge centrifugation can achieve only 12 to 20% solids by weight (Fulton, 1978b).

Vacuum Filtration - Vacuum filtration typically uses a rotary drum with a tilter cloth or medium stretched across its surface. The filter medium can be traveling cloth or a pre-coated type. The selection of a proper filter medium contributes to the effectiveness of the process. The drum is placed under vacuum or pressure in a reservoir of sludge that is to be dewatered. The pre-coated filter drum rotates slowly at 5 to 12 revolutions per minute depending on the permeability of the deposited cake and the grade of pre-coat medium. The average pre-coat layer of 2 to 3 inches is applied and may be shaved off in very small increments. Approximately 50 to 60 minutes is required for pre-coating a vacuum filter (Westerhoff, 1978). The process of vacuum filtration includes three basic phases: cake formation, cake drying, and cake discharge. The floc size distribution is the key factor in the performance of the vacuum filter. The sludge cake develops on the outer surface of the medium and is subsequently removed by a scraper and disposed of.

The vacuum filter has long been a popular method of dewatering sludge from sewage treatment plants and chemical industries. However, the vacuum filtration process has had only limited success when used for coagulated sludge. It is difficult to dewater alum sludge generated from raw water with turbidities between 4 and 10 TU (Westerhoff, 1978). Acid is added to the thickened sludge for aluminum recovery. Acidified alum sludge is easier to dewater.

Vacuum filters are often successfully used for dewatering lime-softening sludge. A pre-coat is necessary with hydroxide sludge. It was reported that vacuum filter dewatering of lime sludge produced final cake solids concentrations in the range of 45 to 65% suspended solids, with an acceptable filtrate produced (AWWA, 1969b). Filter loadings were as much as 293 kg/m2 /h (60 lb/sq.ft/h) of dry solids per filter surface area.

Pressure Filtration - The pressure filter is basically made up of a number of porous filter plates containing depressions, held vertically in a supporting frame. Each plate face is covered with a proper filter cloth. A common feed hole or multiple holes for the sludge inlet extend through the plates. Under pressure, either by mechanical or hydraulic means, sludge is pumped into the filter through the feed holes to the chambers formed by the depressions between the plates. The liquid seeps through the filter medium, leaving the solids behind between the plates. With continual pumping, sludge cakes form and ultimately fill the chamber. After the filtration cycle, the plates are separated and the dewatered solids fall easily to a discharge conveyance. An automatic cake remover can also be used. Details of pressure filters and operational variables are discussed elsewhere (Fulton, 1976; AWWA, 1978b; Vesilind, 1979).

The pressure filtration process was first applied to water treatment plant sludge in the United States in the mid-1960s. Its lack of popularity is due to its cyclical operation. However, the process is popular in Europe. It has been used extensively in the chemical industry for dewatering sludge. A number of different kinds of pressure filters are in the market. Pressure filtration has the capacity of producing filter cakes with a relatively high solid concentration and high-quality filtrate in terms of low suspended solids. The process is flexible and fits any operational mode.

Dewatering of alum sludge by pressure filtration is likely to need sludge conditioning to lower the resistance to filtration. This can be done by the addition of lime, polymers, or fly ash. The choice of conditioning agents is based on the costs for each application. Lime is added to alum sludge to raise the pH of the slurry to about 11 with a minimum contact time of 30 minutes (Westerhoff, 1978). If fly ash from power plants could be used successfully for conditioning alum sludge this would be beneficial to both industries.

Literature on the application of pressure filtration to lime-softening sludge is limited. No conditioning of the lime sludge is required.

Belt Filtration - The belt press, or the belt filter press, consists of two endless filtration fabric belts held in close contact with each other by guide parallel rollers. The lower belt is made of coarse mesh fabric media consisting of twisted metal, plastic, or mixed fibers. The upper belt is solid. The conditioned sludge is fed onto the belt press at one end (draining zone) and is continuously dewatered by the pressure applied between the two belts (press zone and shear zone). The liquid drains off by gravity. The solid cake is scraped off by a blade at the other end of the belts.

A number of belt filter presses have been introduced. These devices have been used in Europe since the early 1960s for dewatering sewage sludge. In the United States, their use for dewatering water plant sludge in full-scale operations is not documented. Although belt presses are widely used in industries, especially in paper and pulp manufacturing, the process has also been successful for sewage sludge dewatering.

In 1982 a belt filter press was installed at the Belvidere, Illinois, wastewater treatment plant to replace two inefficient vacuum filters. In 1980 the plant dewatered 8000 lb/d of dry solids (23.5 tons/d of wet sludge at 77% cake solid from vacuum filters). A three-year operational record showed an average savings of $60,000 in costs for power, labor, and polymers with the belt press. The 1985 total annual cost for operating the belt press was less than $70,000. The final sludge cake from the belt press contained 23% solid.

Pellet Flocculation - Pellet flocculation is a relatively new process and has been developed in Japan, where a few plants have been using it (Chandler, 1982). The device basically consists of a slowly rotating horizontal drum, the reactor, which is divided into three sections. The conditioned sludge is fed into the first section of the reactor, where the rolling action causes the formation of sludge pellets. The liquid is drained off in the second section, and the sludge is consolidated and further dehydrated by the combined effects of piling up and rotation in the final section.

Dewatering of sludge by the pellet flocculation process is a continuous operation. Its operation and maintenance costs are minimal due to the low rotating speed. A study of a pellet flocculation reactor of 0.5-m diameter at the Hula Filter Station, New Zealand, determined that a final sludge cake of 12 to 15% solids was produced from a conditioned sludge feed of 3 to 4% solids. The unit performance depended on the polyelectrolyte dose, feed rate, and reactor speed (Chandler, 1982).

An AWWA Committee Report (1981) described the sludge pelletization occurring during the suspended-bed cold-softening process used primarily in the southeastern United

States. The process seems to work best on high-calcium, warm-temperature ground water. The detention time in a suspended-bed softening reactor is about 8 to 10 minutes. Lime is injected into the reactor while the raw water flow is gradually increased from a low initial rate to design capacity. The lime reacts with calcium bicarbonate and carbon dioxide to form calcium carbonate, which precipitates on the suspended particles. The pelletized sludge contains approximately 60% solids by weight as it leaves the reactor. The volume of pelletized sludge is 10 to 20 times less than that of conventional sludge which is not dewatered. The pelletized sludge has to be transported away for final disposal.

2.7 Sludge Reuse

Sludge is no longer viewed simply as a waste stream but as a saleable product that can provide an additional revenue stream. Treated sludge is already sold to farmers for use as a fertilizer and has been used to improve soil conditions at degraded mine sites and on forestry land. Nutrient-rich sludge streams are ideal media for recovering phosphorus and nitrogen, which can also be extracted from sludge return liquid and incinerated sludge ash. The reclamation of phosphorus from sludge will become increasingly attractive as phosphorus mine deposits are depleted. Sludge and sludge ash can also be used as raw materials in the manufacture of construction products such as cement, mine filler and building bricks. The main opportunity in this market segment is the ability to reduce disposal costs while showcasing a green approach to sludge management to the public.

Depending on the strength of the characteristics of sludge of water works presently generated, more than eleven reuse options were identified globally and are classified into three main categories. Those are;

- Use water work sludge in wastewater treatment process
- Use water work sludge as building & construction materials
- Use water work sludge in land based application
- Use water work sludge in phosphorus removal

Table 2.1 shows the summary of sludge reuse applications given in the literature.

Table 2. 1: Summary of Sludge Reuse Applications

Sludge Reuse	Application	Literature
In wastewater treatment process	Coagulant recovery and reuse	Babatunde & Zhao, 2007
		Bustamante & Waite, 1995
	Coagulant in wastewater treatment	Horth et al. 1994 Mohammed & Rashid, 2012 Kemira.com, 2014
	Adsorbent for pollutants and metals in wastewater	Sujana et al., 1998
		Wu et al., 2004
	Co-conditioning and dewatering with sewage sludge	Lai & Liu , 2004
	Constructed wetland substrate	IWA,2000
As building & construction Materials	Brick manufacturing	Illangasinghe et al., 2015
		Victoria et al., 2013
		Hegazy et al. 2012
		Hegazy et al. 2011
		Chiang et al. 2009
		Ramadon et al., 2008
	Hollow block manufacturing	Kaosol, 2009
	Use in pavement and geotechnical works	Lin et al., 2005
		Okamura et al., 1994
		Sahu et al., 2013
	Manufacture of cement and cementious materials	Alqamet al., 2011
In Land based application	As fertilizer	Miroslav, 2008
Phosphorus Removal from Municipal Wastewater		Mohammed & Rashid, 2012
		Kemira.com, 2014

2.7.1 Use Water Work Sludge in Wastewater Treatment Process

Water treatment sludge especially alum sludge have been used to enhance the treatment performance in waste water treatment process. Such use is to increase the efficiency of the plant (Guan et al., 2005), enhance sewage sludge conditioning (Lai and Liu, 2004) and enhance P removal during waste water treatment (Galareau and Gehr, 1997). Sludge can be used in following ways in waste water treatment process.

1. Coagulant recovery and reuse
2. Coagulant in wastewater treatment
3. Absorbent for pollutants and metals in wastewater
4. Co-conditioning and dewatering with sewage sludge
5. Constructed wetland substrate

2.7.1.1 Coagulant recovery and reuse

In water treatment plants, hydrolyzing metal salts and organic polymers are added to coagulate suspended and dissolved contaminants as a major step towards wastewater purification. The use of such metal salts or organic polymers represents a significant part of the overall treatment process cost and the coagulants form an integral part of the sludge produced. Attempts at recovering and reusing the coagulants embedded in this sludge matrix for use in wastewater treatment process especially for the coagulation of various wastewaters contaminants, dates back to the 19th century with the first patented process by Jewel, W.M in 1903 (Moran and Charles, 1960) cited in Babatunde & Zhao, (2007) and at some later stages, acid treatment followed by the membrane separation techniques was built upon to recover and reuse the entrapped coagulants (Arup and Bo, 1992; Stendahl et al.,2005).

Other recovery methods have included acidifying with sulfuric acid (Abdo, 1993; Vaeziand Batebi, 2001), alkaline treatment (Masscheein and Devleminck, 1985) cited in Babatunde& Zhao (2007),liquid/liquid extraction using the liquid ion exchange (LIE) technique (Dhage et al.,1985; Petruzelli et al., 1998), reduction-acidification concept (Paul et al., 1978), the Donan membrane process (DMP) (Prakash et al. 2003; 2004) and the composite membrane method (Li and Sengupta, 1995). The effectiveness of the recovered coagulants have been generally varied, but nonetheless adjudged satisfactory in most cases. However, the purity of such recovered coagulants remains a contentious issue just as the economy of the recovery process is still a subject of debate. Bustamante and Waite (1995) reported that aluminium recovered from dewatered alum sludge through alkaline leaching was used to effectively reduce phosphorus concentration in wastewater from 9 mg/l to below 1 mg/l. Recently, Stendahl et al. (2005) also reported a multi-step method called the REAL process used to recover the aluminium from the impurities in an alum sludge and thus reuse it as coagulant in water purification process.

2.7.1.2 Coagulant in wastewater treatment

While purity and economic considerations have narrowed the applicability of the coagulant recovery option, several attempts have been made and reported on the direct use of waterworks sludge as a coagulant in the treatment of various wastewaters. Horth et al. (1994) reported a study on the effect of adding aluminium based waterworks sludge to a wastewater treatment plant. It was shown that under certain conditions of optimal alum sludge addition, the treatment and final sludge characteristics at the wastewater treatment plant were improved significantly. In France, it was reported that aluminium hydroxide sludge discharged to a sewer in a treatment plant has proved completely successful with phosphate removal up to 94%, at a dose ratio of 0.3 to 1 corresponding to about 3.5mmole/l of Al (Horth et al., 1994).

2.7.1.3 Adsorbent for pollutants and metals in wastewater

Currently, the development of cost-effective composite adsorbents from by-products is gaining considerable attention, as a possible alternative to commonly used adsorbents. Waterworks sludge is no exception and so far it has been preliminarily studied as a potential adsorbent for the removal of various pollutants and metals in wastewaters, e.g. lead, Copper (Wu et al., 2004a) and fluoride (Sujana et al., 1998). Wu et al. (2004b) also reported that sintered waterworks sludge adsorbed significant amount of toxics from a synthesised toxic wastewater and noted in particular that the sintering process can effectively prevent the release of harmful substances in the waterworks sludge to the environment.

2.7.1.4 Co-conditioning and dewatering with sewage sludge

Although attempts at co-discharging waterworks sludge and sewage sludge are not entirely new, the use of waterworks sludge in co-conditioning and enhancing sewage sludge treatability remains an attractive option in research and practice. Studies have shown the beneficial effect of waterworks sludge as a co-conditioner in sewage sludge conditioning and dewatering process. For example, the findings of a study into the feasibility of co-conditioning and dewatering of alum sludge and waste activated sludge by Lai and Liu (2004) showed that sludge dewater ability and settle ability was enhanced with increasing proportion of alum sludge in the mixed sludge and with a corresponding decrease in the required dosage of the cationic polyelectrolyte.

2.7.1.5 Constructed wetlands substrate

In recent years, constructed wetlands (CWs) have been increasingly used worldwide as a popular alternative technology for the treatment of numerous wastewaters (IWA,2000). Due to their low energy requirement and aesthetical appearance, CWs are seen as a "green" wastewater treatment technique. The media in CWs play an integral role in various biological, physical and chemical processes that remove pollutants from the wastewater. One of the main objectives of research in wetland technology today is to discover new medium material that will increase the effectiveness and, hopefully reduce the capital cost. Traditionally, different combinations of soil, sand and gravel have been used as media in the wetlands. Numerous studies have shown that the wetlands based on these conventional media are capable of meeting the requirement of BOD_5 and COD reductions. However, it is often difficult to achieve substantial removal of certain in organic nutrients, e.g. orthophosphate and ammoniacal-nitrogen, in wetlands with the conventional media.

2.7.2 Use Water Work Sludge as Building and Construction Materials

Even though the water treatment sludge have been preliminary studied and used as building construction materials, still they are to be fully accepted in the industry. Efforts made so far for incorporating them into the construction industry are as follows.

- Brick manufacturing
- Hollow block manufacturing
- Use in pavement and geotechnical works
- Manufacture of cement and cementious materials

2.7.2.1 Brick manufacturing

Due to the clay-like nature of the dewatered sludge, the use of it in the manufacturing of burnt clay bricks has become an area of interest for researchers who investigate the use of the sludge as a secondary raw material. A study was done using the sludge from the Meewatura water treatment plant, Kandy, Sri Lanka, to find out the suitability of water treatment sludge as a raw material for local clay brick manufacturing industry (Illangasinghe et al., 2015). Air dried sludge at the Meewatura sludge drying lagoons were collected and mixed with clay in the proportions 25%:75% and 50%:50% by volume. A set of bricks consisting of the manufacturer's original composition of clay and earth was made as a control sample. In order to assess the quality, the manufactured bricks were tested for dimensions, compressive strength, water absorption and efflorescence. All tests were conducted in accordance with SLS 39:1978.

The results showed that the dimensions of all the sets of bricks, including the manufacturer's original composition, were out of the tolerance limit and the compressive strength was less than the standard strength. Also the brick samples using the sludge exceeded the specified water absorption limits. The study concluded that the dried sludge in combination with clay could not produce bricks with expected standards. Further studies with less sludge percentage and mixing with other locally available materials were encouraged.

Victoria (2013) did a similar study in Nigeria, in which water treatment sludge was used as a supplement for clay. The sludge was used in five different mixing ratios of 0, 5, 10, 15 and 20 percent of total weight. These bricks were fired at five different temperatures of 850°C, 900°C, 950°C, 1000°C and 1050°C. The physical properties of the produced bricks were then determined and evaluated according to Nigerian Standard Specifications and British Standard Specifications and compared to control brick prepared from clay. From the results obtained, the study concluded that the sludge proportion in the mixture and the firing temperature are the two key factors affecting the quality of bricks and the water treatment plant sludge can be used as brick material for improved workability and physical appearance for environmental sustainability.

Hegazy et al. in 2011 have conducted a study on brick making, in which water treatment sludge was incorporated with Silica Fume (SF) and used as a complete substitution for brick clay. The sludge was incorporated with varying proportions of Silica Fume (SF). The objective was to produce a lab scale brick units made by mixtures of sludge & SF with various ratios, through the sintering process, that meet the Egyptian standard specification. The considered samples were sludge to silica fume in the following proportions; 25%: 75%, 50%: 50%, 75%: 25% by total weight of the mixture. A 100% clay bricks were made as a control sample. These bricks were fired at temperatures of 900, 1000, 1100, and 1200 ^{0}C. The physical and mechanical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications (E.S.S.) and compared to control brick made entirely from clay. From the results obtained, it was concluded that by operating at the temperature commonly practiced in the brick kiln, 50 % was the optimum sludge addition to produce brick from sludge-SF mixture. The properties of produced bricks were superior to control clay brick.

Another similar study was done by Hegazy et al. in 2012, in which water treatment sludge was incorporated with varying proportions of Rice Husk Ash (RHA) and used as a complete substitution for clay. The RHA was, one of the most common agricultural wastes in Egypt. RHA contains high amounts silica. The objective was to provide an environmentally sound manner to reuse both the water treatment sludge and rice husk ash. The considered samples were sludge to rice husk in the following proportions; 25%: 75%, 50%: 50%, 75%: 25% by total weight of the mixture. A 100% clay bricks were made as a control sample. They were fired at900, 1000, 1100, and 1200 ^{0}C. The physical and mechanical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications (E.S.S.) and compared to control brick made entirely from clay. From the results obtained, it was concluded that by operating at the temperature commonly practiced in the brick kiln, 75 % was the optimum sludge addition to produce brick from sludge-RHA mixture.

The complete substitution of brick clay by water treatment sludge incorporated with varying proportions of Rice Husk Ash (RHA) and Silica Fume (SF) were investigated by Hegazy et al. (2012) in Egypt. RHA is one of the most common agricultural wastes in Egypt contains high amounts silica. The SF is a byproduct of producing silicon metal or ferrosilicon alloys in smelters using electric arc furnace. Three different series of sludge to SF to RHA proportions of (25%: 50%: 25%), (50%: 25%: 25%) and (25%: 25%: 50%) by total weight of the mixture was prepared. A 100% clay bricks were made as a control sample. Each four series bricks were fired at temperatures of 900, 1000, 1100, and 1200 ^{0}C. The physical and mechanical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications (E.S.S.) and compared to control brick made entirely from clay. From the results obtained, it was concluded that by operating at the temperature commonly practiced in the brick kiln, A mixture consists of 50% of WTP sludge, 25% of SF and 25 % of RHA was the optimum sludge addition to produce brick from water treatment sludge, SF and RHA mixture.

A similar study has been carried out in Taiwan by Chiang et al. (2009) to investigate the use of water treatment sludge together with rice husk in manufacturing light weight bricks. Rice husk contains above 90% silica with a highly porous, lightweight specific surface area. The increasing trend in water treatment residual production and the large rice husk waste production has motivated the Taiwan Government to encourage beneficial reuse.

According to the modern green building concepts, the amount of inner pores in bricks is a critical factor contributing to the thermal insulation capability of bricks. Lightweight bricks are usually manufactured by adding combustible additives as a foaming agent while controlling the appropriate amount of pores, particle size and firing temperature. The type of additives to be used for this is a topic of interest. Keeping pace with this concept, the experiment was carried out with dried Water Treatment Plant (WTP) sludge and rice husk mixed together. The considered additions of rice husk were 0, 5, 10, 20, and 25% (by weight). Compacted samples were prepared by adding 20% water to the dry powder and uni-axially pressing at 60 kgf/cm^2 (800 psi) to form 20mm diameter cylindrical specimens that were approximately 55mm high.

The temperature was increased at 5◦C/min in an electric furnace. The temperature was then increased to a sintering temperature between 800 and1100 ◦C and held for 180 min. The sintered samples were tested for bulk density, water absorption, and dimensional change after sintering, compressive strength and Micro-structural analysis of sintered specimens. The results obtained indicated that the bulk density of the proposed sintered product decreased significantly with increasing rice husk addition and decreasing sintering temperature. The compressive strength gradually decreased with increasing rice husk addition. Therefore, to simultaneously enhance the bulk density and compressive strength, further research to study the optimum rice husk addition amount, initial pressing pressure and firing temperature profile was encouraged. The amount of open pores in the sintered products manufactured from WTP sludge and rice husk addition showed a gradual increase compared to bricks made from WTP sludge alone. Thus it was concluded that the sintered products have good thermal insulation properties for future green building applications.

Ramadan, (2008) did a study in Egypt, in which water treatment sludge was used as partial substitute for clay. The considered samples were sludge to clay in the following proportions; 50%: 50%, 60%: 40%, 70%: 30% and 80%: 20% by total weight of the sludge clay mixture. These bricks were fired at temperatures of 950°C, 1000°C, 1050°C and 1100°C. The physical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications and British Standards. From the results obtained, 50 % was the optimum sludge addition to produce brick from sludge-clay mixture with operating at the temperature commonly practiced in the brick kiln.

2.7.2.2 Hollow Concrete Block Manufacturing

Concrete block is used as building construction material in the construction of walls and gaining importance in developing countries. A study has been carried out to utilize the water treatment sludge as fine aggregate in the concrete mix for hollow concrete block. The concrete used to make hollow concrete block was mixture of powdered Portland cement, sand, cement, water treatment sludge, crushed stone dust and water. The samples were prepared using the fine aggregate partially replaced by water treatment sludge at the percentage of 10, 20, 30, 40 & 50. From the results obtained, it was concluded that optimum water treatment sludge addition of 10% and 20% in mixture to make hollow load bearing concrete block and 50% in mixture to make hollow non load bearing concrete block. Also it will be a profitable disposal alternative in the future.

2.7.2.3 Paving Blocks / Bricks

According to Cheng-Fang Lin et al. (2005) molten slag originating either from bottom/ fly ash or sludge, can be converted into pavement bricks which are widely used in public areas in Japan, providing an excellent sustainable practice. Most bricks sintered from molten slag, water treatment sludge and recovered sludge/ash mixtures can exhibit satisfactory engineering properties (Wiebusch and Seyfried, 1997; Liaw et al., 1998; Nishigaki, 2000 cited in Recovery of municipal waste incineration bottom ash and water treatment sludge to water permeable pavement materials by Cheng-Fang Lin et al. 2005).

For instance, Nishigaki (2000) produced pavement bricks with compressive strength of 1278 kg/cm2 from molten slag. The bricks made from water treatment sludge by a sintering process exhibit a compressive strength of 1150 kg/cm2 at 1100 _C, which is higher than the Japanese Industrial Standards (JIS) brick no. 3 of 200 kg/cm2 and Chinese National Standards (CNS) brick no. 1 of 150 kg/cm2 (Sun, 2001). However, the major point that limits its application as pavement bricks is the low water permeability, especially when considering the heat phenomena encountered. Without using special materials and procedures, a permeability of 0.01 cm/s is almost unachievable in regular brick-making process (Ho, 2003).

Natural clay has been widely used in making bricks with low water permeability, because after sintering process the compressed fine clay particles will seal the inner pores to limit water permeating through the brick. If replacing clay with coarse sand, the brick will exhibit a better water permeable property but bears a low compressive strength due to the larger pores within the brick. Therefore, some researchers have developed new methods making water permeable blocks while using recovered materials such as melting slag, bottom and fly ash, and water treatment and sewage sludge (Okamura et al., 1994). Those methods all involve a key step of producing artificial aggregate which acts as coarse medium providing pores for water to infiltrate through. At the same time, clay is added to serve as binding agents during the sintering process. Some successful examples have been reported from Okamura et al. (1994) and Nishigaki (2000). The bricks produced generally have comparable compressive strength of larger than 170 kg/cm2 and reliable water permeability larger than 0.01 cm/s.

Another study by Vaishali Sahu et al. (2013) identified that the sludge can be used in producing pavement blocks. The compressive strength results indicate that the pavement blocks of 10% and 20% sludge as a substitute for cement provide more than 80% of the strength of commercial blocks with no sludge. Water adsorption of each block meets BIS requirement. When sludge is used for building blocks, with increase in percentage of sludge the compressive strength is found to be decreasing.

Also Morais et al. stated that in recent years, various uses of incinerator ash have been developed in order to ease the burden of the disposal. For example, the ash has been used to replace part of the Portland cement to make construction materials, e.g. brick, paving block, and tile.

2.7.2.4 Paving tiles

Several studies have been carried out on the use of sludge as a cement replacement. One such study had been done in Jordan to investigate the use of water treatment sludge in the production of paving tiles meant for external use (Alqamet et al., 2011). The sludge was incorporated in the lower layer of the paving tile as a cement replacement. The objectives of the study were to reduce the cost of production of the construction material and simultaneously provide an environmentally friendly option for the disposal of the increasing amounts of sludge generated by the water treatment industry.

Sun dried ferric chloride sludge was used in this application in different proportions of cement-sludge replacement. The considered replacement percentages were 10%, 20%, 30%, 40% and 50%. The produced tiles were tested for breaking strength, water absorption and leaching of sludge metals. The results showed that all tiles produced were non-vitreous, with a water absorption rate of approximately 10%. With the exception of 50% sludge-cement replacement, the other samples showed a development of breaking strength with age. All of the tiles produced had complied with the minimum breaking strength of 2.8 MPa required by the BS EN 13748-2:2004 standards. Additionally, the study concluded that a decrease in the breaking strength of tiles is accompanied with an increase in the amount of sludge-cement replacement. Also a linear relationship was produced to predict breaking strengths of tiles produced with sludge-cement replacement percentages not investigated in this context. That study showed that very low concentrations of metals are detected in the Toxicity Characteristic Leaching Procedure (TCLP) leachate of tiles.

The investigation ultimately concluded that sludge-cement replacement can potentially be used to yield paving tiles that comply with the standards for tiles intended for external use leading to a significant reduction in the cost of tiles and provide a safe and environmentally sound option for the disposal of water treatment sludge.

2.7.3 Land Based Applications

Land-based application of waterworks sludge is the controlled spreading of the sludge onto or incorporation into the surface layer of soil to stabilize, degrade and immobilize the sludge constituents (Elliot and Dempsey, 1991). Historically, the most notable land application of waterworks sludge is the use of lime softening sludge as a substitute for agricultural limestone. Currently land based applications of waterworks sludge are gaining increasing attention as alternative disposal means (Basta, 2000; Titshall and Hughes, 2005). This is most probably hinged on the fact that the physical, chemical and biological properties of soils can be used to assimilate the applied waste without adverse effects on soil quality (Elliot and Dempsey, 1991) and even with the possibility of enhancing soil quality (Roy and Coulliard, 1998). In comparison with land filling option, land based applications are viewed as a low cost and favourable alternative, which may not necessarily require regulatory permits, although considerable land area may be needed. Over the years, the scope of such applications have typically been as a sustainable means to dispose waterworks sludge, improve or reclaim certain soil qualities or used as part of growing medium for crops. The major concern however has been its perception as a metal hydroxide waste, which could have potential deleterious effect on both soil and crop planted. On the basis of this review, three main factors are crucial to the success of the land based applications, such as Determining the optimum effective application rate with the least consequences, the particular nature of the sludge and the exact intent of the application.

With regards to the disposal of waterworks sludge, potential toxicity to the surrounding environment is a primary concern for both public & environmental authorities. Because of toxicity it may affect the receiving water quality. Reuse of waterworks sludge is a sustainable end point solution and it has been preferred as an alternative to sludge disposal. Reuse of water work sludge in various commercial and manufacturing process have been reported in UK, Europe, USA and Australia.

2.7.3.1 Use of sludge as a fertilizer

The use of alum sludge on croplands is an area of study that has been investigated by several researchers. According to Elliott et al. (1990) (cited in Environmental Protection Agency, USA, 1996) implementation of this method of disposal should not adversely affect the fertility and physical properties of the soil, for it to be considered a successful method. The physical characteristics of soil that determine whether it can support vegetative growth include cohesion, aggregation, strength, and texture. These parameters directly affect the hydraulic properties of a soil, such as moisture-holding capacity, infiltration, permeability, and drainage. Any adverse impact on these hydraulic soil characteristics from land-applied WTP residuals can affect crop growth and ultimately degrade ground water quality.

In the coagulation process of water treatment, the aluminum sulphate transforms into aluminum hydroxide that is similar to alumina hydroxides present naturally in soil. The aluminum hydroxide can increase the buffering capacity of the soil and increase adsorption of some ions or compounds. The adsorption can be either favourable or harmful, depending on the characteristics of sludge and types of plants. The possible effects are identified as the decrease of contents of usable phosphorus in the soil, alumina toxicity for plants and withdrawal of heavy metals in sludge by plants (Lucas et al. cited in Miroslav, 2008).

In a study done on possible reuse of water treatment sludge, Miroslav (2008) refers to an experiment carried out with alumina sludge in Newport, USA. The aim of the investigation had been to monitor the crop of fescue grass and the contents of metals in plants following the application of alumina sludge (Lucas et al. cited in Miroslav, 2008). The study went on to conclude that the alumina sludge slowed down the growth of the fescue grass because it blocked phosphorus in the soil. Application of additional phosphorus had increased the crop of the fescue grass by decreasing the phosphorus deficit caused by the sludge. The sludge loading had increased the concentration of Mn in vegetable tissues. However, the influence of the higher Mn concentration on the growth of the fescue grass had been very little. Also the sludge loading had increased the concentration of Cu in vegetable tissues.

A research was done by Bugbee and Frink (1985) to identify the use of alum sludge as a soil amendment. The study had two main objectives: the first was to substitute dried alum sludge for various constituents in potting soil mixtures, and to measure their ability to support plant growth. The second objective was to spray wet alum sludge on forest plots and measure effects on soil, litter decomposition, and tree growth.

For the experiment on using alum sludge as a potting medium, seven different combinations of dried alum sludge with regular potting medium was considered. The alum sludge was obtained from two different raw water sources. After the study, it was concluded that dried alum can improve the aeration and available moisture holding capacity of a less than optimum potting media. Also deficiencies in plant-available phosphorus that occurred in media amended with alum had been probably due to phosphorus fixation by aluminum. To further study the phosphorus deficiency, a second experiment was conducted in two methods: the first by doubling the phosphorus fertilization and the second by adjusting the percentage of added alum sludge. This experiment gave results that indicated that Phosphorus deficiencies caused by addition of dried alum could not be overcome by doubling the initial phosphorus fertilization.

For the next experiment two types of forest areas were selected and liquid alum sludge was applied on to 15m x 11m plots. The application was done in two steps; one half in the fall of that year and the next half in the spring of the next year. The alum sludge was sprayed from a fire hose connected to a tank. Soil samples were taken from each plot prior to the alum sludge addition and the diameter at breast height (DBH) of each tree in the plot was measured. One year later, soil samples were taken and analyzed, DBH of each tree was taken and needles and leaves were analyzed for the uptake of nutrients. No significant change had been observed except for the pH value of the top soil has been raised by 0.5 to 1.0 units.

The study concluded that dried alum sludge improved the physical properties of potting media and acted as a liming material. However the growth of plants were restricted by phosphorus deficiencies induced by the ability of the alum to adsorb phosphorus in fertilizer and convert it into forms unavailable for plant growth. No toxic effects of the sludge or any of its constituents were observed.

Liquid alum sludge sprayed on deciduous and coniferous forest plots at the rate of approximately 124,800 gal/ acre had increased soil pH by about 0.5 to 1.0, but has had no effect on the nutrition or growth of the trees.

2.7.4 Use of Sludge for Phosphorus Removal

2.7.4.1 Use of oven dried Alum sludge for Phosphorus removal

Industrial and municipal wastewater contains high concentrations of orthophosphates which contribute to the eutrophication of natural water bodies through excessive algae growth. Thus it is imperative that Phosphorous is removed from the effluent before it is being discharged to a natural water body (Lenntech Water Treatment Solutions, 2015.). Thus it is considered one of the major challenges in wastewater treatment plants. Processes that are currently in use for this purpose can be categorized into chemical, physical, or biological-based treatment systems (Mohammed and Rashid, 2012).

One of the common physical-chemical P-removal processes is the removal through phosphorous through precipitation. Chemical precipitation is used to remove the inorganic forms of phosphate by the addition of a coagulant. The most frequently used are calcium, aluminium and iron. The basic reaction for phosphorous precipitation by aluminum is $Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4 + nH^+$ (Lenntech Water Treatment Solutions, 2015). A study has been carried out by Mohammed and Rashid (2012) of University of Baghdad, Baghdad, Iraq to explore the efficiency of Alum sludge from water treatment plants for this purpose. Aluminum-based residuals have been known to be a viable option for being an effective phosphorus removal material. Alum is typically effective in phosphorus removal in chemical precipitation process (Aguilar et al. (2002) cited in Mohammed and Rashid, 2012).

The test has been carried out by using oven-dried alum sludge for adsorption of orthophosphate from deionized water and the results were compared with the conventional adsorbent (i.e., activated carbon). The alum sludge was heated in an oven at for 24 hours and then cooled at room temperature. The sludge particles were then crushed to produce a particle size of 0.5–4.75 mm. The study concluded that the oven-dried alum sludge was effective in adsorbing phosphorus from deionized water. The percent removal of phosphorus had shown an increase with increase in the oven-dried alum sludge dose.

2.7.4.2 Eutrophic lake recovery

Lakes are a vulnerable and significant part of the ecosystem. Both natural and artificial lakes are the home to a wide variety of plants and animals, as well as popular recreation spots. Pollution from various sources such as municipal and industrial flows or seepage from agriculture nearby can damage the complex ecosystem of the lake. Eutrophication of lakes follows from excess amounts of nutrients such as phosphorus leading to excessive growth of algae as well as plant and fish deaths (Kemira.com, 2014).

One of the proven methods of reducing eutrophication in lakes is the control of phosphorus input (Schindler, 2012). The mode of doing so is to precipitate the phosphorus at the input source. P removal through aluminum hydroxide is one of several methods that have been identified to serve this purpose.

According to Cooke, Welch and Peterson (2013), as published in the book, Lake and Reservoir Restoration, Harper et al. (1983) had been the first to attempt to use $Al(OH)_3$ sludge, formed during flocculation-clarification process of drinking water treatment, to attempt P removal from water entering a lake. The process has been tested for Lake Eola, Florida, USA, which had become eutrophic from storm water inflows. A filtration system had been built and a 50-50 mixture of sludge and coarse sand had been used as the filter medium. The filtered water had been discharged to the lake. The filtration system had removed 99% of orthophosphate and 80% of total P as well as more than 70% of suspended solids and organic N.

However, several negative impacts of this procedure have also been identified. If a drinking water treatment plant extracts water from a eutrophic reservoir, the produced sludge (by aluminum sulphate addition) will be high in total P and organic matter. The addition of such sludge for lake restoration will result in addition of excessive amounts of BOD and phosphorus, thereby defeating the purpose of treatment.

Also the addition of alum may have adverse effects on aquatic life (George et al, 1991). Lake treatment with alum may also be a potential hazard if bioaccumulation of aluminum occurs, which could result in high concentrations of dissolved aluminum in poorly buffered waters. Therefore the authors have encouraged further studies on the bioaccumulation of aluminum in various lake organisms.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Methodology of Overall Study

This research was conducted to determine the current sludge management practices and to investigate the sustainable disposal practices by re using the sludge in Civil Engineering Construction. Figure 3.1 shows the flow chart of the methodology.

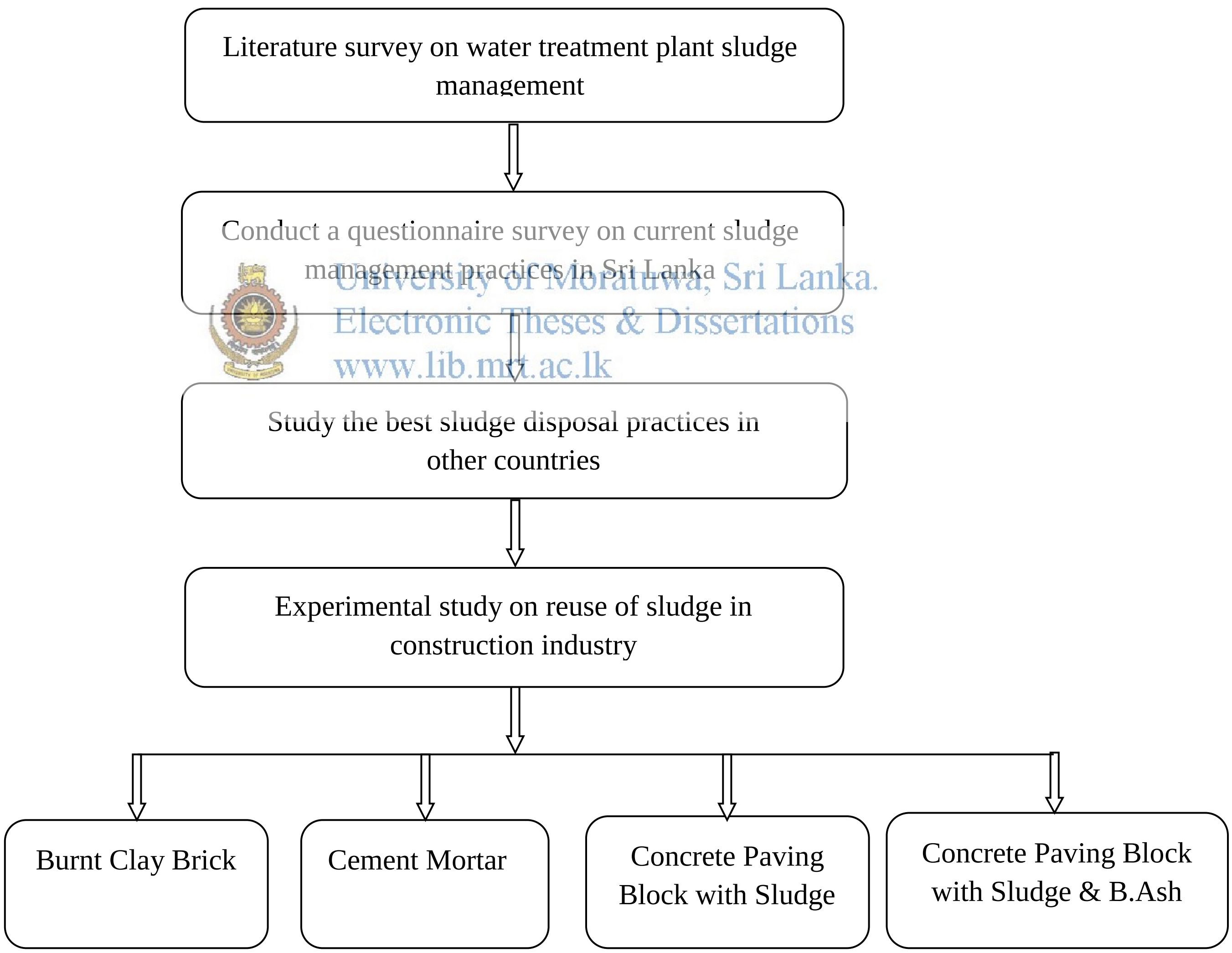

Figure 3.1: Flow Chart of the Methodology

3.2 Questionnaire Survey on Current Sludge Management Practices in Sri Lanka

In order to obtain the details of current sludge management practices in water treatment plants in Sri Lanka, a questionnaire (Appendix A) was prepared and circulated among the water treatment plants having a capacity of more than 5000m^3/day of National Water Supply and Drainage Board.

The key parameters obtained through the questionnaire survey are;

A. Capacity
B. Raw water source & quality
C. Water treatment process / method used
D. Chemical used in treatment process, especially coagulation
E. The quantity and composition of sludge produced by water treatment plants
F. Methods of handling and treatment of sludge
G. Ultimate sludge disposal method and beneficial uses
H. The cost of sludge treatment and disposal, if available

A Questionnaire was circulated to 35 Water Treatment Plants of the National Water Supply and Drainage Board. Table 3.1 and Figure 3.2 shows the name and location of WTPs used for this study.

Table 3.1: Selected Water Treatment Plants Used for this Study

No.	Name of WTP	District
1	Ambatale	Colombo
2	Kalatuwawa	Colombo
3	Labugama	Colombo
4	Kandana	Kalutara
5	Kethhena	Kalutara
6	Bambukuliya	Gampaka
7	Raddoluwa	Gampaka
8	Paradeka	Kandy
9	Ulapane	Kandy
10	University	Kandy
11	Katugastota	Kandy
12	Arattana	Kandy
13	Meewathura	Kandy
14	Eluduwa	Badulla
15	Embilipitiya	Ratnapura
16	Ratnapura	Ratnapura
17	Udawalawa	Ratnapura
18	Hiriwadunna	Kegalle
19	Morontota	Kegalle
20	Mawanella	Kegalle
21	Wakwella	Galle
22	Hapugala	Galle
23	Baddegama	Galle
24	Hallalla	Matara
25	Malimbada	Matara
26	Nadugala	Matara
27	Ranna	Hambantota
28	Kirindioya	Hambantota
29	Tangalle	Hambantota
30	Kanthale	Trincomalle
31	Wavunathivu	Baticollo
32	Pothuvil	Ampara
33	Thirukkovil	Ampara
34	Konduwatuwana	Ampara
35	Eachchalampattu	Trincomalle

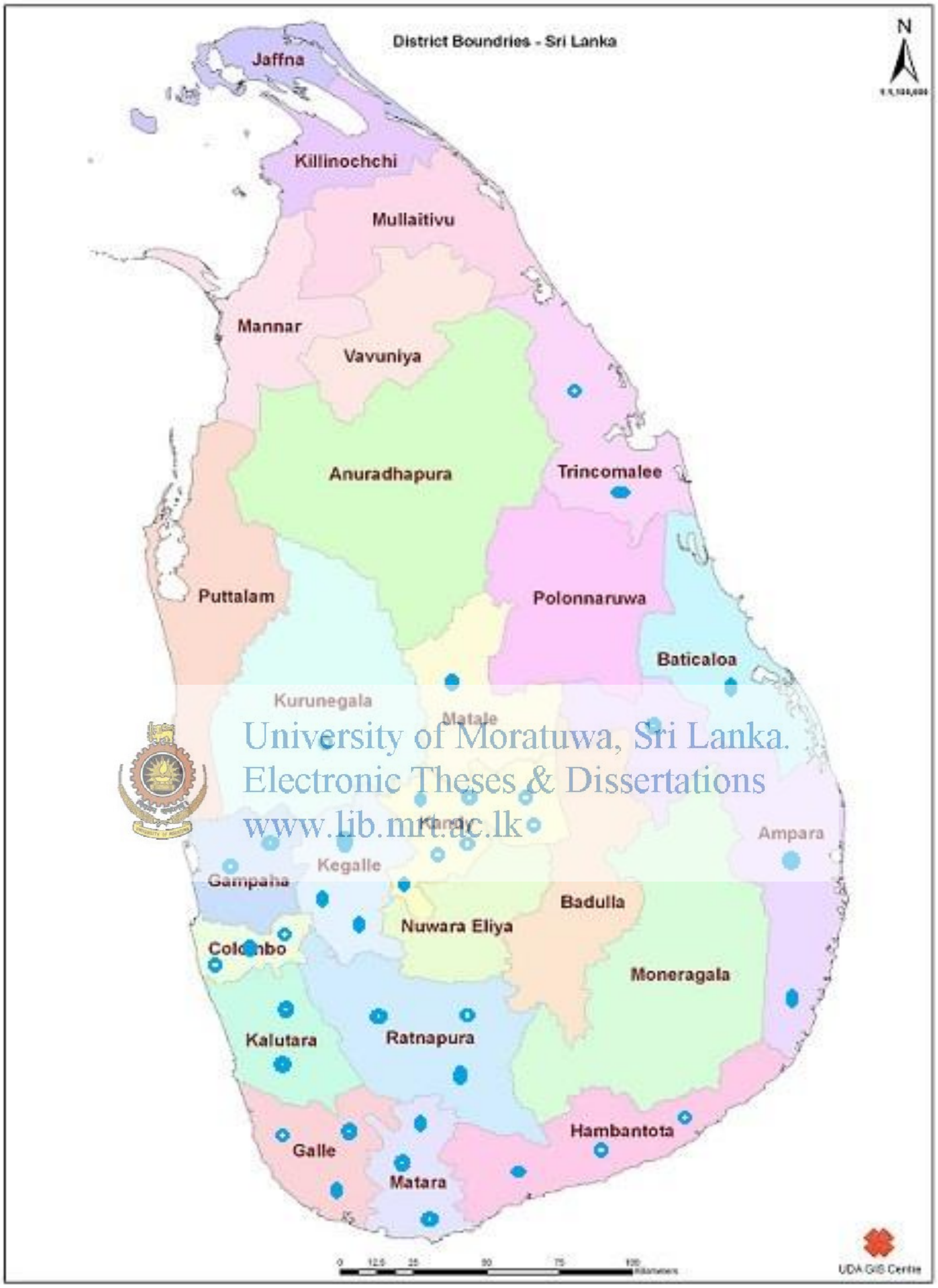

Figure 3.2: Selected Water Treatment Plants for the Study

Data collected through the questionnaire survey was summarized and reviewed to determine the current sludge management practices.

3.3 Reuse of Water Treatment Sludge in Brick Manufacturing as Substitute for Clay

3.3.1 Water Treatment Plant (WTP) Sludge

The sludge (1) used in this study was collected from the sludge drying bed of the Kethhena Water Treatment Plant, located in Kalutara, using Poly Aluminum Chloride (PAC) as coagulant. The sludge produced in the sedimentation tank and filter is directly fed to the sludge drying bed for air drying. The dried sludge was used in brick making without further treatment.

The sludge (2) used in this study was collected from the sludge lagoon of the Kandana Water Treatment Plant, located in Horana, using Alum (Aluminum Sulfate) as coagulant. The sludge produced in the sedimentation tank and filter is directly fed to the sludge lagoons for air drying. The dried sludge was used in brick making without further treatment.

3.3.2 Clay

The clay used in this sludge was the commercial local clay obtained from the selected local brick manufacturer in Dankottuwa, Negombo. The clay was air dried for three days in a cool dry place.

3.3.3 Characterization of Water Treatment Plant (WTP) Sludge

3.3.3.1 Moisture Content and Volatile Organic Content

The test was carried out according to ASTM D 3173 for both sludge samples. The moisture content of the sludge was determined in triplicate by heating samples of known weight to $110^{o}C$ for 24 hours.

Following the moisture content, the same samples were used to determine the Volatile Organic Content (VOC) by heating to $550^{o}C$. The test was carried out according to ASTM D 3175 standards for both sludge samples.

3.3.3.2 Particle Size Distribution

Sieve analysis was carried out according to BS 812: Part 103: 1985. Both sludge samples were tested for particle size distribution separately. The testing procedure was as follows;

Step 1: Ensured that all the sieves are clean, and assembled in the ascending order of sieve numbers. The sieve sizes are 4.25, 2.800, 1.180, 0.850, 0.600, 0.300, 0.150 and pan. Sludge samples were carefully poured into the top sieve and the cap placed over it.

Step 2: Placed the sieve stack in the mechanical shaker and was shaken for 5 minutes.

Step 3: Removed the stack from the shaker and carefully weighed and recorded the weight of each sieve with its retained sludge.

3.3.4 Characterization of Clay

3.3.4.1 Moisture Content and Particle Size Distribution

The moisture content of the clay sample was determined in triplicate by heating samples to 110ºC for 24 hours and the sieve analysis was carried out by the same procedure followed for the sludge.

3.3.5 Manufacturing Process of Bricks

The local large scale clay manufacture in Dankotuwa area was chosen as manufacturer.

3.3.5.1 Collection of Material

The sludge (1) in the sludge drying bed of Kethhena Water Treatment Plant and the sludge (2) in the sludge lagoon of Kandana Water Treatment Plant were collected in different gunny bags and transported to the brick manufacturing site and clay was collected in the manufacturing site. Both sludge and clay was air dried for 4-7 days depending on the weather condition.

3.3.5.2 Preparation of Samples

Batching method by volume was used in mixing the bricks components to produce the bricks with the slandered size of 220mm length, 105mm width and 65mm high as per the SLS 39:1978.

To investigate the effects of sludge on the properties of sludge clay bricks, the groups of mixtures were randomly prepared for both sludge 1 and 2 separately. The percentage of sludge used as supplement for clay is shown in Table 3.2. Also 100% clay bricks were also prepared as control sample. A total of 210 bricks were produced by 30 individual bricks in each mix. Moisture content tests were carried out for each mix.

Table 3.2: Composition of Brick Materials

	Mix No.	**Replacement Percentage of Sludge (%)**	**Percentage of Clay (%)**
Sludge 1	1	10	90
	2	20	80
	3	30	70
Sludge 2	1	10	90
	2	20	80
	3	30	70
Control Sample	4	0	100

The measured sample of brick material was spread using a shovel to a reasonably large surface area, until homogeneous mix with uniform colour was obtained. Then sludge was spread evenly on the clay and the composite material thoroughly mixed with the shovel. The mixing was done on an impermeable surface made free from harmful material. The water was gradually added to the dry mixture while mixing, until optimum moisture content was obtained.

Hand mould method with the wooden mould size of 210mmX105mmX65mm was used for brick casting. The internal faces of the wooden mould were lubricated with water for easy removal and to get a smooth surface. The mixture was placed in a mould and compacted. The excess mixture was scraped off and the surface was leveled. Three sludge- Clay bricks series for both sludge and sample containing only clay as reference specimen were made and each bricks were clearly marked and numbered to identify it. Casted bricks were stacked at the site for three days for air drying together with the regular batch as shown in Fig 3.3and loaded to the kiln for burning. After cooling, the bricks were transported to the University of Moratuwa for testing.

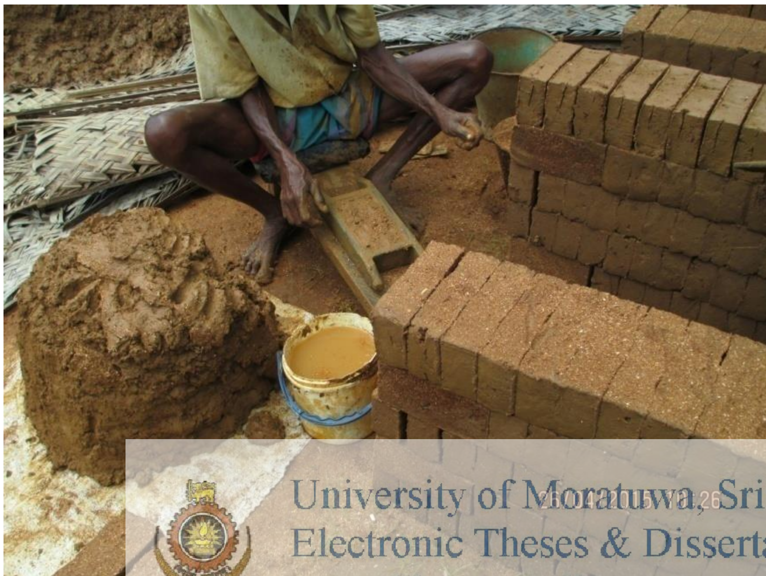

Figure 3.3: Casting Bricks and Stacked in the Site for Drying

3.3.6 Determination of Properties of Bricks

Tests were carried out according to the Sri Lankan Standard39:1978, Specification for common burnt clay building bricks. All four Parameters specified in the specification were tested in order to assess the quality of bricks such as dimensions, compressive strength, water absorption and efflorescence.

3.3.6.1 Dimension

Twenty Four bricks (24) were selected from each set and grouped. The overall dimension was measured by placing each set of 24 bricks in contact in a straight line, upon a level surface using the appropriate arrangement for any blisters, small projections or loose particles of clay adhering to each brick were removed. The overall dimension of each set was measured to the nearest millimeter, using the inextensible (length, width, high) steel tape as shown in Figure 3.4.

Figure 3.4: Dimension Test on Bricks

3.3.6.2 Compressive Strength

Ten bricks (10) were selected from each mix type. The overall dimension of each bed surface was measured and the area was calculated. Bricks were immersed in water for 72 hours at the room temperature. After 72 hours immersion bricks were removed and allowed to drain at room temperature, wiped surplus moisture and subjected to the test.

Bricks were placed between 2 plywood sheets and carefully centered between the platens of the machine as shown in Figure 3.5. Then the load was applied axially to the direction of thickness of the brick until failure occurs. The maximum load at failure was noted. The compressive strength was calculated by dividing the maximum load at failure by the area of the face on which load was applied. Averages of 10 bricks were calculated for each set separately.

Figure 3.5: Compressive Strength Test on Bricks

3.3.6.3 Water Absorption

Five bricks (5) of each mix were selected and dried to constant mass, in a well ventilated oven at 100°C to 115°C and they were cooled to approximately room temperature and weighed. The dry bricks were immersed in water at room temperature for 24 hours as far as possible to each surface has free access to water. Each bricks were removed and surface water wiped off with a damp cloth and weighed in a balance sensitive to about 0.1% of brick weight. The percentage of water absorption were calculated by subtracting the dry weight from the mass of the brick after immersion and divided by mass of the dry brick in to 100%.

3.3.6.4 Efflorescence

Bricks of each mix were placed in a shallow flat bottom dish having an area of 0.1$m^2$and distilled water was placed to the depth of 25mm. It was placed in a well-ventilated room until all the water in the dish evaporates. When the water had been absorbed and bricks appeared as dry, similar quantity of water was placed in the dish and allowed to evaporate as earlier. Then bricks were examined for Efflorescence.

3.4 Reuse of Water Treatment Sludge in Cement mortar as substitute for cement (Binding material)

3.4.1 Water Treatment Plant Sludge

The sludge used in this study was collected from the sludge lagoon of the Kandana Water Treatment Plant, located in Horana. The dried sludge was used in preparation of mortar.

3.4.2 Sand

Natural sand was used.

3.4.3 Ordinary Portland Cement

Ordinary Portland cement (OPC) made by Tokyo super was used as the binding material, which belongs to the strength class of 42.5kN and in compliance with SLS 107: specification for OPC.

3.4.4 Characterization of Water Treatment Plant Sludge

3.4.4.1 Specific Gravity

Specific gravity test was carried out according to BS 812: Part 107: 1988
(Appendix B)

3.4.5 Characterization of Sand

3.4.5.1 Specific Gravity and Particle Size Distribution

Specific gravity test was carried out according to BS 812: Part 107: 1988 as specified in 3.4.4.1 above. Sieve analysis was carried out according to BS 812: Part 103: 1985 as specified in 3.3.3.2 above.

3.4.6 Preparation of Mortar

The ICTAD specifications for mortars specify the ratio of Cement: Sand for mortar can be 1:5 to 1:8. A proportion of 1:5 was chosen for this research; hence it is widely used in practice. To investigate the effects of sludge on the properties of mortar, the groups of mixtures were randomly prepared. The percentage of sludge used as supplement for cement is shown in Table 3.3.Batching method by weight was used in mixing the mortar components to produce the samples as per the BS 4551: Part 1:1998. Mortar was made manually at the Building materials laboratory of the University of Moratuwa.

Table 3.3: Composition of Binding Materials in Mortar

	Mix No.	Binding Material	
		Replacement Percentage of Sludge (%)	Percentage of Cement (%)
Control Sample	1	0	100
Sludge	2	10	90
	3	20	80
	4	30	70

3.4.7 Determination of Properties of Mortar Samples

Mortar tests were done for both fresh state flow and hardened state compressive strength.

3.4.7.1 Fresh state – Flow by Flow Table Test

This test was carried out as per BSEN1015: Part 3: 1999. All Four mortar mixes shown in Table 3.3were prepared with the water cement ratios of 0.5, 0.7, 0.9, 1.1, 1.3 &1.5.The testing procedure was as follows;

Step 1: The flow table was wiped clean and dry and mould was placed at the center of the flow table

Step 2: Sample was filled in two layers; each layer was tamped 20 times with a tamper. The mould was held firmly in place during the operation.

Step 3: The excess mortar was removed from the top of the mould with a palette knife and the area around the base of the mould was cleaned with a cloth as shown in Figure3.6. Then mould was removed.

Step 4: Immediately, the table was raised and dropped 25 times within 15 seconds.

Step 5: The diameter of the spread mortar was measured in two directions at right angles as shown in Figure3.7. Test was repeated once again to get more accurate result.

Step 6: The average of these four values was calculated. The flow is resulting increase in average base diameter of the mortar and flow was expressed in the percentage of the original base diameter.

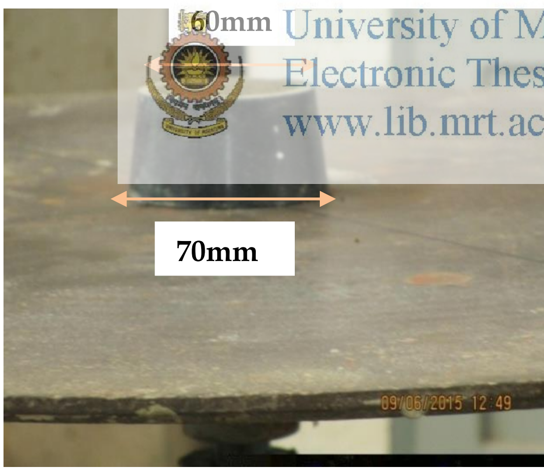

Figure 3.6: Flow Test Mould

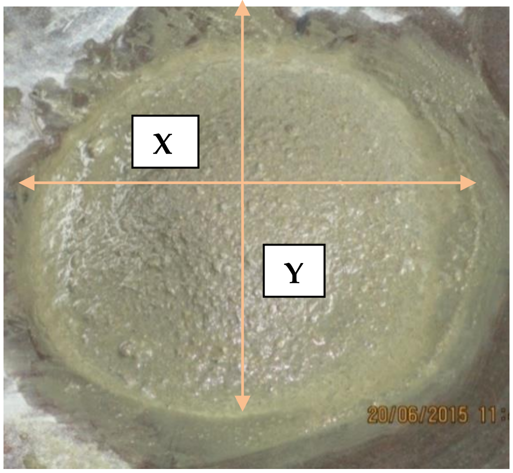

Figure 3.7: Flow after Vibration

3.4.7.2 Hardened state - Compressive Strength of Mortar

As specified in ASTM C 270 – 07, the laboratory mortar required an initial flow of 110±5% and the construction mortar required 130 to 150% in order to produce workability satisfactory to the mason. So the water cement ratios of each mortar mixes had the flow within this range were considered for the test.

The test was carried out according to BS 4551: Part 1:1998 to determine the compressive strength of the hardened mortar. The most common and the easiest method to test mortar at site is the mortar cube test. Test cubes were casted in a standard mould, which is 70 mm x 70 mm x 70 mm in size. Nine cubes were casted in each mix. The test method is described as follows:

Step 1: The standard mortar moulds were checked to see whether they were clean and dimensionally correct. Then they were assembled and oil was applied to the internal surfaces.

Step 2: The mortar was placed in the mould in 3 layers (approximately to the height of 1/2, 2/3, full of the mould) and manually compacted after putting each layer.

Step 3: Top surface was smoothened and cubes were numbered. The next day, moulds were removed and the cubes were fully immersed in water.

Step 4: After 7, 14 & 28 days 3 cubes of each mix were taken from water and tested for compressive strength.

A Compressive force was applied to each test cube separately by compression testing machine as shown in Figure 3.8. The crushing strength is taken as the compressive strength, which can be directly read from the dial gauge. Finally, the average compressive strength is taken as the compressive strength of the test cubes. The test was done at the University of Moratuwa.

Figure 3.8: Compressive Strength Test on Mortar Cubes

3.5 Reuse of Water Treatment Sludge in Concrete Paving Block Manufacturing as Substitute for Sand

3.5.1 Ordinary Portland Cement

Ordinary Portland cement (OPC) made by Tokyo super was used as the binding material, which belongs to the strength class of 42.5kN and in compliance with SLS 107: specification for OPC.

3.5.2 Water Treatment Plant Sludge

The sludge used in this study was collected from the sludge drying bed of the Kethhena Water Treatment Plant, located in Kalutara. The sludge produced in the sedimentation tank and filter is directly fed to the sludge drying bed for air drying. The dried sludge was used in preparation of Concrete Paving Blocks.

3.5.3 Aggregates

Natural sand was used as fine aggregate and 10mmmetal chips were used as coarse aggregate.

3.5.4 Bottom Ash

Air dried bottom ash obtained from the coal power plant at Norochcholai was used.

3.5.5 Characterization of Water Treatment Plant Sludge

3.5.5.1 Specific Gravity and Particle Size Distribution

Specific gravity test was carried out according to BS 812: Part 107: 1988as specified in 3.4.4.1 above and sieve analysis was carried out according to BS 812: Part 103: 1985as specified in 3.3.3.2 above.

3.5.5.2 Moisture Content

The moisture content of the sludge sample was determined in triplicate by heating samples to 110°C for 24 hours.

3.5.6 Characterization of Aggregates

3.5.6.1 Specific Gravity and Particle Size Distribution

Specific gravity test was carried out according to BS 812: Part 107: 1988as specified in 3.4.4.1 above and the sieve analysis was carried out according to BS 812: Part 103: 1985as specified in 3.3.3.2 above.

3.5.7 Characterization of Bottom Ash

3.5.7.1 Specific gravity and Particle Size Distribution

Specific gravity test was carried out according to BS 812: Part 107: 1988as specified in 3.4.4.1 above and the sieve analysis was carried out according to BS 812: Part 103: 1985as specified in 3.3.3.2 above.

3.5.7.2 Moisture content

The moisture content of the sludge sample was determined in triplicate by heating samples to 110°C for 24 hours.

3.5.8 Preparation of Concrete Paving Blocks

To investigate the effects of sludge on the properties of concrete paving blocks, the groups of mixtures were randomly prepared with the constant water cement ratio of 0.5 and aggregate cement ratio of 3.5. Batching method by weight was used in mixing the components to produce the samples with the standard size of 220mm x 110mm x 80mm. The percentage of sludge was used as supplement for sand (fine aggregate) and 10% of bottom ash and sludge were used as supplement for sand as shown in Table 3.4 and Table 3.5.Components of the concrete was mixed in a concrete mixer and paving blocks were produced by machine as shown in Figure 3.9 at the Building Materials laboratory of University of Moratuwa. Total of 180 numbers paving blocks were prepared as 20 in each mix and clearly numbered. As shown in Figure 3.10 blocks were immersed in a curing tank after 24 hours.

Table 3.4: Composition of Fine Aggregates in Paving Block

	Mix No.	Fine aggregate	
		Replacement Percentage of Sludge (%)	Percentage of Sand (%)
Control	1	0	100
Sludge	2	10	90
	3	20	80
	4	30	70
	5	40	60

Table 3.5: Composition of Fine Aggregates in Paving Block with Bottom ash

Mix No.	Fine aggregate		
	Replacement Percentage of Sludge (%)	Percentage of Bottom ash (%)	Percentage of Sand (%)
6	0	10	90
7	10	10	80
8	20	10	70
9	30	10	60

Figure 3.9: Casted Concrete Paving Blocks

Figure 3.10: Concrete Paving Blocks Immersed in Water

3.5.9 Determination of Properties of Concrete Paving Blocks

Tests were carried out according to the Sri Lankan Standard1425: Part 1: 2011, Specification for Concrete Paving Blocks. The parameters specified in the specification were tested in order to assess the quality of concrete paving blocks such as compressive strength, water absorption, slip resistance and dry density.

3.5.9.1 Compressive Strength

The compressive strength at 7, 14 and 28 days were determined to test the load bearing capacity of the Paving blocks.

Three blocks of each mix were selected and placed on the cardboard and traced around it perimeter. Then the shape was cut out accurately and weighed to the nearest 0.01g. A rectangle having size of 200mm x 100mm was cut accurately from the same card board and weighed to the nearest 0.01g. Plane area of the each block was calculated to the nearest 10mm^2 by using the equation given in the Sri Lankan Standard1425: Part 2: 2011, Specification for Concrete Paving Blocks as follows;

$$A_s = \frac{20\,000\, m_3}{m_r}$$

Where;

m_3 is the mass of a card board shape matching the block (in g)

m_r is the mass of 200mm x 100mm card board rectangle (in g)

Sample was placed in water for 24 hours and taken out and cleaned. Plywood packing was placed between the upper and lower faces of the block and the machine platens as shown in Figure 3.11. A load was applied without shock and increased it continuously at a rate of 15$\pm$3 N/mm min until no greater load can be sustained by the block. Maximum load applied to the block was recorded. The crushing strength of each block was calculated by dividing the maximum load by the plan area and multiplying the resulting value by the appropriate factor from the Table 2 of Sri Lankan Standard1425: Part 2: 2011, Specification for Concrete Paving Blocks. Averages of 3 blocks were calculated for each set separately.

Figure 3.11: Compressive Strength Test on Concrete Paving Block

3.5.9.2 Water Absorption

The water absorption of paving blocks were measured according to the method described in Sri Lankan Standard 1425: Part 2:2011 Specification for Concrete Paving Blocks (Appendix B). An average value of three samples was calculated.

3.5.9.3 Unpolished Slip Resistance Value (USRV)

The slip/skid resistance test of paving block was performed in accordance with the method described in Sri Lanka Standard 1425: Part 2:2011 Specification for Concrete Paving Blocks (Appendix B).

The measurement of USRV on the specimen was done using the pendulum test equipment to evaluate the frictional properties of the specimen on the upper surface. Five observations were taken for each specimen and the average value was calculated.

3.6 Characteristic of wastewater (Over flow water in Sludge drying bed/ lagoon)

Properties of waste water were analyzed to check whether that satisfies the tolerance limit of industrial wastewater discharged to inland surface water given by the CEA.

3.7 Environmental Cost Benefit analysis

Environmental Cost-Benefit analysis for the sludge reuse practices was carried out to check whether the practices are environmentally beneficial.

3.7.1 Analysis of Environmental Costs & Benefit

- The impacts due to discharging the sludge in to surface waters and sludge dumped in open dumps were identified.
- The benefits obtained through the sludge reuse practices were identified.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Current Sludge Management Practices in Sri Lanka

Thirty Five (35) questionnaires distributed to the Water Treatment Plants (WTPs) having a capacity of more than 5000m^3/day, out of which 25 respective offices of WTPs responded. The data collected from the questionnaire returns are attached in Appendix C.

4.1.1 General Information

The name and title of those who responded to the questionnaire and the general details of WTP such as year of establishment, location/region, name, address, region and the contact numbers of the water treatment plants are attached in Appendix C-1.

4.1.2 Raw Water Sources

The water sources of Water Treatment Plants (WTPs) and flows are listed in Appendix C-2 and summary is shown in Figure 4.1. Questionnaire responses indicate that most (97%) of the WTPs use surface water as their water source. Only 3% of WTPs are using ground water as water source.

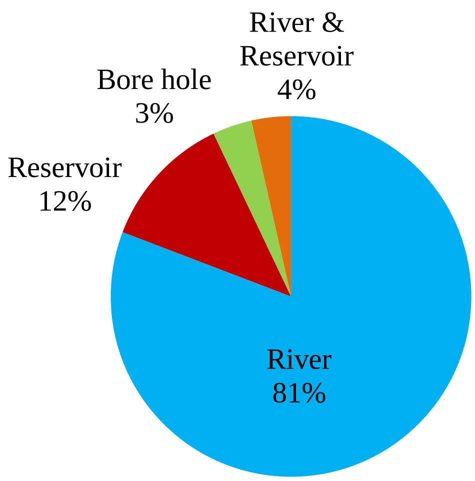

Figure 4.1: Raw Water Sources

Two types of surface water sources are used in WTPS. Those are Rivers, such as Kelani Ganga, KaaluGanga, Gin Ganga, NilwalaGanga, MahawaliGanga, etc. and Reservoirs, such as Labugama, Kalatuwewa, Kantale, Sagamam, etc. Bore holes are used as the ground water source. 81% of WTPs use the river as the raw water source.

4.1.3 Water Quality

Appendix C-3 shows the average raw water quality of source water of WTPs. Raw water turbidity is widely varied from 2 NTU to 80 NTU. The pH values for all water supplies varied from 6.1 to 7.5. All WTPs reporting, the average total alkalinity is varied from a low of 6.8mg/l as $CaCO_3$ to a high of 100 mg/l as $CaCO_3$ and the average total hardness ranged from 6 mg/l as $CaCO_3$ to 100mg/l as $CaCO_3$.

4.1.4 Treatment Process

Appendix C-4lists the water treatment processes used by the WTPs and summary is given in Table 4.1. The questionnaire responses indicate that the majority of surface water treatment contains the process of Aeration, Coagulation, Flocculation, Sedimentation, Filtration & Disinfection. There are some WTPs not having Aeration and three WTPs having Dissolved Air Flotation (DAF) instead of Sedimentation (Eg: Konduwadduwana, Wavunathiwu and Ruhunupura WTPs). Ground water treatment use Filtration& Disinfection process.

Table 4.1: Summary of Water Treatment Process

Process of Arrangement	WTP	
	Number	**Percentage**
Aeration, Coagulation, Flocculation, Sedimentation, Filtration & Disinfection	17	68
Coagulation, Flocculation, Sedimentation, Filtration & Disinfection	4	16
Aeration, Coagulation, Flocculation, DAF, Filtration & Disinfection	1	4
Coagulation, Flocculation, DAF, Filtration & Disinfection	2	8
Only Filtration	1	4

4.1.5 Chemical Dosage

Chemical dosages for all WTPs are tabulated in Appendix C-5. Annual average values and ranges for each chemical used are given and summary is given in Figure 4.3. As shown in Figure 4.2, Most of the WTPs use Alum as a coagulant. Out of twenty five, seventeen WTPs use alum, which is 68% as a percentage. Seven WTPs use Poly Aluminum Chloride. Ground WTPs does not use any chemical.

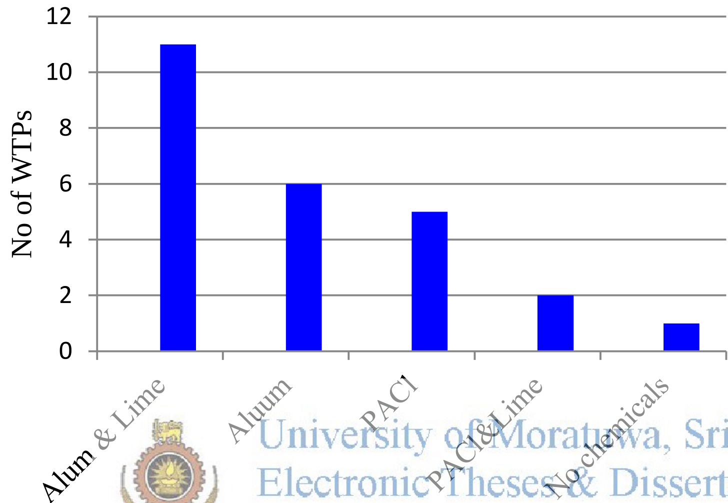

Figure 4.2: Chemical Usage of WTPs

4.1.6 Sludge Production & Characteristics

Appendix C-6 shows type and quantity of sludge production and sludge characteristics. All (100%) are Alum sludge. Only four WTPs have the sludge production details and only three WTPs have the sludge characteristic details.

4.1.7 Sludge Removal& Discharge

Appendix C-7 lists the methods of removing sludge from the basins and methods of sludge disposal. Summary of sludge removal information and sludge disposal methods are given in Table 4.2 & Table 4.3 respectively. Most popular sludge removal methods are flushing with fire hose, continuous mechanical removal and manual removal.

According to the questionnaire responses most of the WTPs discharge their waste into streams.

Table 4.2: Methods of Removing Sludge from Basins

Methods	WTP	
	Number	Percentage (%)
Flushing	4	16
Continuous Mechanical Removal	4	16
Manual	17	68

Table 4.3: Methods of Sludge Disposed from Basins

Methods (Discharge in to)	WTP	
	Number	Percentage (%)
Stream	11	44
Lake or Reservoir	1	4
Impounding Basins	10	40
Others	3	12

4.1.8 Sludge Treatment

Appendix C-8 lists the sludge treatment methods and summary of sludge treatment information is given in Table 4.4. According to the responses to the questionnaire majority (52%) of WTPs has no any treatment and directly discharge in to the stream. Only two WTPs use gravity thickener and another two use centrifuge as thickener.

Table 4.4: Sludge Treatment Methods

Methods	WTP	
	Number	Percentage
Gravity Thickening	2	8
Centrifuge	2	8
Lagooning/Drying beds	12	40
No treatment	12	52

4.1.9 Sludge Dewatering

Methods of sludge dewatering and number & size of dewatering units are listed in Appendix C-9 and summary is shown in Figure 4.3. Sludge drying bed is the most popular method for dewatering. Only8% treatment plants use centrifuge for thickening and sludge drying beds for dewatering.

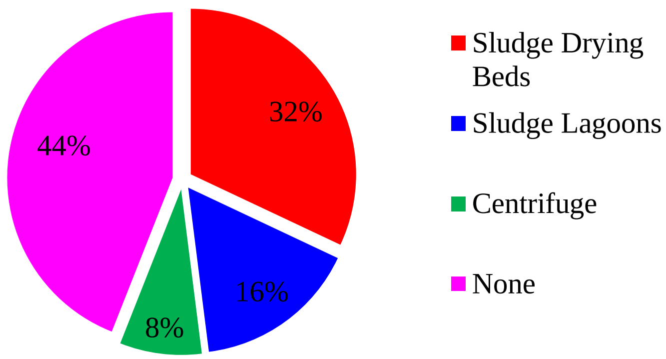

Figure 4.3: Methods of Sludge Dewatering

4.1.10 Sludge Final Disposal

Final sludge disposal methods are given in Appendix C-10 and summary is shown in Figure 4.4. 36% of the treatment plants use the sludge as fill material or for land fill. Only one plant (Thirukkovil) sludge is used for agricultural purpose.

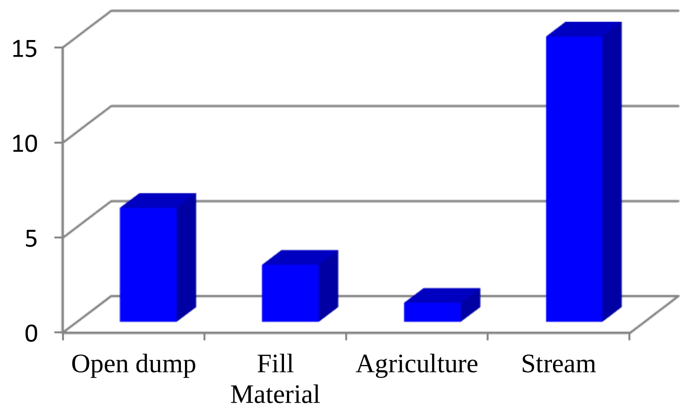

Figure 4.4: Final Sludge disposal Methods

Sludge production is an inevitable outcome of potable water treatment. The environmental pollution/acceptable levels of final sludge disposal methods are shown in Figure 4.5. The main disposal method used in the observed WTPs is to return the sludge into surface water without any further treatment.

The second widely used method is dump on freely available land or sends to land fill. This can cause environmental problems as openly dumped sludge washed away to surface waters with rain water. Also ground water quality can be affected due to leaching of sludge into the soil.

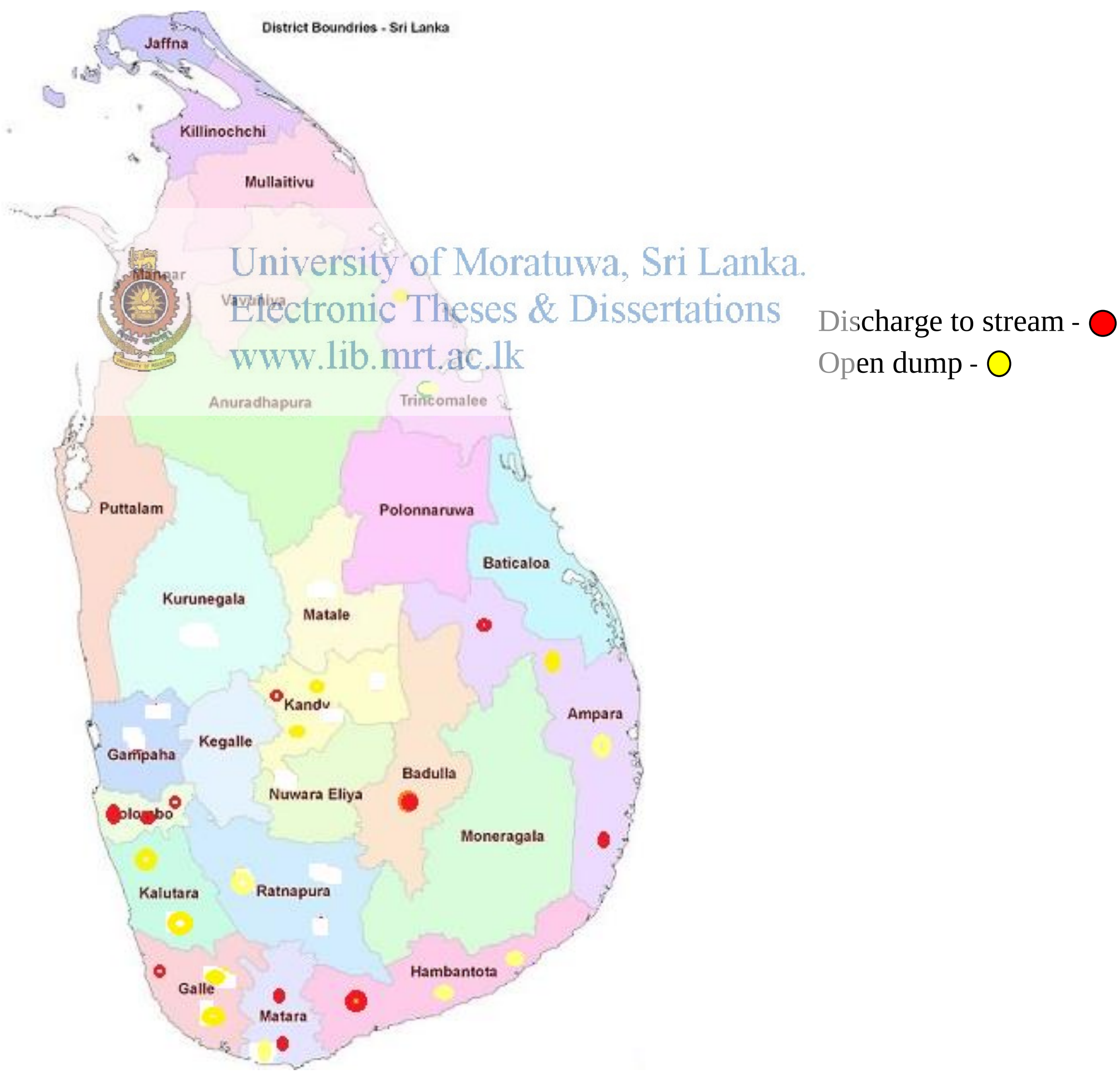

Figure 4.5: Environmental Pollution/Acceptable Levels of Sludge disposal Methods

4.2 Reuse of Water Treatment Sludge in Brick Manufacturing as Substitute for Clay

4.2.1 Properties of Raw Materials

4.2.1.1 Moisture Content &Volatile Organic Content

The Moisture Content test was conducted to the dewatered sample taken from the sludge disposal unit and manufacturer clay used for this research. The volatile organic content of the WTP sludge was measured to get an insight to its characteristics. The test results of moisture content & volatile organic content of the chosen sludge & clay is tabulated in Appendix D and the average is given in Table 4.5.

Table 4.5: Moisture Content & Volatile Organic Content of WTP Sludge & Clay

Characteristic	Moisture Content (%)	Volatile Organic Content (%)
Water Treatment Plant Sludge 1 (Kethhena)	33.61	22.83
Water Treatment Plant Sludge 2 (Kandana)	29.69	22.70
Clay	17.88	-

The results indicated that the WTP sludge has high average water content than clay. Hence the sludge was sun dried for 6-7 days (depending on the weather condition) to achieve required level of dryness.

4.2.1.2 Particle Size Distribution

Figure 4.6 shows the particle size distribution of WTP sludge.

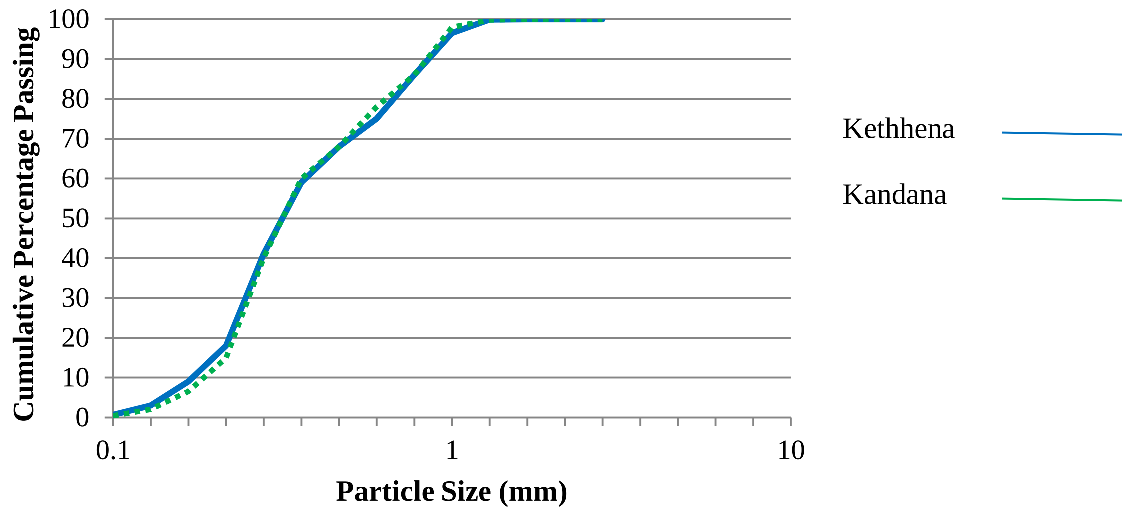

Figure 4.6: Particle Size Distribution Curve for Sludge

4.2.2 Characteristics of Clay Sludge Mix

Table 4.6 gives the moisture content of each mixes and the detail results are given in Appendix D. The optimum moisture content (OMC) of mixture was based on the moisture requirement in which maximum bonding among the mixture particles is retained.

Table 4.6: Characteristics of Clay Sludge Mix

Sample	Sludge 1			Sludge 2			Control
	M1	M2	M3	M1	M2	M3	M4
Sludge proportion (% by weight)	10	20	30	10	20	30	0
Clay proportion (% by weight)	90	80	70	90	80	70	100
Optimum moisture content (%)	28.01	30.26	31.78	28.22	29.68	31.32	26.85

From Table 4.6, it can be seen that the OMC increased as the quantity of sludge increases. The test results show that the OMC of only clay mixture is 26.85%. Increasing the sludge proportion in the mixtures resulted in an increase of OMC.

4.2.3 Properties of Bricks

The properties of bricks were tested according to the Sri Lankan Standard39:1978, Specification for common burnt clay building bricks.

4.2.3.1 Dimension

The overall dimension test results for different proportion of sludge in mixture given in table 4.7 indicates that the dimension of the bricks decreases with the increase of sludge content. The control sample (only clay) bricks have the overall dimension of 4690 mm length, 2309 mm width and 1374mm height. The Kethhena Water Treatment Sludge (WTS) clay brick dimension is ranged between 4663mm to 4531mm length, 2310mm to 2238mm width and 1370mm to 1350mm height and Kandana Water Treatment Sludge (WTS) clay brick dimension is ranged between 4615mm to 4523mm length, 2305mm to 2228mm width and 1369mm to 1350mm height.

Table 4.7: Overall Dimension of 24 Bricks

	Mix Proportion Sludge: Clay (%)	Length	Width	**Height**
Requirement(SLS 39:1978)		5280±75	2520±40	1560±40
Kethhena WTP Sludge	10:90	4663	2310	1370
	20:80	4588	2262	1358
	30:70	4531	2238	1350
Kandana WTP Sludge	10:90	4615	2305	1369
	20:80	4554	2255	1355
	30:70	4523	2228	1350
Manufacturer	0:100	4690	2309	1374

The test results of individual dimension of clay and sludge- clay bricks are given in Appendix D and an average of individual dimension is given in Table 4.8. The individual dimension test results for different proportion of sludge in mixture as given in Table 4.8 indicates that the dimension of the bricks decreases with the increased sludge content.

The control sample (only clay) bricks have the dimension of 195 mm length, 96 mm width and 57mm height. The Kethhena WTS clay brick dimension is ranged between 194mm to 189mm length, 96mm to 93mm width and 57mm to 55mm height and Kandana WTS clay brick dimension is ranged between 192mm to 190mm length, 96mm to 93mm width and 57mm to 56mm height.

Table 4.8: Dimension of Individual Bricks

	Mix Proportion Sludge: Clay (%)	**Length**	**Width**	**Height**
Requirement:	**Dimension of brick SLS 39:1978**			
Kethhena WTP Sludge	10:90	194	96	57
	20:80	191	94	56
	30:70	189	93	55
Kandana WTP Sludge	10:90	192	96	57
	20:80	190	94	56
	30:70	188	93	56
Manufacturer	0:100	195	96	57

4.2.3.2 Compressive Strength

Compressive strength determines the applicability potential of the bricks, which is normally affected by the porosity, pore size and type of crystallization. The test results of compressive strength are given in Appendix D. Table 4.9 gives the average compressive strength of clay and sludge clay bricks.

Table 4.9: Compressive Strength of Bricks

	Mix Proportion Sludge: Clay (%)	Avg. Compressive Strength N/mm2
Requirement(Type 2Grade II), SLS 39:1978		**2.8**
Kethhena WTP Sludge	10:90	2.87
	20:80	2.49
	30:70	1.91
Kandana WTP Sludge	10:90	2.76
	20:80	2.24
	30:70	1.85
Manufacturer	0:100	4.23

Figure 4.7 shows that the compressive strength is greatly dependent on the amount of sludge in the brick. The strength of brick decreases with the increased sludge content. The average compressive strength of control sample is 4.23N/mm^2.The average compressive strength of Kethhena WTP sludge clay brick is varied between 2.87 and 1.91 N/mm^2 and Kandana WTP sludge clay brick is varied between 2.76 and 1.85 N/mm^2. With the addition of 10% sludge to clay, the sludge clay brick strength met the minimum requirement of 2.8 N/mm^2 (SLS 39:1978) as building brick.

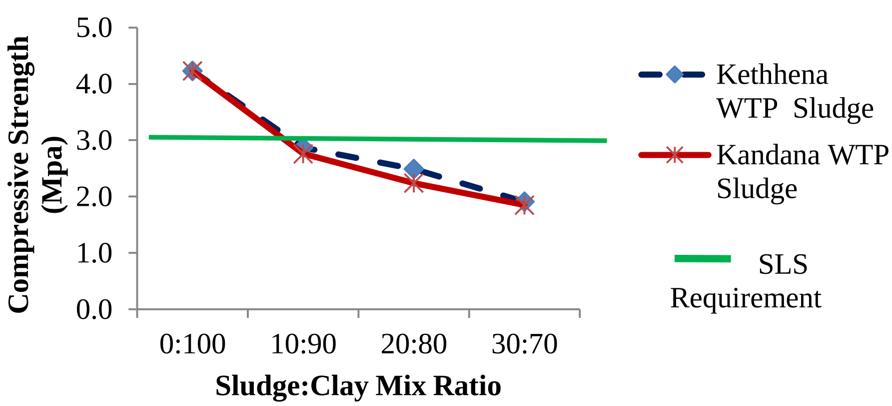

Figure 4.7: Compressive Strength of Bricks

4.2.3.3 Water Absorption

Water absorption is a key factor that affects the durability of bricks. Hence the lesser amount of water infiltrated to the brick makes the brick more durable. The test results of water absorption are tabulated in Appendix D. The water absorption test results for different proportions of sludge in mixture given in Table 4.10, indicates that the water absorption for the bricks increases with the increased sludge content.

The control sample has the water absorption of 20.22% and the results of water absorption ranged between 23.59% to 26.30% and 23.11% to 30.29% for Kethhena and Kandana WTP sludge clay brick respectively. Compared to control clay brick, all of the sludge clay brick exhibited higher water absorption than the 100% clay brick type. The addition of 10%, 20% & 30% of Kethhena WTP sludge to clay and addition of 10%& 20% of Kandana WTP sludge to clay, the sludge clay brick obtained water absorption of maximum requirement of 28% (SLS 39:1978) as building brick.

Table 4.10: Water Absorption of Bricks

	Mix Proportion Sludge: Clay (%)	**Avg. Absorption (Percentage)**
Requirement: Type 2, Grade II (SLS 39:1978)		**28**
Kethhena WTP Sludge	10:90	23.59
	20:80	25.42
	30:70	26.30
Kandana WTP Sludge	10:90	23.11
	20:80	25.36
	30:70	30.29
Manufacturer	0:100	20.22

4.2.3.4 Efflorescence

Table 4.11 shows the test results of efflorescence.

Table 4.11: Efflorescence of Bricks

	Mix Proportion Sludge: Clay (%)	**Efflorescence**
Requirement: Type 2, Grade II (SLS 39:1978)		**Moderate**
Kethhena WTP Sludge	10:90	Slight
	20:80	
	30:70	
Kandana WTP Sludge	10:90	
	20:80	
	30:70	
Manufacturer	0:100	

All sludge clay mixes has satisfies the minimum requirement of efflorescence (SLS 39:1978) as building brick.

Table 4.12: Comparison with Previous Study – Brick Dimensions

Average Dimension (mm)	This study							Illanghasinghe et.al, 2015		
	Control	Kethhena WTP Sludge			Kandana WTP Sludge			Meewatura WTP Sludge		
	100:0	90:10	80:20	70:30	90:10	80:20	70:30	100:0	75:25	50:50
Length	195	194	191	189	192	190	188	229	225	222.5
Width	96	96	94	93	96	94	94	107	108	100
Height	57	57	56	55	57	56	56	62	62	60
Length	4690	4663	4588	4531	4615	4554	4523	5494	5399	5342
Width	2309	2310	2262	2238	2305	2255	2228	2575	2597	2417
Height	1374	1370	1358	1350	1355	1350	1374	1497	1484	1444

Table 4.13: Comparison with Previous Study – Brick Properties

	This study							Illanghasinghe et.al, 2015		
	Control	Kethhena WTP Sludge			Kandana WTP Sludge			Meewatura WTP Sludge		
	100:0	90:10	80:20	70:30	90:10	80:20	70:30	100:0	75:25	50:50
Compressive Strength (N/mm^2)	4.23	2.87	2.49	1.91	2.76	2.24	1.85	1.82	0.53	0.49
Water Absorption (%)	20.22	23.59	25.42	26.3	23.11	25.36	30.29	20.2	30.2	34
Efflorescence	Slight							Slight		

The tables 4.12 and 4.13 compare the results of this study with a previous study done for the brick production. As illustrated on the referred tables two different samples of sludge from different Water Treatment Plants (Kethhena & Kandana) were selected for this study. The average compressive strength of Kethhena WTP sludge clay brick varied between 2.87 and 1.91 N/mm^2 and Kandana WTP sludge clay brick varied between 2.76 and 1.85 N/mm^2. However, the previous study result shows a range compressive strength between 1.82 and 0.49 N/mm^2 which is far from the result of this study. Even though the sludge to clay mix ratio used in these two studies are different, compressive strength recorded for control sample (clay to sludge ratio 100:0) shows different compressive strengths of 4.23 and 1.82 respectively in current and previous studies. In the previous study, even 100% clay brick has not achieved the minimum requirement. It may be because of properties of clay and sludge such as fineness content, porosity, plasticity index etc. or brick may not be burnt with the required firing temperature. Victoria (2013) in Nigeria did a performance evaluation of water treatment sludge as brick material and demonstrated that sludge clay burnt bricks can be successfully produced using WTP sludge as supplement for clay. It is widely practiced in some countries. Also his results indicate that the strength greatly depends on the firing temperature. The results of Kethhena sludge shows an acceptable compressive strength with the addition of 10% sludge to clay, the sludge clay brick strength met the minimum requirement of 2.8 N/mm^2 (SLS 39:1978) as building brick.

The results of water absorption ranged between 23.59% to 26.30% and 23.11% to 30.29% for Kethhena and Kandana WTP sludge clay brick, where the results of previous study ranged between 20.2% and 34% for Meewatura WTP sludge. Compared to control clay brick, all of the sludge clay brick exhibited higher water absorption than the 100% clay brick type. The water absorption percentage for control sample on both the current and previous studies shows approximately same values such as 20.22 and 20.2. As per the current study the addition of 10% sludge to clay mix obtained water absorption of a maximum requirement of 25% (SLS 39:1978) as building brick.

Table 4.14: Comparison with Previous Studies – Brick Properties

Study	Sludge	Material %				Compressive Strength (N/mm^2)	Water Absorption (%)	Firing Temperature (°C)
		Sludge	Clay	RHA	SF			
This Study	Control	0	100	-	-	4.2	20	600
	Kethhena	10	90	-	-	2.9	23	
		20	80	-	-	2.5	25	
		30	70	-	-	1.9	26	
	Kandana	10	90	-	-	2.8	23	
		20	80	-	-	2.2	25	
		30	70	-	-	1.8	30	
Victoriya (2013)	Nigeria	0	100	-	-	6.5	21	850
		5	95	-	-	5.0	22	
		10	90	-	-	3.5	23	
		15	85	-	-	1.0	26	
		20	80	-	-	0.5	31	
Hegazy et al. (2012)	Egypt	0	100	-	-	5.4	11	900
		25	-	25	50	6.8	39	
		50	-	25	25	6.7	48	
		25	-	50	25	4.9	52	
Hegazy et al. (2012)	Egypt	0	100	-	-	5.7	11	900
		25	-	-	-	2.7	73	
		50	-	50	-	2.9	60	
		75	-	25	-	3.4	59	
Hegazy et al. (2011)	Egypt	0	100	-	-	5.9	11	900
		25	-	-	75	48.0	24	
		50	-	-	50	30.4	25	
		75	-	-	25	7.4	27	

The table 4.14 compares the results of this study with the previous studies done for the brick production in various countries. When comparing with the study done by Victoriya (2013), Nigeria, It shows that the compressive strength of brick can be increased by increasing the firing temperature. The study done by Hegazy et al. (2012 & 2011) shows that compressive strength can be enhanced by the addition of agricultural waste and industrial waste, which contain high silica content, such as Rice husk ash silica fume respectively. Even though they have high compressive strength, addition of RHA bricks has very high water absorption. Durability of the brick depends on the water absorption.

4.3 Reuse of Water Treatment Sludge in Cement mortar as substitute for cement (Binding material)

4.3.1 Properties of Raw Materials

4.3.1.1 **Moisture Content**

The Moisture Content test was conducted to the sludge used for this research. The results are attached in Appendix D. The average moisture content of the WTP Sludge is 13.67%.

4.3.1.2 Particle Size Distribution

Particle size distribution of sand was carried out when cement replaced by sludge for cement mortar. Figure 4.8 shows the particle size distribution of Sand.The particle size of sand lies between 0.1- 0.6 mm.

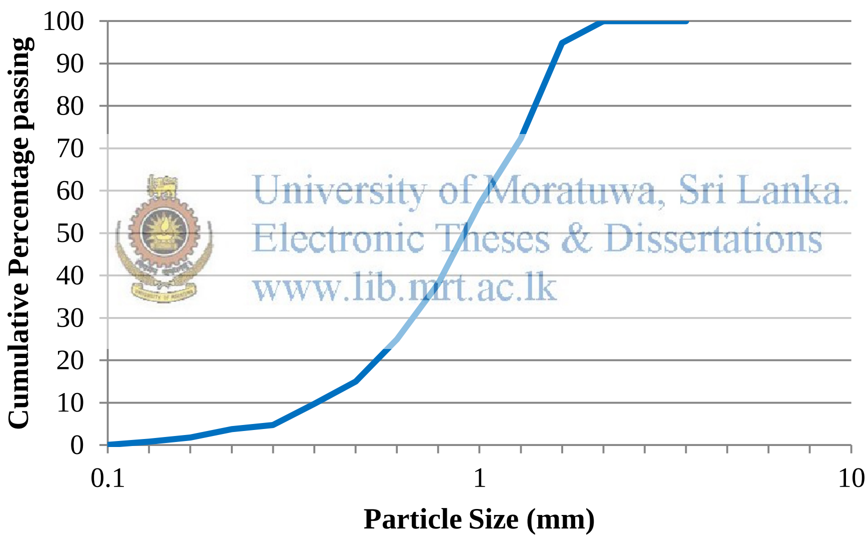

Figure 4.8: Particle Size Distribution Curve

4.3.1.3 Specific Gravity

The specific gravity test was conducted to the sludge & sand used for this research and the average specific gravity results are given in table 4.15.

Table 4.15: Specific Gravity of WTP Sludge & Sand

Characteristic	Specific Gravity
Water Treatment Plant Sludge (Kandana)	**1.62**
Sand	**2.65**

4.3.2 Properties of Mortar

In this study, the sludge was used as supplementary cementious material used to replace the cement (binding material), the ratio of cementious materials to sand was kept constant at 1:5. Sludge was added to the mortar by varying their proportions. The composite mortars tried are having the cement to sludge as 90:10, 80:20 and 70:30 and 100:0 (Control sample). In order to accomplish this, the mortars are prepared by varying the water content to achieve a constant workability which is determined using much flow.

4.3.2.1 Fresh state - Workability (Fluidity)

Workability is the most important property of mortar. It is the result of a ball bearing affect of aggregate particles lubricated by the cementing paste. Workability is a combination of several properties including plasticity, consistency, cohesion & adhesion. Good workability is essential for maximum bond with masonry unit. Workable mortar can be spread easily with a trowel into the separation & crevices of the masonry unit. Workable mortar supports the weight of masonry unit when placed & facilitate alignment.

Workability of fresh mortar mixes were determined by flow table test. The flow obtained with the OPC and sludge mortars with different water cement ratios are attached in Appendix E and the average flow value is graphically presented in Figures 4.9 to 4.12.

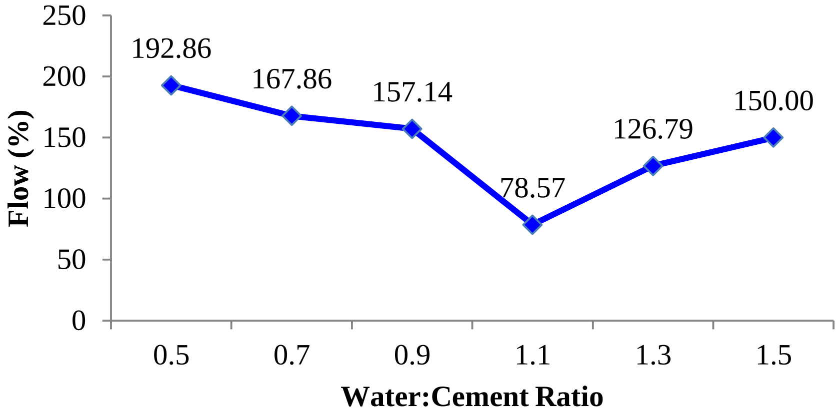

Figure 4.9: Flow Percentage of Mortar with Water Cement Ratio for Mix1(0:100)

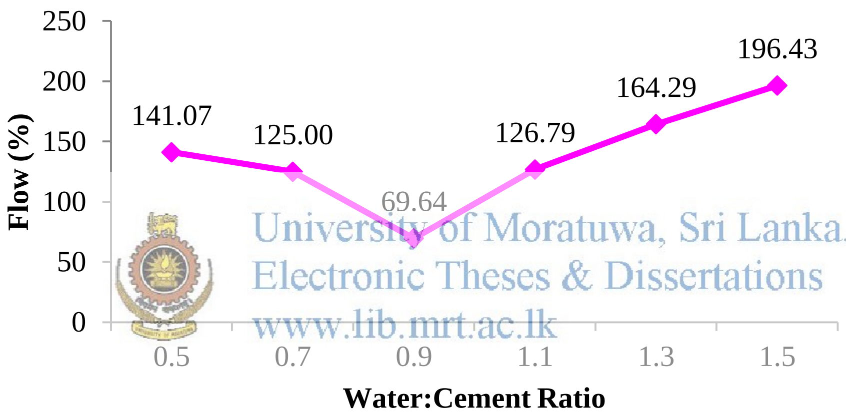

Figure 4. 10: Flow Percentage of Mortar with Water Cement Ratio for Mix 2(10:90)

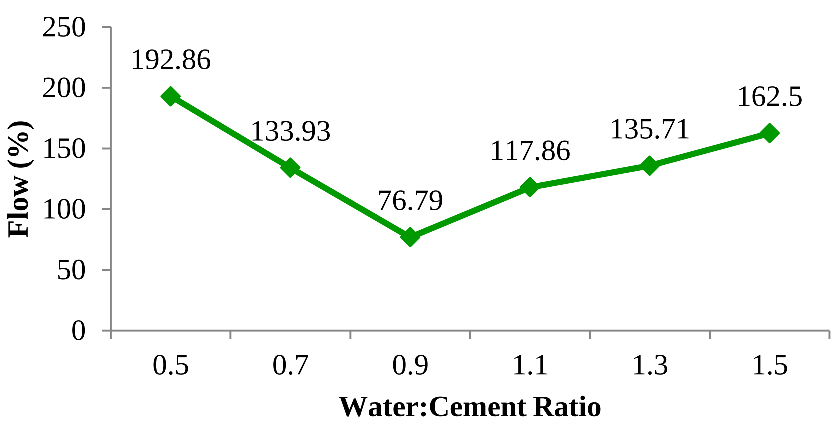

Figure 4. 11 : Flow Percentage of Mortar with Water Cement Ratio for Mix 3(20:80)

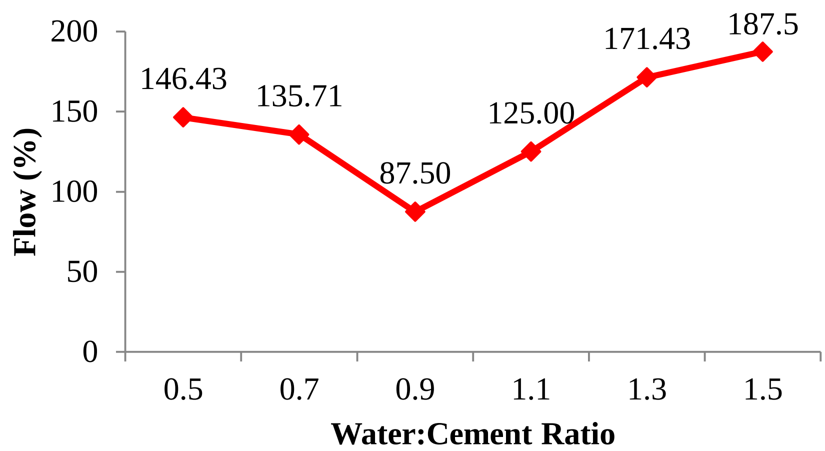

Figure 4. 12: Flow Percentage of Mortar with Water Cement Ratio for Mix 4(30:70)

Flow obtained for the different mortars shows that some of the mortars have achieved greater flow with less water cement ratio. Due to addition of sludge into normal mortar the specific surface area of these materials reduced the water content, making the mortar more workable within available water content which induces greater flow table spread.

Mortar standards commonly require minimum water retention of 75%, based on an initial flow of only 105 to 115%. The Figure 4.13 shows the flow value of each mix and the standard requirement. When the water cement ratio is increasing up to 0.5 to 0.9, the flow value of mortar is decreasing. Then the water cement ratio is increasing up to 0.9 to 1.5, the flow value of mortar is increasing for cement sludge mortar. The Figure 4.13 indicates that the water cement ratios between 0.9 and 1.3 of control samples and the water cement ratios between 0.7 and 1.1 of sludge cement mortars achieved the required flow.

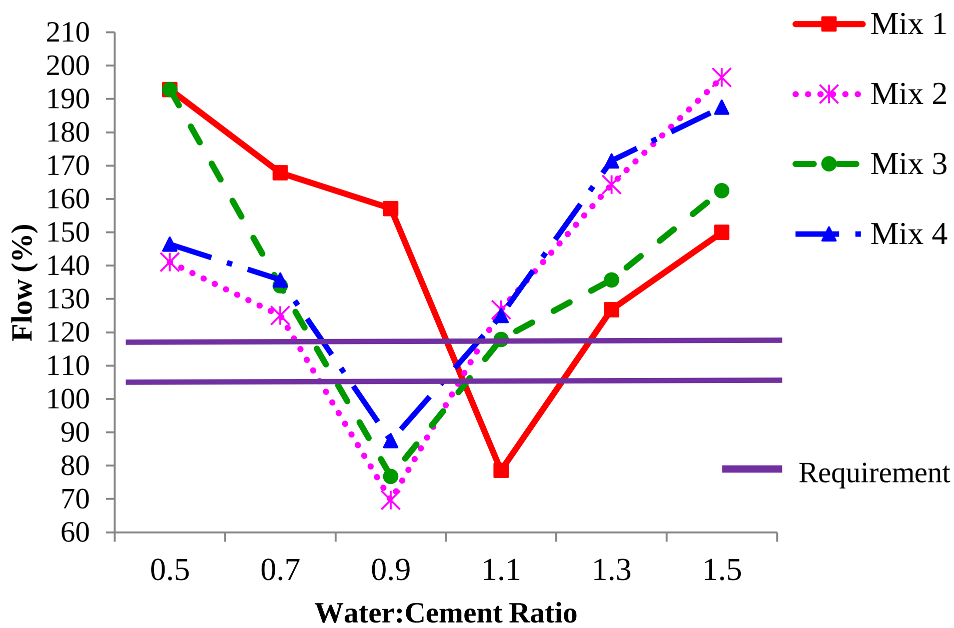

Figure 4. 13: **Flow percentage of mortar with water cement ratio**

4.3.2.2 Hardened State - Compressive Strength of Mortar

The compressive strength test was carried out to the mixes that achieved the required flow of standard requirement. The test results of compressive strength at 7, 14 & 28 days of OPC and sludge mortars are tabulated in Appendix E. Figures 4.14 to 4.17 shows mortar compressive strength variation with water cement ratio for different cement sludge mixes. It shows that the compressive strength is greatly dependent on the water cement ratios. When the water cement ratios are increasing, the compressive strength of each type of mortar mix is decreasing.

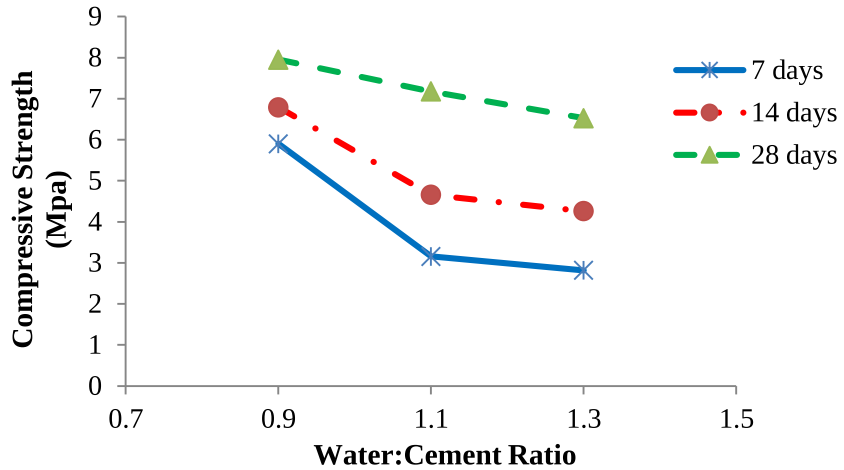

Figure 4. 14: Compressive Strength of Mortar with W/C Ratio for Mix 1 (0:100)

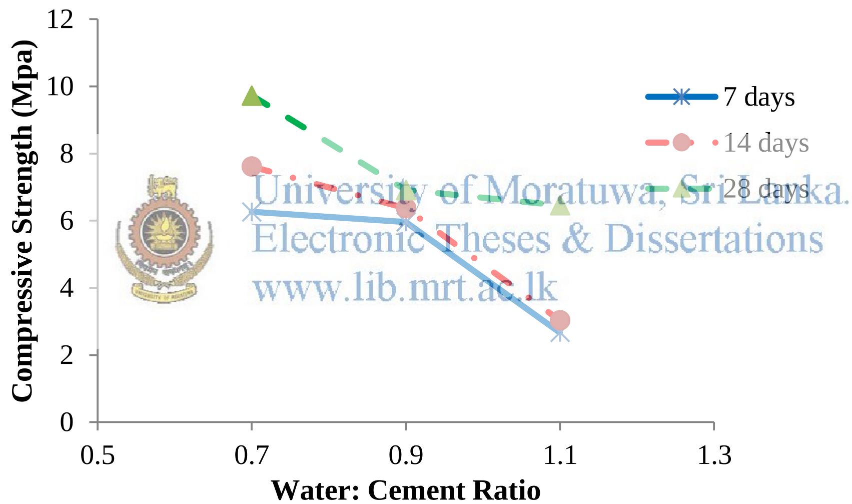

Figure 4. 15: Compressive Strength of Mortar with W/C Ratio for Mix 2 (10:90)

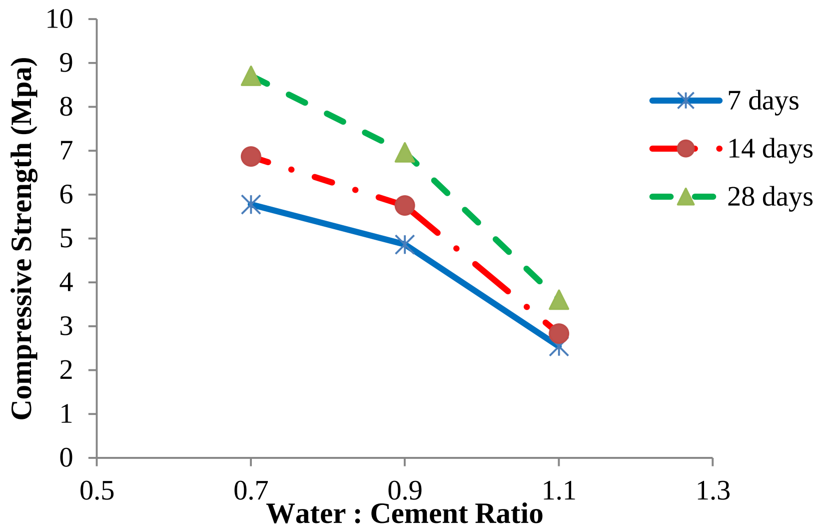

Figure 4. 16: Compressive Strength of Mortar with W/C Ratio for Mix 3 (20:80%)

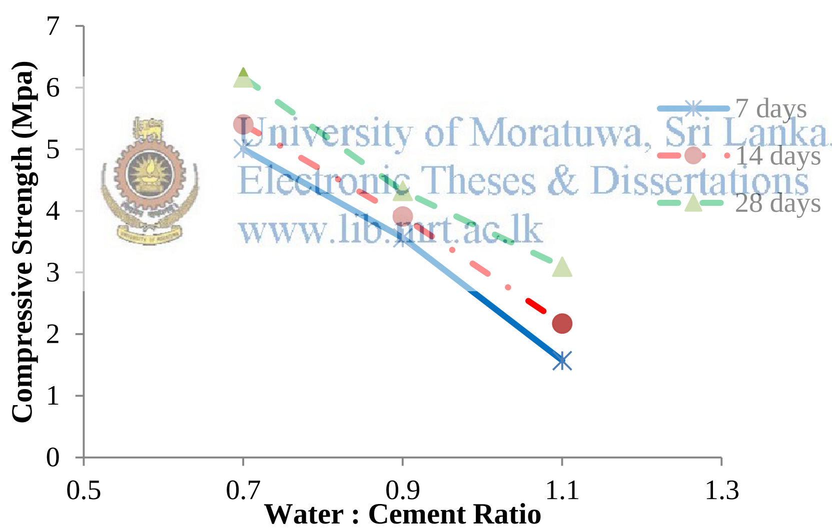

Figure 4. 17: Compressive Strength of Mortar with W/C Ratio for Mix 4 (30:70%)

The Figure 4.18 shows the 28 days compressive strength of each mix at different water cement ratios and the standard requirement. The compressive strength of mortar decreases with increased water cement ratios and the increased sludge content in the mix. Compressive strength of all mixes of 1:5 mortar satisfied ICTAD specifications, which should be greater than 5 N/mm^2. According to the results compressive strength of mortar is higher than 5 N/mm^2.

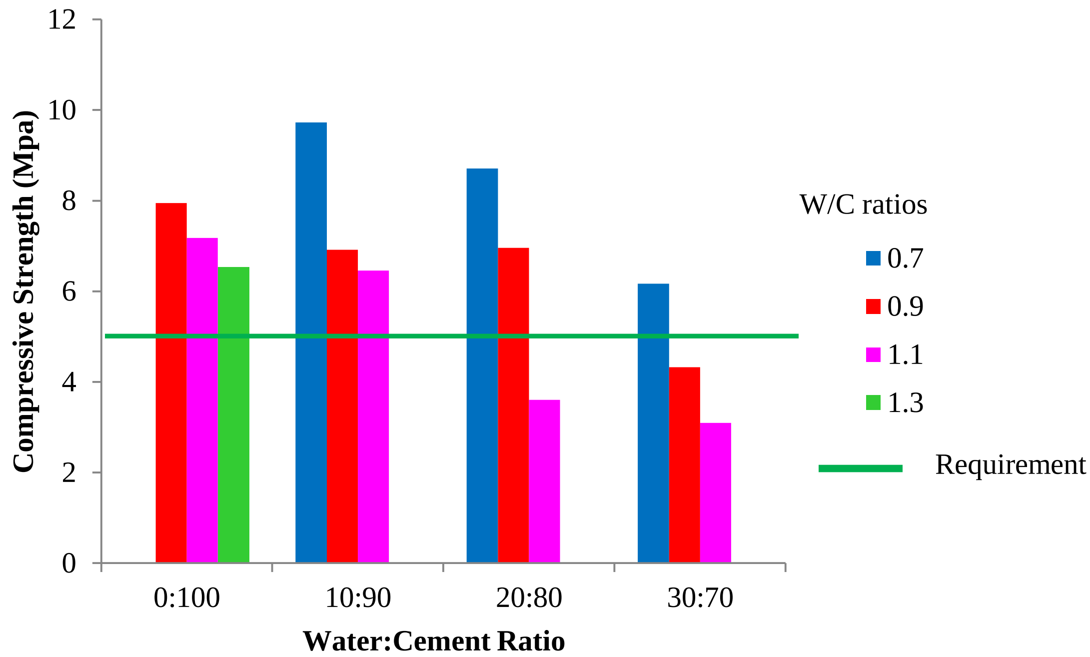

Figure 4. 18: Compressive Strength of Mortar at 28 days

The compressive strength of control samples with water cement ratios of 0.9, 1.1 &1.3 met the requirement. Addition of 10% sludge met the requirement with the water cement ratios of 0.7, 0.9 & 1.1,addition of 20% sludge met the requirement with the water cement ratios of 0.7 & 0.9 and an addition of 30% sludge met the requirement with the water cement ratio of 0.7 only.

4.4 Reuse of Water Treatment Sludge in Concrete Paving Block Manufacturing as Substitute for Sand

4.4.1 Properties of Raw Materials

4.4.1.1 Moisture Content

The Moisture Content test was conducted to the sludge and bottom ash used for this research. The results of average moisture content are given in Table 4.16.

Table 4.16: Moisture Content of Raw Materials

Characteristic	Moisture Content (%)
Water Treatment Plant Sludge (Kethhena)	**23.87**
Bottom Ash	**20.62**

4.4.1.2 Particle Size Distribution

Figure 4.19 shows the particle size distribution of Sand, Botttom Ash and Water Treatment Plant Sludge.

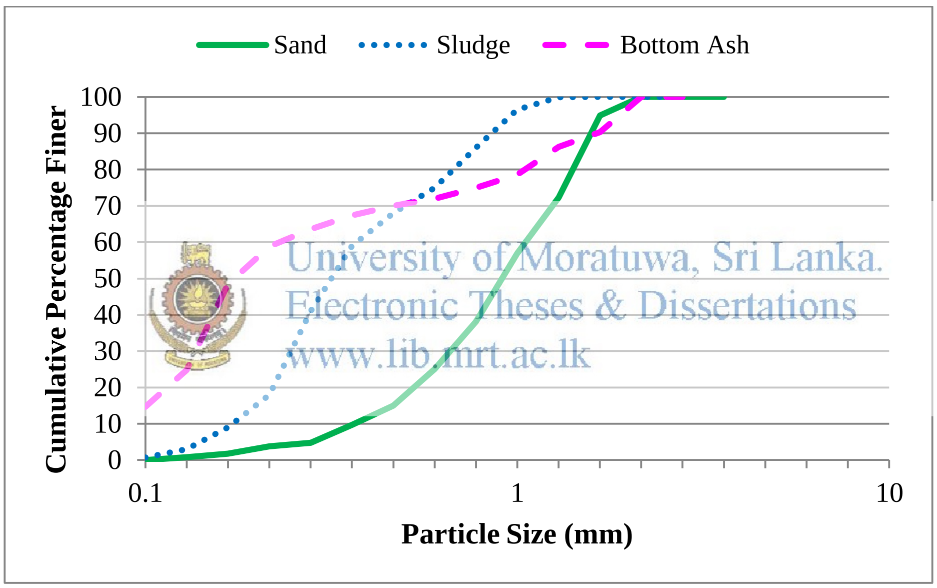

Figure 4. 19: Particle Size Distribution of Sand, Sludge & Bottom Ash

4.4.1.3 Specific Gravity

The specific gravity test was conducted to the sludge, bottom ash, coarse aggregate& sand used for this research and the average specific gravity results are given in Table 4.17.

Table 4.17: Specific Gravity of Raw Materials

Characteristic	Specific Gravity
Sand	**2.46**
Coarse Aggregate	**2.28**
Water Treatment Plant Sludge (Kethhena)	**1.30**
Bottom Ash	**1.55**

4.4.1.4 Chemical Composition of Bottom Ash

The chemical composition and the loss on ignition for bottom ash are shown in the Table 4.18 and Figure 4.20.

Table 4.18: Chemical Composition and Loss on Ignition for Bottom Ash

Parameter	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	LOI
Percentage (%)	57.33	24.97	12.84	0.02	1.14	3.29	1.02

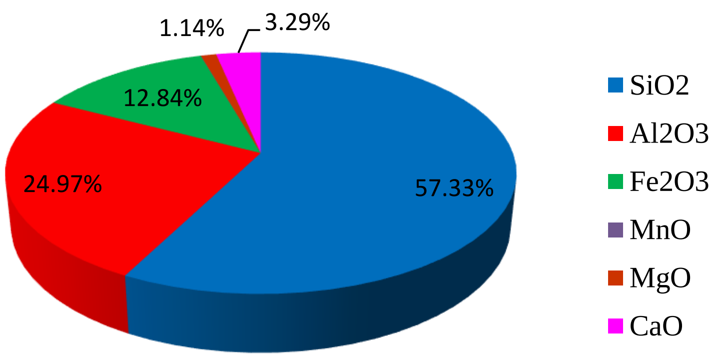

Figure 4. 20: Chemical Composition and the Loss on Ignition for Bottom Ash

4.4.2 Properties of Concrete Paving Blocks

4.4.2.1 Compressive Strength

Compressive strength is an important parameter in evaluation of concrete paving block (CPB). The effect of fine aggregate replaced with WTS and WTS with 10% bottom ash on compressive strength of CPB are presented in Appendix F. Figures 4.21& 4.22 shows the average compressive strength results of CPB at 7,14 and 28 days for CPB made with sludge & CPB made with sludge & bottom ash respectively. As seen clearly from Figures 4.21& 4.22, the compressive strength at 7, 14 & 28 days decreases as the sludge ratio, sludge& bottom ash ratio increases.

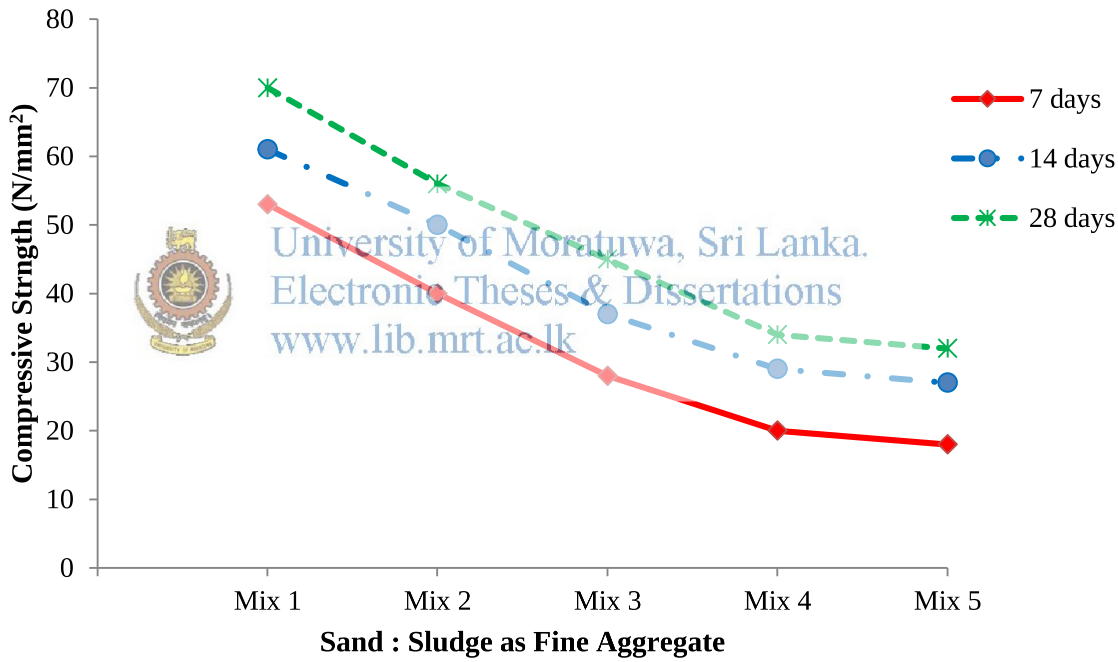

Figure 4. 21: Compressive Strength of Paving Blocks Made with Sludge

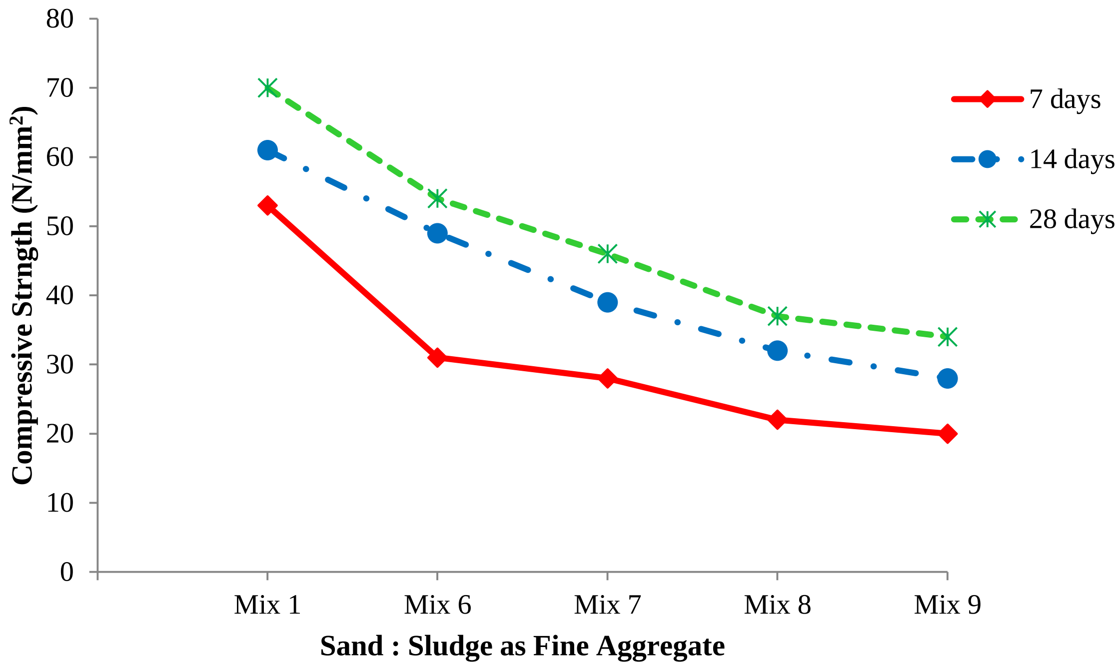

Figure 4. 22: Compressive Strength of Paving Blocks Made with Bottom Ash & Sludge

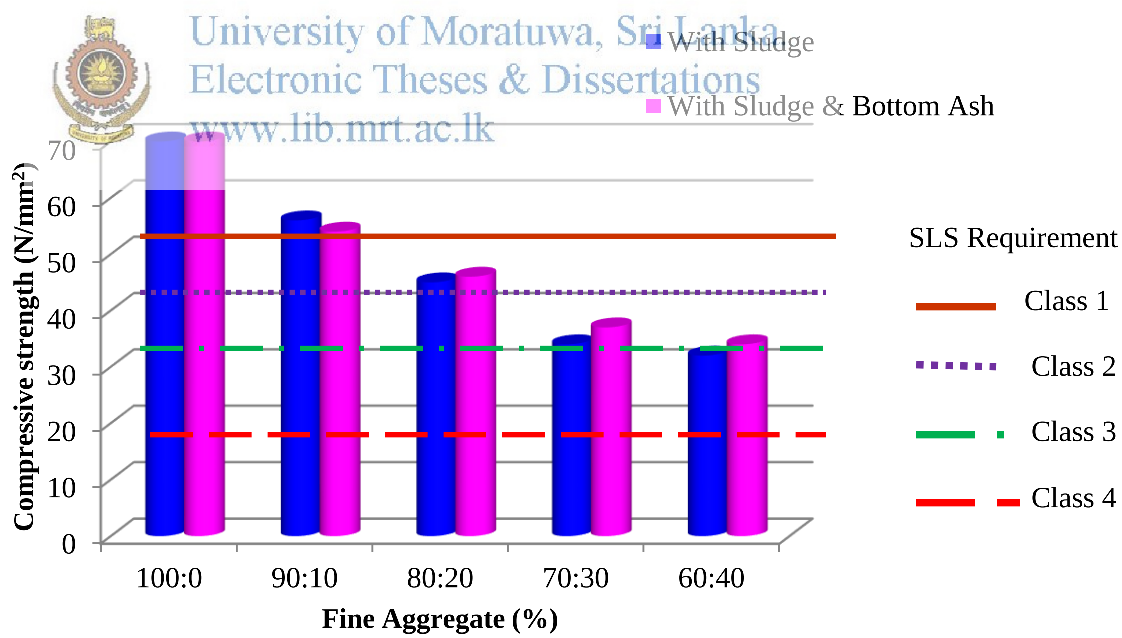

Figure 4. 23: Compressive Strength of Paving Blocks at 28 days

Figure 4.23 represents the 28 days compressive strength for the fine aggregate replaced with WTS and WTS with 10% bottom ash of CPB and the variation of the results with

SLS specification. All the mixtures up to 40% of sludge addition met the SLS requirement of strength class 4 (Pedestrian use only). Only 10% sludge as fine aggregate and 10% bottom ash as fine aggregate mixtures met the SLS requirement of strength class 1 (heavy traffic).

4.4.2. Unpolished Skid/Slip Resistance Value (USRV)

The unpolished slip resistance values of CPBs made with sludge and CPBs made with sludge& bottom ash are given in the Appendix F. The variation of USRV with the SLS specification is graphically represented in Figure 4.24.

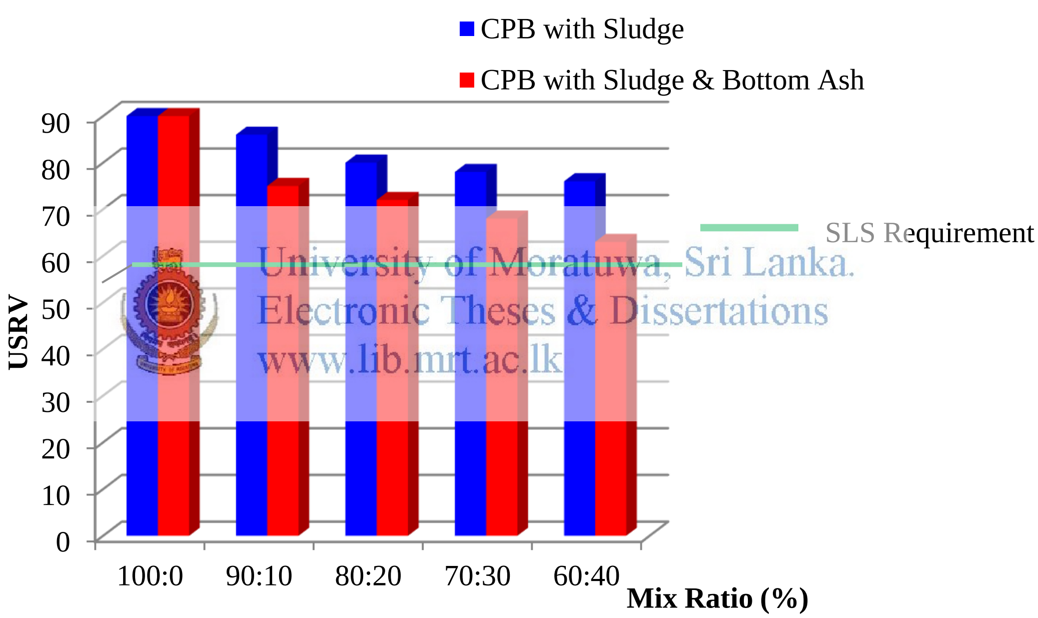

Figure 4. 24: Unpolished Slip Resistance Value of Paving Blocks

The Figure 4.24 clearly indicates that the USRV decreases with the sludge content increases in the mix. Even though all the CPBs have met the SLS requirement of USRV greater than 55, CPBs made with only sludge mix has more USRV than the sludge & bottom ash mix.

4.4.3 Water Absorption

The water absorption test results of CPBs made with sludge and CPBs made with sludge& bottom ash are given in Appendix F. The variations of the water absorption with the SLS specification are graphically represented in Figure 4.25.

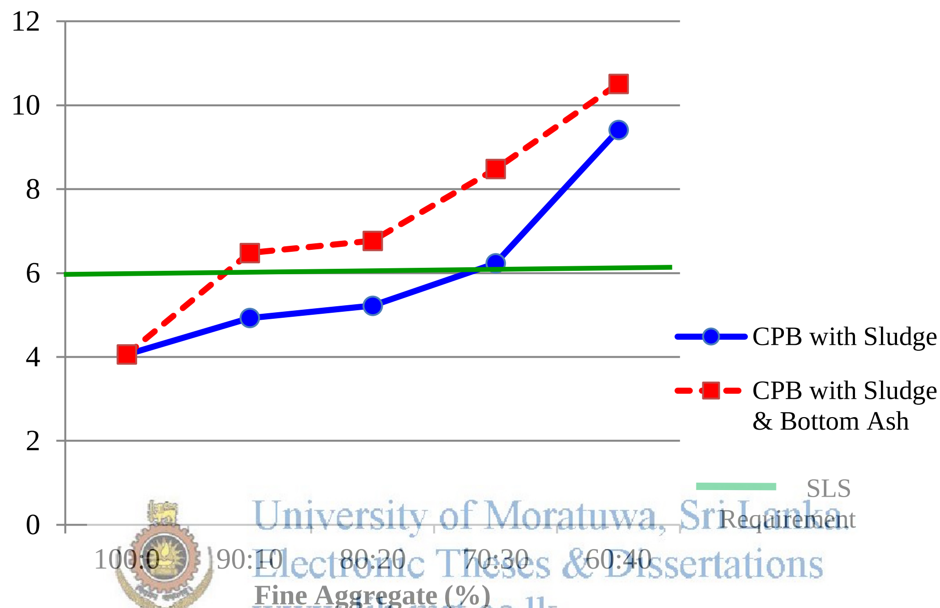

Figure 4. 25: Water Absorption of Paving Blocks

Figure 4.25 clearly indicates that the water absorption of CPB increases with the increased sludge content. The control sample has the water absorption of 4.06% and the results of water absorption ranged between 4.93% to 9.41% and 6.48% to 10.51% for CPBs made with sludge and CPB made with sludge & 10% bottom ash respectively. Compared to control CPB, all of the CPBs exhibited higher water absorption than the 100% sand as fine aggregate. The addition of 10% & 20% addition of sludge CPB obtain water absorption of less than 6% and met the SLS requirement.

4.4.4 Dry Density

The detail test results of dry density of CPBs are attached in Appendix F. The variation of average dry density results of CPBs made with sludge and CPBs made with sludge & 10% bottom ash is graphically represented in Figure 4.26 and clearly indicates that the dry density of CPB decreases with the increased sludge content.

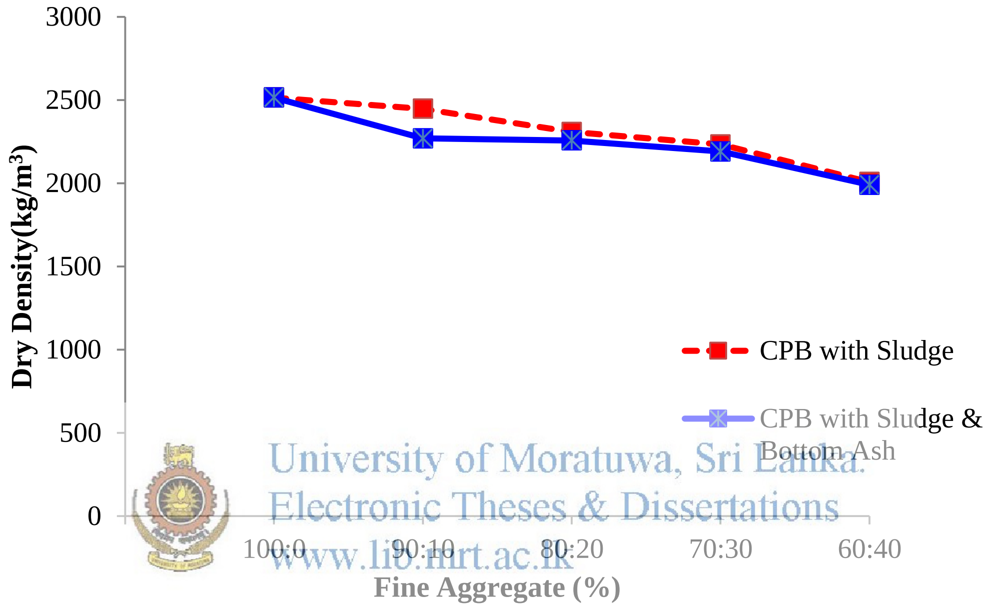

Figure 4. 26: Dry Density of Paving Blocks

The control sample has the dry density of 2515 kg/m^3 and the results of dry density ranged between 2447kg/m^{3}to 2005kg/m^3 and 2270kg/m^3 to 1991kg/m^3 for CPBs made with sludge and CPB made with sludge & 10% bottom ash respectively. Compared to control CPB, all of the CPBs exhibited lower dry density.

4.5 Discharge of Wastewater

4.5.1 Reuse of water collected from water treatment sludge

According to a technical brief prepared by CARE International and ProAct Network for Global Wash Cluster "during the water treatment process, most treatment waste is in the form of slurry and needs to be dewatered before it can be managed further". Dewatering can be performed in several methods as elaborated in Section 2.4.2 (page 10) of this report. However the above referred technical brief notes that "the least costly approach is to pump the treatment waste slurry into holding ponds where evaporation infiltration or both reduce water content. The water collected from such systems needs to be tested and depending on chemical content may be recycled back into treatment process or handled as hazardous material or return to the source".

Perhaps the most common liquid waste generated at WTPs in the past has been spent filter backwash water. The spent filter water associated with filter-to-waste (rewash) has become more common as WTPs prepare for compliance with the water treatment rules and regulations.

Water collected from the water treatment sludge can helps satisfy some water demands, as long as it is adequately treated to ensure water quality appropriate for the use. In uses where there is a greater chance of human exposure to the water, more treatment is required. As for any water source that is not properly treated, health problems could arise from being exposed to this water if it contains disease-causing organisms or other contaminants.

No published researches have been done on the usage of the waste water collected during the water treatment sludge production. However it is believed that this water can be reused by adopting the technologies / procedures used in waste water treatment process. Previous researches done on the usage of recycle water concluded that recycled water is most commonly used for non-potable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation. Other non-potable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, concrete mixing and artificial lakes. Table 4.19 shows the suggested water recycling treatment and the uses.

Table 4.19: Suggested Water Recycling Treatment and Uses

Suggested Water Recycling Treatment and Uses			
Increasing Levels of Treatment; Increasing Acceptable Levels of Human Exposure →			
→ **Primary Treatment:** Sedimentation	→ **Secondary Treatment:** Biological Oxidation, Disinfection	→ **Tertiary / Advanced Treatment:** Chemical Coagulation, Filtration, Disinfection	
• No uses Recommended at this level	• Surface irrigation of orchards and vineyards • Non-food crop irrigation • Restricted landscape impoundments • Groundwater recharge of non potable aquifer** • Wetlands, wildlife habitat, stream augmentation** • Industrial cooling processes**	• Landscape and golf course irrigation • Toilet flushing • Vehicle washing • Food crop irrigation • Unrestricted recreational impoundment	• Indirect potable reuse: Groundwater recharge of potable aquifer and surface water reservoir augmentation**
* Suggested uses are based on Guidelines for Water Reuse, developed by U.S. EPA. ** Recommended level of treatment is site-specific			

Source: http://www3.epa.gov/region9/water/recycling/

This research report analyze/ present the only about the reuse of sludge produced during water treatment and recommend for further research on the reuse of water extracted from water treatment sludge.

4.5.2 Properties of Discharge Wastewater

Table 4.20shows the properties / characteristics of drain out wastewater from the water treatment plants

Table 4.20: Properties of Discharge Wastewater

No.	Parameter	Tolerance Limits for the Industrial waste in to Inland surface water	Discharge wastewater	
			Kandana	Kethhena
1	pH	6.0 - 8.5	8	6.10
2	Conductivity (μs/cm)		156.9	45
3	Temperature	40^0C	40^0C	26.80
4	Total suspended solids	50mg/l, max	8.24	33.0
5	Biochemical Oxygen Demand (BOD_5 in Five days at 20^0C or BOD_3 in a three days at 27^0C)		15.5	24.0
6	Chemical Oxygen Demand (COD)	30 mg/l, max	48.2	168
7	Turbidity (NTU)	250 mg/l, max	8.9	72.00
8	Chlorides		10.8	18.50
9	Iron	70 mg/l, max	0.3	1.31
10	Aluminum (mg/l)		0.4	0.3

No heavy metals observed in the raw water. Hence heavy metals were not analyzed in the waste water. Quality of waste water satisfies the tolerance limits for the industrial waste in to inland surface waters requirement. Hence it can be directly discharged to downstream of the source. It will not affect the quality of stream (No pollution). Also Aluminum concentrations in waste waters were0.4 and 0.3 mg/l for Kandana and Kethhena WTPs respectively. This is satisfies the drinking water standard.

4.6 Environmental Cost Benefit analysis

4.6.1 Identified Impacts

The following items are considered as the impacts of current sludge disposal practices.

- Directly discharging in to the stream is affecting quality of downstream.
- Aluminium can be toxic to fish at pH level below 5 and respiratory blockage in fish
- Colour and turbidity of receiving water become excessively elevated by the sludge discharge. This will affect the aquatic life by blocking light penetration in to the water column.
- The openly dumped sludge washed away with rain water, affects surface water quality. Ground water quality also affected due to leaching of sludge in to soil.
- This extended to environmental pollutions like surface/ground water, land pollution etc.

4.6.2 Identified Benefits

The following items are considered as benefits through the sludge reuse practices.

- When occupying the sludge drying bed/lagoon only over flow water is discharged to stream. This wastewater consist very low Aluminum content (less than 0.5mg/l). This is less than the limit of Aluminum content in drinking water and satisfying the tolerant limit given to discharge of industrial waste water into inland surface water. Hence it will not effect the downstream water quality or aquatic biota.
- The settled sludge in the sludge drying bed can be used as substitute for clay in brick manufacturing, substitute for cement in cement sand mortar preparation and substitute for sand in concrete paving block manufacturing. Then the requirement of land for dumping the sludge will reduce and the pollution will be stopped.

4.6.3 Assessment of Environmental cost benefit analysis

The summary of environmental impacts is given in Table 4. 21.

Table 4.21: Environmental Impacts

No.	Environmental Impacts	Positive	Negative
1	Pollution prevention due to avoiding the sludge discharge into water bodies and dumping on land	(+)	
2	Impacts on bio diversity, eco system	(+)	
3	Quality of surface and ground water	(+)	
4	Human health benefit due to avoiding water / land pollution	(+)	
5	Material savings in Brick, Paving Block and Cement Mortar (Clay, Sand & Cement)	(+)	
6	Avoiding Mining of sand & clay	(+)	
7	Employment in reuse application	(+)	
8	Air pollution due to transporting sludge into work site	(+)	(-)

Table 4.21 clearly shows that this reuse practices has more positive impacts on Environment. Hence this sludge reuse practices are environmentally beneficial and sustainable.

A detail survey has to be done to quantify the cost and benefit. Therefore recommend for further recommendation on extended cost benefit analysis.

CHAPTER FIVE

CONCLUSION AND RECOMENDATION

5.1 Conclusions

The conclusions of this study are;

- The main sludge disposal method used in the observed WTPs is directly discharging the sludge into the surface water without any further treatment. The second widely used method is dumping on freely available land in and around the WTP.

- Water treatment plant sludge is a successful substitute for clay in burnt clay building bricks, substitute for cement in cement mortar and substitute for sand in concrete paving blocks under the conditions and manufacturing methods used in this study. Also this sludge reuse practices are environmentally beneficial.

- The wastewater, which drain out from sludge drying bed or lagoon can be directly discharged in to the downstream of water sources since it satisfies the tolerance limit of discharge of industrial wastewater into inland surface water and contain very less amount of Aluminum which is less than the permissible level of Aluminum content in drinking water. This will sustain the environment.

- The optimum sludge addition to produce burnt clay building brick from sludge and clay mixture was 10%; by operating at the temperature commonly practiced in the brick burning kiln.

- The optimum sludge addition to produce workable and good strength cement mortar from sludge as cement was 10%, 20% and 30% of cement.

- The optimum sludge addition to produce concrete paving blocks for strength class 1(heavy traffic) was 10%sludge as fine aggregate and for strength class 4 (pedestrian use) was 40%. Addition of bottom ash is marginally increasing the strength

5.2 Recommendations

Based on the results of this study the following recommendations are made:

- The sludge accumulated in water treatment process must be treated and disposed of in a safe and effective manner. In order to carry out an effective disposal practice it is important to have data on the sludge generation process. Hence, it is recommended to prepare a database of water treatment plants operated through NWS&DB. This database should include capacity of the plant (design and operation), process details, generation of water or by products, disposal practices and the legal requirements applicable of the plant.

- All the new water treatment plants should include provisions for constructing sludge drying beds or lagoons and the accessibility for vehicles, especially sludge should be defined prior to constructing a treatment plant.

- As at present, the technically and environmentally best option of sludge removal appears to be brick making, use in cement mortar and use in Concrete Paving Block making. The economic feasibility of this option needs to be investigated.

- Burnt brick production can be improved using locally available waste materials such as coir, waste cloth fiber etc. to improve the quality of the brick and such options need to be investigated to introduce recycling.

- Cement replacement by waste sludge is a good option to be investigated for Concrete Paving Block and for cement mortar with more than 30% cement replacement by dried sludge.

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- Further sand replacement by waste sludge is a good option to be investigated with 10% to 50% of sand replaced with dried sludge for cement mortar.

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Appendix A - Questionnaire

Water Treatment Plant Sludge Survey

Please fill the following questionnaire as accurately as possible

Contact Information

Respondent's Name: Designation: Address:	Telephone No: Fax: E-mail address:

1. General

i. Name of WTP:

ii. Year of establishment:

iii. Treatment Plant Installed Capacity:

iv. Quantity of water treated/day:

v. Location:

vi. Region/District:

vii. No. of Beneficiaries:

viii. Coverage Area:
(GN Divisions & DS divisions)

2. Source and Flow

	Name of the Sources	Avg.Flow (m^3/day)	Max.Flow (m^3/day)
Reservoir			
River			

3. Raw Water Quality

	Average	Range
Turbidity NTU		
Total Alkalinity as $CaCO_3$, mg/L		
Total Hardness as $CaCO_3$, mg/L		
Total Suspended Solids, mg/L		
Total Solids, mg/L		
pH		
Temperature		
Conductivity		

4. Treatment Process

(Eg: Aeration, Coagulation, Flocculation, Sedimentation, Filtration, disinfection, etc.)

5. Chemical Usage in Treatment Process

	Average (kg/day)	Range (kg/day)
Alum		
Ferric Sulfate		
Polymer		
PAC		
GAC		
Lime		
Copper Sulfate		

6. **Basin Information**

	Flocculator	**Sedimentation**		
Number				
Capacity (m^3)				
Depth (m)				
Detention time at avg.flow (min)				
Sludge generated (m^3/d)				
Dry Sludge generated (kg/d)				

7. **Filters**

i. Number:
ii. Max.loadingrate:
iii. Size:
iv. Filter aid:
v. Filter run:
vi. Media depth:
   a. Anthracite:
   b. Sand:
   c. GAC:
vii. Max. Back wash rate:
viii. Turbidity (In flow):
ix. Turbidity (Out flow):
x. TSS (In flow):
xi. TSS (Out flow):
xii. Water usage for back washing in % Wash water to average flow:

8. Sludge Production and Disposal

i. Type of Sludge:
   - Alum sludge:
   - Lime sludge:
   - Brine wastes:

ii. Total quantity:
   - Dry (kg/day):
   - Wet (m^3/day):

9. Sludge Characteristics

	Basin sludge	Filter wash water	Brine
% solids			
pH			
TSS, mg/L			
TDS, mg/L			
Al, mg/L			
Fe, mg/L			
Ba, mg/L			
Radioactivity			

**** If not measure please indicate it.**

10. Sludge Discharge and Removal

i. Basin sludge discharged to:

Stream ☐ Sewer system ☐

Lake/reservoir ☐ Recirculation to Treatment facility ☐

Low ground ☐ Impounding basin ☐

If any other please specifies:

ii. Spent GAC disposal to:

iii. Brine disposal to:

iv. Flocculator sludge discharged to:

v. Filter wash water discharged to:

Recovery basin (recycle): Yes ☐ No ☐

Methods of removing sludge from basins:

Flushing with fire hose ☐

Dragline or dozer ☐

Continuous removal ☐

Manual ☐

Combination of the above ☐

Any other please specify:

11. Sludge Treatment

i. Thickening:

Gravity ☐

Flotation ☐

Centrifuge ☐

ii. Stabilization & Disinfection:

Lime treatment ☐

Cl2 treatment ☐

iii. Recycle : Yes ☐ No ☐

If yes, With Settling ☐

Without settling ☐

iv. Dewatering: Yes ☐ No ☐

12. Sludge Dewatering

	Number	Size	Ton/Y generated	% solids
Drying beds				
Drying lagoons				
Centrifuge				
Belt filter				
Filter press				

13. Sludge Final Disposal

i. Composting: Yes ☐ No ☐

ii. Utilization for:

a. Land reclamation ☐

b. Filling material ☐

iii. Land Disposal:

a. Sanitary / Engineered landfill ☐

b. Public land ☐

c. Dumping into private land ☐

iv. Beneficial uses

Land Application - Agricultural use ☐

Cement manufacturing ☐

Brick making ☐

Road Subgrade ☐

Landfill cover ☐

Any other, please specify:

14. Sludge Disposal Limitations

A. Has your utility been ordered by a regulatory agency to stop the discharge of WTP sludge into the water source? (Yes/No)

B. If YES to A, in your opinion, has the stopping of sludge disposal to the water source significantly improved the water quality of the water source? (Yes/No)

C. If No to B, would your utility resume sludge disposal to the water source if the regulatory barriers were removed? (Yes/No)

D. If Yes to C, and your utility was allowed to resume sludge disposal to the water source, what would you estimate the annual cost savings to your utility?

15. Costs

i. Total Annual cost for solids handling & disposal:

ii. Total annual cost for the treatment plant:

Note:

i. Is there additional land/space available in WTP? (Yes/No)

ii. If Yes, Extent (Approximately, m^2) :

iii. Did you make any improvement to treatment process: (Yes/No)

iv. If Yes, Please specify the modification you have done and benefits obtained:

v. Did you face any problems with sludge (treatment & Disposal): (Yes/No)

vi. If Yes, Please specify in detail:

vii. Photos

Remarks: (Use additional Papers for this)

Appendix B - Standard Test Methods

8 DETERMINATION OF UNPOLISHSED SLIP RESISTANCE VALUE (USRV)

8.1 Principle

The measurement of USRV on the specimen is made using the pendulum friction test equipment evaluate the frictional properties of the specimen on the upper face.

The pendulum friction test equipment incorporates a spring loaded slider made of a standard rubber attached to the end of the pendulum. On swinging the pendulum the frictional force between the slider and test surface is measured by the reduction in length of the wing using a calibrated scale.

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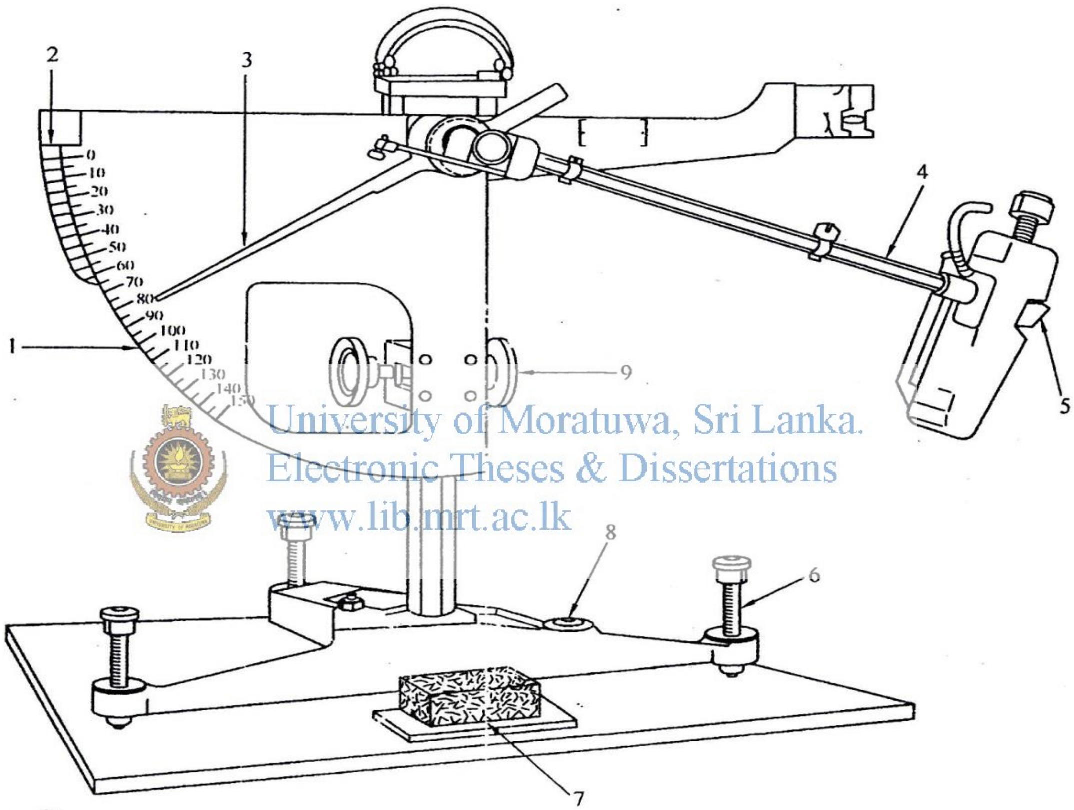
8.2 Apparatus

8.2.1 *Pendulum friction tester*

8.2.1.1 The pendulum friction test equipment shall be manufactured as shown in Figure **8**. All bearings and working parts shall be enclosed as far as possible, and all materials used shall be treated to prevent corrosion under wet conditions.



Key

1 C scale (126 mm sliding length)
2 F scale (76 mm sliding length)
3 Pointer
4 Pendulum
5 Rubber slider
6 Levelling screw
7 Test specimen holder
8 Spirit level
9 Vertical adjustment screw

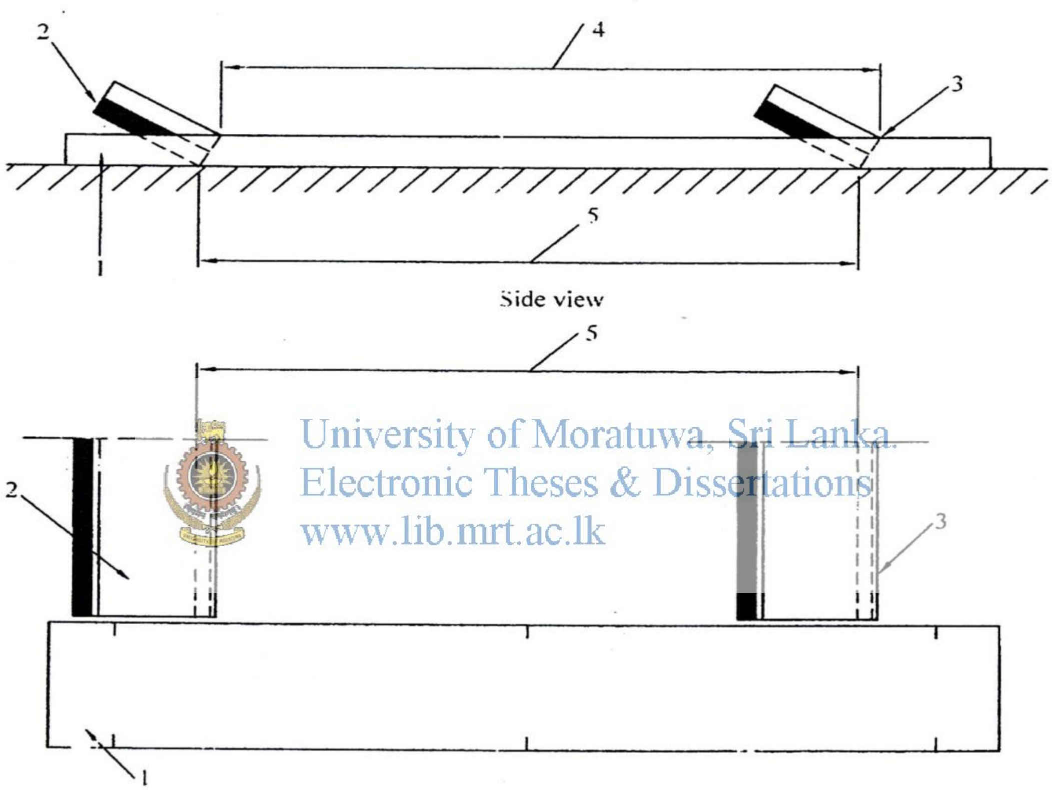
FIGURE 8 - Pendulum friction test equipment

8.2.1.2 The pendulum friction test equipment shall have the following features:

1) a spring loaded rubber coasted slider as specified in **8.2.1.4** to **8.2.1.10**. It shall be mounted on the end of a pendulum arm so that the sliding edge is (510 ± 1) mm from the axis of suspension;
2) means of setting the support column of the equipment vertical;
3) a base of sufficient mass to ensure the equipment remains stable during the test;

4) means of raising and lowering the axis of suspension of the pendulum arm so that the slider can;

- swing clear of the surface of the specimen; and
- be set to traverse a surface over a fixed length of (126 ± 1) mm. A gauge with the distance marked is required as shown in Figure **9**.



Key
1. Gauge
2. Slider
3. Reference edge
4. Sliding length measured
5. Actual sliding length

FIGURE 9 - Sliding length gauge

5) means of holding and releasing the pendulum arm so that it falls freely from a horizontal position;

6) A pointer of nominal length 300 mm, balanced about the axis of suspension, indicating the position of the pendulum arm throughout its forward swing and moving over the circular scale. The mass of the pointer shall be not more than 85 g;

7) the friction in the pointer mechanism shall be adjustable so that, with the pendulum arm swinging freely from a horizontal position, the outward tip of thc pointer may be brought to rest on the forward wing of the arm at a point (10 ± 1) mm below the horizontal. This is the 0 reading;
8) A circular C scale, calibrated for a sliding length of 126 mm on a flat surface, marked from 0 to 150 at intervals of five units;

8.2.1.3 The mass of the pendulum arm, including the slider, shall be (1.50 ± 0.03) kg. The centre of gravity shall be on the axis of the arm at a distance of (410 ± 5) mm from the axis of suspension.

8.2.1.4 The wide slider shall consist of a rubber pad (76.2 ± 0.5) mm wide; (25.4 ± 1.0) mm long (in the direction of swing) and (6.4 ± 0.5) mm thick, the combined mass of slider and base shall be (32 ± 5) g.

8.2.1.5 The slider shall be held on a rigid base with a centre pivoting axis which shall be mounted on the end of the pendulum arm in such a way that, when the arm is at the lowest point of its swing with the trailing edge of the slider in contact with the test surface, the plane of the slider is angled at $(26 \pm 3)^0$ to the horizontal. In this configuration the slider can turn about its axis without obstruction to follow unevenness of the surface of the test specimen as the pendulum swings.

8.2.1.6 The slider shall be spring-loaded against the test surface. When calibrated, the static force on the slider as set by the equipment calibration procedure shall be (22.2 ± 0.5) N in its median position. The change in the static force on the slider shall be not greater than 0.2 N per millimeter deflection of the slider.

8.2.1.7 The initial resilience and hardness of the slider shall conform to Table **3**, and shall have a certificate of conformity including the name of the manufacturer and date of manufacture. A slider shall be discarded when the IRHD value measured in accordance with **SLS ISO 7619** fails to conform to the requirements of the table or not later than three years after manufacture.

TABLE 3 – Properties of the slider rubber

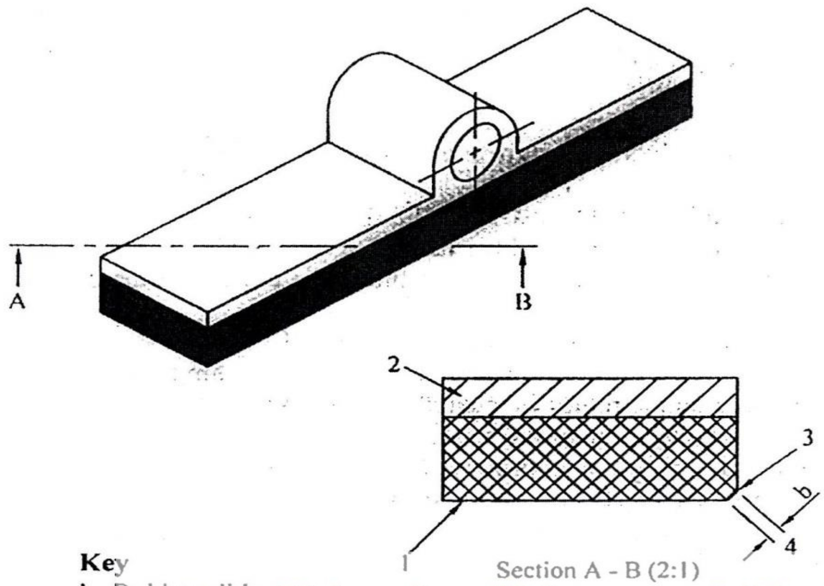
	Temperature ^0C				
Property	0	10	20	30	40
Resilience (%)[a]	43 to 49	58 to 65	66 to 73	71 to 77	74 to 79
Hardness (IRHD)[b]	53 to 65				

[a] Rebound test in accordance with **SLS ISO 4662**
[b] International Rubber Hardness Degrees ion accordance with **SLS ISO 48.**

8.2.1.8 The edges of the slider be square and clean-cut, and the rubber free from contamination by for example, abrasive or oil. The slider shall be stored in the dark at a temperature in the range 5 ^0C to 20 ^0C.

8.2.1.9 Before using a new slider it shall be conditioned to produce a minimum width of striking edge of 1 mm as shown in Figure **10.**

This shall be achieved by setting up the tester and carrying out five swings on a dry surface with a friction value above 40 on the C scale followed by a further 20 swings on the same surface after wetting.



Key
1. Rubber slider
2. Aluminium backing
3. Striking edge
4. Worn width

FIGURE 10 - Slider assembly illustrating the maximum wear of striking edge

8.2.1.10 The slider shall be discarded when the width of the striking edge as shown in Figure **10** exceeds 3 mm or becomes excessively scored or burred. The slider can be reversed to expose a new edge, which will need to be conditioned.

8.2.2 A container with potable water at (27 ± 2) ^{0}C for wetting the surfaces of the test specimen and slider.

8.3 Calibration

The apparatus shall be recalibrated at least annually.

8.4 Sampling

Obtain a representative sample in accordance with **6** of Part **1**.
Each block in the sample shall permit a test area of 136 mm x 86 mm which is representative of the whole block. This area shall be tested using the 76 mm wide slider over a nominal swept length of 126 mm, readings being taken on the C scale.

In the case of large blocks, representative samples shall be cut from them for test.

8.5 Procedure

Keep the friction test equipment, and slider, in a room at a temperature of (27 ± 2) ^{0}C for at least 30 min before the test begins.

Immediately prior to testing with the friction tester, immerse the sample in water at (27 ± 2) ^{0}C for at least 30 min.

Place the friction tester upon a firm level surface and adjust the leveling screws so that the pendulum support column is vertical. Then raise the axis of suspension of the pendulum so that the arm swings freely, and adjust the friction in the pointer mechanism so that when the pendulum arm and pointer are released from the right-had horizontal position the pointer cones to rest at the zero position on the test scale.

Before using a new slider, condition it using the method described in **8.2.1.9**.

Discard any slider that exceeds the requirements given in **8.2.1.10**.

Rigidly locate the test specimen with its longer dimension lying in the track of the pendulum, and centrally with respect to the rubber slider and to the axis of the suspension of the pendulum. Ensure that the track of the slider is parallel to the long axis of the specimen across the sliding distance.

Adjust the height of the pendulum arm so that in traversing the specimen the rubber slider is in contact with it over the whole width of the slider and over the specified swept length. Wet the surfaces of the specimen and the rubber slider with a copious supply of water, being careful not to disturb the slider from its set position. Release the pendulum and pointer from the horizontal position, catch the pendulum arm on its return swing. Record the position of the pointer on the scale (the pendulum test value).. Perform this operation five times, rewetting the specimen each time, and record the mean of the last three readings. Relocate the specimen after rotating though 180^0 and repeat the procedure.

8.6 Calculation of test results

When the wide slider is used over a swept length of 126 mm, calculate the pendulum value of each specimen as the mean of the two recorded mean values measured in opposite directions to the nearest 1 unit on the C scale.

8.7 Test report

The test report shall include the following information;

1) the mean pendulum test value of each specimen; and

2) the mean USRV of the sample.

9 DETERMINATION OF TOTAL WATER ABSORPTION

9.1 Principle

After conditioning the specimen to (27 ± 2) ^{0}C it is soaked to constant mass and dried to constant mass. The loss in mass is expressed as a percentage of the mass of the dry specimen.

9.2 Specimen

If a block weighs more than 5.0 kg it shall be cut through its full height to provide a specimen not greater than 5.0 kg.

9.3 Materials

Potable water.

9.4 Apparatus

9.4.1 Ventilated drying oven with a capacity in litres to an area of ventilation channels in square millimetres less than 0.2 in which the temperature may be controlled to (105 ± 5) ^{0}C. It shall have a volume at least 2.5 times greater than the volume of specimens to be dried at any one time.

9.4.2 Flat based vessel having a capacity at least 2.5 times the volume of the samples to be soaked and a depth at least 50 mm greater than the height of the specimens in the attitude that they will be soaked.

9.4.3 Weighing balance capable of measuring more than 5 kg and accurate to 0.1 % of the reading in grams.

9.4.4 Stiff brush.

9.4.5 Cloth

9.5 Preparation of the test specimens

Remove all dust, flashing, etc. with a brush and ensure that each specimen is at a temperature of (27 ± 2) ^{0}C.

9.6 Procedure

Immerse the specimens in potable water at a temperature of (27 ± 2) ^{0}C using the vessel until constant mass M_1 is reached. Separate the specimens from each other by at least 15 mm and ensure a minimum of 20 mm water above them. The minimum period of immersion shall be three days and constant mass shall be deemed to have been reached when two weighings performed at an interval of 24 h show a difference in mass of the specimen of less than 0.1%. Before each weighing wipe the specimen with the cloth which has been moistened and squeezed to remove any excess of water. The drying is correct when the surface of the concrete is dull.

Place each specimen insides the oven in such a way that the distance between each specimen is at least 15 mm. Dry the specimen at a temperature of (105 ± 5) ^{0}C until reached constant mass M_2 . The minimum period of drying shall be three days and constant mass shall be deemed to have been reached when two weighing performed at an interval of 24 h show a difference in mass of the specimen of less than 0.1%. Allow the specimen to cool to room temperature before they are weighed.

9.7 Calculation of test results

Calculate the water absorption W_a of each specimen as a percentage of its mass from the equation:

$$W_a = \frac{M_1 - M_2}{M_2} \times 100\ \%$$

where

M_1 is the initial mass of the specimen (g);

M_2 is the final mass of the specimen (g).

Calculate the water absorption of the sample as the mean of the water absorption values of the specimens.

9.8 Test report

The test report shall give the value of water absorption for each of the specimens.

Methods

1 Scope

This Part of BS 812 describes two methods for the determination of the particle size distribution of samples of aggregates and fillers by sieving.

NOTE 1. For sampling and testing lightweight aggregates for concrete see BS 3681.

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 812 the definitions given in BS 812 : Part 101 and Part 102 apply.

3 Principle

3.1 Washing and sieving

This is the preferred method (see **7.2**) for aggregates which may contain clay or other materials likely to cause agglomeration of particles. It involves preliminary separation by washing through a fine sieve before determining particle size distribution by dry sieving.

3.2 Dry sieving

This is an alternative method (see **7.3**) which may be used for coarse and fine aggregates free from particles which cause agglomeration.

NOTE 1. Dry sieving gives inaccurate results for aggregates containing clay but is quicker and less laborious to carry out than washing and sieving.

NOTE 2. It is not possible to specify accurately the amount of clay or other materials which will make the method given in **7.3** inappropriate and unless it can be demonstrated (e.g. by previous experience) that that method gives accurate results, it is recommended that the method described in **7.2** should always be used. Because of this some materials specifications may call for washing and sieving to be followed at all times.

4 Sampling

The sample used for the test (the laboratory sample) shall be taken in accordance with the procedures described in clause **5** of BS 812 : Part 102 : 1984.

5 Apparatus

5.1 *A sample divider*, of size appropriate to the maximum particle size to be handled or alternatively a flat shovel and a clean, flat, hard horizontal surface, e.g. a metal tray for use in quartering.

NOTE. A suitable divider is the riffle box illustrated in BS 812 : Part 102.

5.2 *A ventilated oven*, thermostatically controlled to maintain a temperature of 105 ± 5 °C.

5.3 *A balance, or balances,* of suitable capacity accurate to 0.1 % of the mass of the test portion.

NOTE. In general, two balances, one of approximately 5 kg capacity accurate to 1 g and the other of approximately 500 g capacity accurate to 0.1 g, will suffice. If aggregate of larger than 28 mm nominal size is to be tested a balance of 50 kg capacity accurate to 10 g will also be required.

5.4 *Test sieves and nesting guard sieve*, of the sizes and apertures appropriate to the specification of the material being tested, complying with BS 410 and with the appropriate sizes of lid(s) and receivers.

NOTE 1. A set of sieves of the sizes and apertures given in table 1 will cover most applications of the method.

NOTE 2. Some advice on cleaning and checking sieves is given in appendices A and B.

Table 1. Particulars of sieves for sieve analysis

Nominal aperture sizes	
Square hole perforated plate, 450 mm or 300 mm diameter	**Wire cloth, 300 mm or 200 mm diameter**
mm	mm
75.0	3.35
63.0	2.36
50.0	1.70
37.5	1.18
28.0	
20.0	µm
14.0	850
10.0	600
6.30	425
5.00	300
	212
	150
	75*

*For some applications, 63 µm is appropriate.

5.5 *A mechanical sieve shaker* (optional).

5.6 *Trays*, that can be heated in the ventilated oven (**5.2**) without damage or change in mass.

5.7 *Containers*, of a size sufficient to contain the test portion plus five times its volume of water (for washing and sieving method only).

6 Preparation of test portion

Reduce the sample in accordance with the procedures described in clause **6** of BS 812 : Part 102 : 1984 to produce the required number of test portions each of which complies with the minimum mass given in table 2. Dry the test portions by heating at a temperature of 105 ± 5 °C to achieve a dry mass which is constant to within 0.1 %. Allow to cool, weigh and record as M_1.

Table 2. Minimum mass of test portion for sieve analysis

Nominal size of material	Minimum mass of test portion
mm	kg
63	50
50	35
40	15
28	5
20	2
14	1
10	0.5
6	0.2
5	0.2
3	0.2
<3	0.1

7 Procedure

7.1 General

7.1.1 For some materials, e.g. all in aggregates or hoggin, the particle size distribution may result in excess mass on one or more sieves particularly on the finer sizes. Therefore, if it is not possible to include extra sieves of appropriate intermediate size to reduce the loading, adopt one of the following procedures.

(a) Subdivide the test portion into two or more sub-portions. Determine the particle size distribution for each portion and combine the results for the purpose of reporting.

(b) Separate the test portion on an appropriate sieve, e.g. 20 mm or 5 mm. Weigh the retained and passing fractions to determine the proportion of each present. Determine the particle size distribution of each fraction separately, reducing where necessary by quartering or by means of a sample divider (**5.1**) as described in clause **6** of BS 812 : Part 102 : 1984. Calculate the particle size distribution of the original sample by combining the results for each fraction in the proportions present.

7.1.2 When special procedures for fillers are required to measure the amount finer than 75 μm, carry these out either in accordance with **7.2** of BS 812 : Part 1 : 1975 or BS 812 : Part 104*.

7.2 Washing and sieving method

7.2.1 *Preliminary separation*

7.2.1.1 Wet both sides of a 75 μm test sieve (**5.4**), reserved for use in this test only, and fit a nesting guard sieve (e.g. 1.18 mm) on top. Mount the sieves in such a way that the suspension passing the test sieve can be run to waste or, when required, collected in a suitable vessel.

7.2.1.2 Place the weighed oven dried test portion in a container (**5.7**) and add sufficient water to half fill the container. Agitate the contents so that particles smaller than 75 μm are completely separated from coarser particles.

NOTE. Soaking or continued agitation or, in the case of large particles, brushing may be required to achieve complete separation.

7.2.1.3 Pour the suspension of fine solids on to the guarded 75 μm test sieve.

NOTE. The suspension passing the test sieve may be run to waste unless it is required for other purposes.

7.2.1.4 Continue washing the coarse residue until the water passing the test sieve is clear (see note 2) and then wash all the residues from the container and sieve(s) into the tray (**5.6**). Remove excess free water by careful decantation through the test sieve, avoiding transfer of solids (see note 2) and dry the residue in the oven (**5.2**) at 105 ± 5 °C until constant mass is achieved. Cool, weigh and record as M_2.

NOTE 1. Avoid excess water flows which may damage or flood the sieves.

NOTE 2. If some transfer of solids does occur wash them back into the tray and repeat the operation.

NOTE 3. Fine sieves are fragile and the integrity of the mesh should be checked frequently (see appendix B).

7.2.1.5 Determine the mass of material passing the test sieve as $M_1 - M_2$.

7.2.2 *Sieving the dried residue*

7.2.2.1 Nest the clean and dry sieves on a fitting receiver in order of increasing aperture size from bottom to top. Place the dried residue on the top coarsest sieve and cover with a fitting lid. Either by hand or using the mechanical sieve shaker (**5.5**), shake the sieves for a sufficient time to separate the test sample into the size fractions determined by the sieve apertures used.

NOTE. Experience has shown that the preliminary separation (**7.2.1**) does not necessarily remove all the particles smaller than 75 μm because of capillary action of water on particle surfaces. It is therefore necessary to incorporate a 75 μm test sieve in the series of test sieves used to sieve the dried residue.

7.2.2.2 When the mechanical sieve shaker is used, after sieving, check that separation is complete by briefly hand sieving. When sieving is done by hand alone start with the coarsest sieve and shake each sieve separately over a clean tray or receiver until not more than a trace passes, but in any case for a period of not less than 2 min. Do the shaking with a varied motion, backwards and forwards, left to right, circular, clockwise and anti-clockwise, and with frequent jarring so that the material is kept moving over the sieve surface in frequently changing directions. Do not force materials through the sieve by hand pressure but placing of particles is permitted. Break lumps of agglomerated material which consist of particles representative of the bulk by gentle pressure with the fingers against the side of the sieve.

7.2.2.3 Record any extraneous material not representative of the bulk that will not readily break down into individual particles, such as clay lumps, and remove from the sieve for separate weighing.

*At the time of publication, BS 812 : Part 104 is in preparation. When published, it will supersede 7.2 of BS 812 : Part 1 : 1975.

7.2.2.4 Do not apply pressure to the surface of the sieve to force particles through the mesh. Light brushing with a soft brush on the underside of the sieve may be used to clear sieve openings. Light brushing with a fine camel-hair brush may be used on the 150 µm and 75 µm sieves to prevent agglomeration of the powder and blinding of the apertures. Do not use stiff or worn-down brushes for this purpose.

7.2.2.5 In order to prevent blinding of the sieve apertures by overloading, ensure that the mass of aggregate retained on the sieve at completion of the operation does not exceed the value for that sieve shown in table 3.

NOTE 1. Some sample masses shown in table 1 will thus require additional operations on some sieves, as described in **7.1**.

NOTE 2. In some cases it may be possible to reduce sufficiently the load on a sieve by incorporating an intermediate sieve into the test series.

7.2.2.6 Weigh the material retained on each sieve, together with any material cleaned from the mesh, on completion of sieving on that sieve.

NOTE. Samples containing dust should be sieved into a receiver to prevent loss.

7.2.2.7 Add the aggregate passing the sieve to the next sieve in the series before commencing the operation on that sieve.

7.3 Dry sieving method

Use the procedure described in 7.2.2.

8 Calculation and expression of results

Calculate the mass retained on each sieve as a percentage of the original dry mass (M_1). For the mass of material passing the finest sieve, add that passing during washing ($M_1 - M_2$) to that found during the dry sieving.

Calculate the mass passing each sieve as a cumulative percentage of the total sample mass.

9 Precision

Estimates of the repeatability and reproducibility of sieve analysis using the methods described in this Part of BS 812 are given in table 4 for a limited range of materials.

NOTE 1. Reference should be made to BS 812 : Part 101 for guidance on assessing the precision of the methods given in this standard.

NOTE 2. There is insufficient data available to permit the inclusion of values for V_s (variance arising from sampling errors) in table 4. When data is available it will be incorporated by amendment. Some values of V_s for a single experiment are given in Supplementary Report 831 published by the Transport and Road Research Laboratory.

10 Test report

The report shall affirm that the particle size distribution was determined in accordance with this Part of BS 812 and whether or not a certificate of sampling is available. If available, a copy of the certificate of sampling shall be provided. The test report shall include the following additional information:

(a) sample identification;

(b) either the cumulative percentage of the mass of the total sample passing each of the sieves, to the nearest whole number; or the percentage of the mass of the total sample passing one sieve and retained on the next smaller sieve, to the nearest whole number;

NOTE. A specimen chart which may be used for illustrating the results graphically is shown in figure 3.

(c) the method used by reference to either **7.2** or **7.3** of this Part of BS 812;

Table 3. Maximum mass to be retained at the completion of sieving

BS test sieve nominal aperture size	Maximum mass		BS test sieve nominal aperture size		Maximum mass	
	450 mm diameter sieves	300 mm diameter sieves			300 mm diameter sieves	200 mm diameter sieves
mm	kg	kg	mm	µm	g	g
50.0	14	5	5.00		750	350
37.5	10	4	3.35		550	250
			2.36		450	200
28.0	8	3	1.70		375	150
20.0	6	2.5	1.18		300	125
14.0	4	2				
10.0	3	1.5		850	260	115
				600	225	100
				425	180	80
6.30	2	1		300	150	65
5.00	1.5	0.75		212	130	60
3.35	1	0.55		150	110	50
				75	75	30

(d) whether or not lumps of material not representative of the bulk, such as clay lumps, were found to be present and the sieve sizes on which they were retained, together with the total amount present expressed as an overall percentage by mass of the total sample.

Table 4. Precision data for determination of particle size distribution

Description of material used	All values as cumulative percentage passing stated sieve							Details of precision experiment		
								Number of		
	Sieve size	Mean value	r	r_1	R	R_1	R_2	Participating laboratories	Outliers	Date
Chippings (1)	75 µm	0.38	—	0.2	—	0.35	—	17	—	1982
(2)	75 µm	0.81	—	0.2	—	0.35	—	17	1	1982
Type 2 granular sub-base	20 mm	90	—	5	5	6	9	9	—	1983
	10 mm	75	—	7	6	9	12			
	5 mm	65	—	6	3	9	11			
	600 µm	35	—	4	3	5	7			
	150 µm	15	—	2	—	3	4			
	75 µm	10	—	1	2	2	3			
20 mm crushed rock	600 µm	6.6	—	1.6	—	1.6	—	8	—	1983
	150 µm	3.6	—	0.3	—	1.0	—			
	75 µm	2.6	—	0.5	—	1.1	—			
14 mm single sized basalt or sandstone	14 mm	90	—	4.8	—	5.6	—	8	—	1982
	10 mm	25	—	5.2	—	8.5	—			
	2.36 mm	1.0	—	0.2	—	1.1	—			
	75 µm	0.75	—	0.2	—	1.0	—			
Building sands (means of 11 different sands)	600 µm	90	—	0.8	—	1.4	—	11	—	1981
	300 µm	57	—	1.8	—	4.8	—			
	150 µm	19	—	1.8	—	6.6	—			
	75 µm	5.5	—	0.8	—	1.5	—			

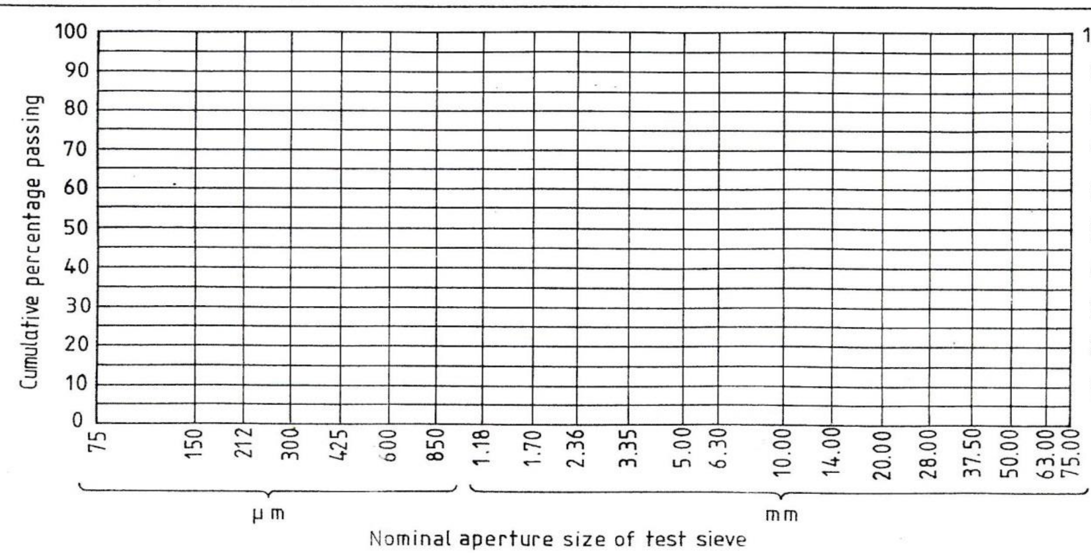


Figure 1. Chart for recording sieve analysis results

Appendix C - Summary of Questionnaire Returns

Appendix C-1: Water Treatment Plants Facility Information

No	Water Treatment Plants	Year of Establishment	Installed Capacity (m3/day)	Quantity Treated (m3/day)	Location	Region	Population served
1	Ambatale WTP		517,500	603,000	Ambatale		
2	Biyagama WTP		180,000	177,000		Gampaka	1,000,000
3	Kalatuwawa WTP	1960	91,000	70,000	KakatywawaTumodara	Ratnapura	282,495
4	Labugama WTP		65,000	41,000	Labugama		
5	Kandana WTP	2006	60,000	73,000	KandanaHorana	Kalutara	400,000
6	Kethhena WTP	1986	54,000	41,500	Thebuwana	Kalutara	
7	Paradeka WTP	2009	6,000	5,400	Kandy South	Kandy	33,000
8	Ulapane WTP	2009	8,000	8,000	Kandy South	Kandy	
9	Katugastota WTP	2007	48,000	48,000	Katugastota	Kandy	
10	Wakwella WTP	1976	30,000	24,000	Galle	Galle	
11	Hallalla WTP	1995,2007	8,000	8,000	welpitiya	Matara	60,000
12	Malimbada WTP	1985, 1996, 2006	45,000	42,000	Malimbada	Matara	
13	Nadugala WTP	1963	6,500	6,500	Nadugala	Matara	
14	Ambalantota/Hambantota	2010	15,000	13,800	Ambalantota	Hambantota	
15	RannaWTP	2005	13,000	12,500	Ranna	Hambantota	
16	Tangalle WTP	1958	7,500	7,500	Nalagama	Hambantota	57,500
17	Eluduwa WTP	1993	9,100	9,100	Badulla	Bandarewela	40,000
No.	**Water Treatment**	**Year of Establi**	**Installed Capacity**	**Quantity Treated**	**Location**	**Region**	**Population served**

	Plants	shment	(m3/day)	(m3/day)			
18	Ruhunupura WTP	2015	17,500	17,500	Sooriyawewa	Hambantota	55,000
19	Kanthale WTP		54,000	48,000	Kantale	Trincomale e	
20	Pothuvil WTP	2008	5,600	1,700	Ulla	Ampara	3,343
21	Thirukkovil WTP	2009	6,500	600		Ampara	1,500
22	Konduwattuwan a	2002	72,000	35,000	Ampara	Ampara	400,000
23	Vavunathivu WTP	2012	40,000	13,000	Wawnathiwu	Batticalo	300,000
24	Eachchalampatt u	2011	6,000	6,000		Trincomal e	16,400
25	Seethawaka WTP	1999	9,450	9,450		Ratnapura	

Appendix C-2: Source of Water

No.	Water Treatment Plants	Surface Water		Ground Water		Avg. Flow (m3/d)	Max. Flow (m3/d)
		River	Reservoir	Bore hole	Dug well		
1	Ambatale WTP	Kelani Ganga					
2	Biyagama WTP	Kelani Ganga				177,300	187,300
3	Kalatuwawa WTP		Kalatuwawa Tank			84,000	86,000
4	Labugama WTP		Labugama Tank				
5	Kandana WTP	Kalu Ganga					
6	Kethhena WTP	Kalu Ganga				44,000	46,000
7	Paradeka WTP	Paradekaoya				8,000	120,000
8	Ulapane WTP						
9	Katugastota WTP	Mahawali Ganga					
10	Wakwella WTP	Gin Ganga					
11	Hallalla WTP	Polathu Ganga				172,800	
12	Malimbada WTP	Nilwala Ganga					
13	Nadugala WTP	Nilwala Ganga					
14	Ambalantota/Hambantota	Walawe Ganga				16,000	24,000
15	RannaWTP	Kattakaduwa River				12,500	13,200
16	Tangalle WTP	KiramaOya	Nawayalawila			6,500	9,000
17	Eluduwa WTP	BadullaOya				8,500	100,000
18	Ruhunupura WTP	Walawe Ganga	Ridiyagama Tank				
19	Kanthale WTP	Mahawali Ganga	Kantale Tank				

No.	Water Treatment Plants	Surface Water		Ground Water		Avg. Flow (m3/d)	Max. Flow (m3/d)
		River	Reservoir	Bore hole	Dug well		
20	Pothuvil WTP			√		1,700	5,600
21	Thirukkovil WTP		Sagammam			600	6,500
22	Konduwattuwana WTP		Konduwattu wana Tank			38,400	
23	Vavunathivu WTP		Unnichchai Tank			14,000	15,000
24	Eachchalampattu	VerugalAru				61,395	
25	Seethawaka WTP	Kelani Ganga				9,450	

Appendix C-3: Raw Water Quality

No.	Water Treatment Plants	Raw Water Quality (Avg.)						
		Turbidity NTU	Alkalinity mg/L	Hardness mg/L	TSS mg/L	pH	Temperature	Conductivity
1	Ambatale WTP							
2	Biyagama WTP	7.78	21.3	18.3	16.62	6.67	26	66.8
3	Kalatuwawa WTP	2.3	6.8	6.3		6.1		10.8
4	Labugama WTP							
5	Kandana WTP	29.3	26.4	26.4	10.2	6.7	25.1	66.7
6	Kethhena WTP	15.5	12.0	14.0		6.6		40.1
7	Paradeka WTP	5	34.0	35.0		7.5	23	82
8	Ulapane WTP							
9	Katugastota WTP	60	34.0	30.0		7.2		94
10	Wakwella WTP	15.4	15.7	19.2		7.04		36.9
11	Hallalla WTP	12.5	20.0	30.0		6.2	30	70
12	Malimbada WTP	12	22.0	23.0		6.2		50.1
13	Nadugala WTP	18	30.0	32.0		7		62.5
14	Ambalantota/ Hambantota	14.16	140.0	130.0		7.2	30	298
15	RannaWTP	15.96	147.0	132.0		7.5		
16	Tangalle WTP	45				6.7		
17	Eluduwa WTP	80	90.0	100.0		7.5		170
18	Ruhunupura WTP	6				7.8		

No.	Water Treatment Plants	Raw Water Quality (Avg.)						
		Turbidity NTU	Alkalinity mg/L	Hardness mg/L	TSS mg/L	pH	Temperature	Conductivity
19	Kanthale WTP	45	70.0	65.0		6.5	28	200
20	Pothuvil WTP	31	146.0	91.0		7.4	28	524
21	Thirukkovil WTP	80	58.0	60.0		7.3	28	200
22	Konduwattuwana	7.55	37.0	47.0		7.49	33	88
23	Vavunathivu WTP	10	18.0	17.0		6.2	29	49
24	Eachchalampattu WTP	31.8	100.0	98.0		7.4	29.1	265
25	Seethawaka WTP	30	11.0	18.0	1.1	6.2	28	35

Appendix C-4: Water Treatment Process

No.	Water Treatment Plants	Treatment Process					
		Aeration	Coagulaion	Flocculation	Sedimentation	Filtration	Disinfection
1	Ambatale WTP						
2	Biyagama WTP	√	√	√	√	√	√
3	Kalatuwawa WTP	√	√	√	√	√	√
4	Labugama WTP						
5	Kandana WTP		√	√	√	√	√
6	Kethhena WTP	√	√	√	√	√	√
7	Paradeka WTP	√	√	√	√	√	√
8	Ulapane WTP	√	√	√	√	√	√
9	Katugastota WTP		√	√	√	√	√
10	Wakwella WTP	√	√	√	√	√	√
11	Hallalla WTP		√	√	√	√	√
12	Malimbada WTP	√			√	√	√
13	Nadugala WTP	√	√	√	√	√	√
14	Ambalantota/Hambantota	√	√	√	√	√	√
15	RannaWTP	√	√	√	√	√	√
16	Tangalle WTP	√	√		√	√	√
17	Eluduwa WTP		√	√		√	√
18	Ruhunupura WTP	√	√	√	DAF	√	√
19	Kanthale WTP	√	√		√	√	√
20	Pothuvil WTP					√	√

No.	Water Treatment Plants	Treatment Process					
		Aeration	Coagulaion	Flocculation	Sedimentation	Filtration	Disinfection
21	Thirukkovil WTP	√	√	√	√	√	√
22	Konduwattuwana		√	√	DAF	√	√
23	Vavunathivu WTP		√	√	DAF	√	√
24	Eachchalampattu WTP	√	√	√	√	√	√
25	Seethawaka WTP		√	√	√	√	√

Appendix C-5: Chemical Dosage

No.	Water Treatment Plants	Alum (kg/day)		Lime (kg/day)		PACl (kg/day)	
		Avg.	Range	Avg.	Range	Avg.	Range
1	Ambatale WTP						
2	Biyagama WTP	1660					
3	Kalatuwawa WTP			800		375	
4	Labugama WTP						
5	Kandana WTP	800	550-1400	400	320-550		
6	Kethhena WTP			200	160-200	225	175-225
7	Paradeka WTP					40	30-50
8	Ulapane WTP						
9	Katugastota WTP			30		250	
10	Wakwella WTP	200	150-250	150	100-175		
11	Hallalla WTP	85	75-90	90	80-100		
12	Malimbada WTP	500	450-600	200	160-280		
13	Nadugala WTP	95	75-120	13	10-15		
14	Ambalantota/Hambantota	750					
15	RannaWTP	400	400-425				
16	Tangalle WTP	250	150-350	30	28-50		
17	Eluduwa WTP	150	80-250	10	5-15		
18	Ruhunupura WTP	7.5x175					
19	Kanthale WTP	400					
20	Pothuvil WTP						
21	Thirukkovil WTP	45	25-50				
22	Konduwattuwana			280	250-350	500	400-550

No.	Water Treatment Plants	Alum (kg/day)		Lime (kg/day)		PACl (kg/day)	
		Avg.	Range	Avg.	Range	Avg.	Range
23	Vavunathivu WTP	155	150-200	130	100-200		
24	Eachchalampattu WTP						
25	Seethawaka WTP	45	30-80	50	20-90		

Appendix C-6: Sludge Production & Characteristics

No.	Water Treatment Plants	Type		Quantity		Characteristics			
		Alum	Lime	Dry (kg/day)	Wet (m3/day)	% Solid	pH	TSS (mg/L)	TDS (mg/L)
1	Ambatale WTP	√							
2	Biyagama WTP	√					7.1	120.75	
3	Kalatuwawa WTP	√					6	210	15
4	Labugama WTP	√							
5	Kandana WTP	√		2135	125	23.25			
6	Kethhena WTP	√							
7	Paradeka WTP	√							
8	Ulapane WTP	√							
9	Katugastota WTP	√							
10	Wakwella WTP	√							
11	Hallalla WTP	√			59				
12	Malimbada WTP	√							
13	Nadugala WTP	√							
14	Ambalantota/Hambantota	√							
15	RannaWTP	√							
16	Tangalle WTP	√							
17	Eluduwa WTP	√							
18	Ruhunupura WTP	√		100					
19	Kanthale WTP	√							
20	Pothuvil WTP	√							
21	Thirukkovil WTP	√		634					
22	Konduwattuwana	√		840	30	2.5-3.0	7.1	0.08	

No.	Water Treatment Plants	Type		Quantity		Characteristics			
		Alum	Lime	Dry (kg/day)	Wet (m3/day)	% Solid	pH	TSS (mg/L)	TDS (mg/L)
23	Vavunathivu WTP	√							
24	Eachchalampattu WTP	√							
25	Seethawaka WTP	√							

Appendix C-7: Sludge Removal & Discharge

No.	Water Treatment Plants	Removal			Basin Sludge Discharge to				
		Flushing	Continuous Mechanical Removal	Manual	Stream	Lake / Reservoir	Low ground	Sewer system	Impounding basin
1	Ambatale WTP	√			√				
2	Biyagama WTP		√				√		
3	Kalatuwawa WTP	√			√				
4	Labugama WTP	√			√				
5	Kandana WTP			√					√
6	Kethhena WTP			√					√
7	Paradeka WTP			√	□				√
8	Ulapane WTP			√	√				□
9	Katugastota WTP			√					√
10	Wakwella WTP			√	√				
11	Hallalla WTP			√	√				
12	Malimbada WTP			√					√
13	Nadugala WTP			√	√				
14	Ambalantota/Hambantota			√		√			
15	RannaWTP		√		√				
16	Tangalle WTP			√	√				
17	Eluduwa WTP			√	√				
18	Ruhunupura WTP			√					√
19	Kanthale WTP			√					√

No.	Water Treatment Plants	Removal			Basin Sludge Discharge to				
		Flushing	Continuous Mechanical Removal	Manual	Stream	Lake / Reservoir	Low ground	Sewer system	Impounding basin
20	Pothuvil WTP			√	√				
21	Thirukkovil WTP			√			√		
22	Konduwattuwana		√						√
23	Vavunathivu WTP		√						√
24	Eachchalampattu WTP			√					√
25	Seethawaka WTP			√				√	

Appendix C-8: Sludge Treatment

No.	Water Treatment Plants	Thickening			Wash water Recycle	Sludge Dewatering
		Gravity	Flotation	Centrifuge		
1	Ambatale WTP					
2	Biyagama WTP			√		√
3	Kalatuwawa WTP					
4	Labugama WTP					
5	Kandana WTP					√
6	Keththena WTP					√
7	Paradeka WTP					√
8	Ulapane WTP					□
9	Katugastota WTP					√
10	Walwella WTP					
11	Hallalla WTP					
12	Malimbada WTP					√
13	Nadugala WTP					
14	Ambalantota/Hambantota					
15	RannaWTP					
16	Tangalle WTP					
17	Eluduwa WTP					
18	Ruhunupura WTP	√				√
19	Kanthale WTP				√	√
20	Pothuvil WTP	□			√	
21	Thirukkovil WTP	√				√
22	Konduwattuwana			√	√	√
23	Vavunathivu WTP					√
24	Eachchalampattu WTP					√
25	Seethawaka WTP	□				

Appendix C-9: Sludge Dewatering

No.	Water Treatment Plants	Method				
		Drying beds	Lagoons	Centrifuge	Gravity Thickner	Filter press
1	Ambatale WTP					
2	Biyagama WTP			√		
3	Kalatuwawa WTP					
4	Labugama WTP					
5	Kandana WTP		√			
6	Kethhena WTP	√				
7	Paradeka WTP	√				
8	Ulapane WTP					
9	Katugastota WTP		√			
10	Wakwella WTP					
11	Hallalla WTP					
12	Malimbada WTP		√			
13	Nadugala WTP					
14	Ambalantota/Hambantota					
15	RannaWTP					
16	Tangalle WTP					
17	Eluduwa WTP					
18	Ruhunupura WTP	√				
19	Kanthale WTP	√				
20	Pothuvil WTP	√				
21	Thirukkovil WTP	√			√	
22	Konduwattuwana	□		√		
23	Vavunathivu WTP	□	√			
24	Eachchalampattu WTP	√			√	
25	Seethawaka WTP					

Appendix C-10: Sludge Final Disposal

No.	Water Treatment Plants	Utilization for		Dispose to Land	
		land Reclamation	Filling Material	Open dump	Dedicated Land
1	Ambatale WTP				
2	Biyagama WTP		√	□	
3	Kalatuwawa WTP				
4	Labugama WTP				
5	Kandana WTP	√		□	
6	Kethhena WTP			√	
7	Paradeka WTP			√	
8	Ulapane WTP			□	
9	Katugastota WTP			√	
10	Wakwella WTP				
11	Hallalla WTP				
12	Malimbada WTP	√		□	
13	Nadugala WTP				
14	Ambalantota/Hambantota				
15	RannaWTP				
16	Tangalle WTP				
17	Eluduwa WTP				
18	Ruhunupura WTP			√	
19	Kanthale WTP			√	
20	Pothuvil WTP				
21	Thirukkovil WTP		√		
22	Konduwattuwana			√	□
23	Vavunathivu WTP			√	
24	Eachchalampattu WTP			√	
25	Seethawaka WTP			□	

Appendix D - Test Results of Burnt Clay Bricks

Characteristics of Raw Materials

Table D.1: Observation & Results of Moisture Content

Material	Sample No.	Weight of can (g)	Weight of wet soil +can (g)	Weight of dry soil + can (g)	Moisture Content (%)	Avg. Moisture Content (%)
WTP Sludge 1 Kethhena	1	53.144	60.247	57.889	22.258	**33.61**
	2	63.542	84.273	77.226	22.823	
	3	68.236	89.581	82.398	22.799	
WTP Sludge 2 Kandana	1	57.244	84.669	76.584	20.819	**29.69**
	2	53.5121	75.237	68.752	20.728	
	3	68.236	100.187	90.682	20.828	
Clay	1	98.994	111.478	109.258	17.783	**17.88**
	2	105.236	120.024	117.362	17.995	
	3	93.563	112.024	108.723	17.876	

Table D.2: Observation & Results of Volatile Organic Content

Material	Sample No.	Weight of can (g)	Weight of wet soil +can (g)	Weight of dry soil + can 110C (g)	Weight of dry soil + can 550C (g)	Volatile Organic Content (%)	Avg. Volatile Organic Content (%)
WTP Sludge 1 Kethhena	1	10.480	15.687	14.498	13.580	22.847	**22.83**
	2	10.500	16.050	14.780	13.804	22.804	
	3	10.450	15.550	14.383	13.485	22.832	
WTP Sludge 2 Kandana	1	10.460	15.450	14.440	13.540	22.613	**22.70**
	2	10.510	16.200	15.055	14.024	22.684	
	3	10.480	15.620	14.580	13.645	22.805	

Table D.3: Results of Sieve Analysis

Water Treatment Plant Sludge (Kethhena)						
Sieve size (mm)	**Sieve weight (g)**	**Mass + sieve (g)**	**Mass in each sieve (g)**	**Cumulative mass retained (g)**	**Cumulative retained (%By mass)**	**Passing (% By mass)**
3.35	546	546	0	0	0	100
2.36	527	527	0	0	0	100
2	376	377	1	1	0.1	99.9
1.18	366	400	34	35	3.5	96.5
0.6	471	820	349	384	38.4	61.6
0.425	303	700	397	781	78.1	21.9
0.3	299	395	96	877	87.7	12.3
0.212	281	380	99	976	97.6	2.4
0.15	278	280	2	978	97.8	2.2
0.075	402	417	15	993	99.3	0.7
pan	462	466	4	997	99.7	0.3

Water Treatment Plant Sludge (Kandana)						
Sieve size (mm)	**Sieve weight (g)**	**Mass + sieve (g)**	**Mass in each sieve (g)**	**Cumulative mass retained (g)**	**Cumulative retained (%By mass)**	**Passing (% By mass)**
3.35	546	546	0	0	0	100
2.36	527	527	0	0	0	100
2	376	378	2	2	0.2	99.8
1.18	366	382	16	18	1.8	98.2
0.6	471	845	374	392	39.2	60.8
0.425	303	755	452	844	84.4	15.6
0.3	299	390	91	935	93.5	6.5
0.212	281	320	39	974	97.4	2.6
0.15	278	288	10	984	98.4	1.6
0.075	402	410	8	992	99.2	0.8
pan	462	465	3	995	99.5	0.5

Characteristics of Clay- Sludge Mix

Table D.4: Observations & Results of Moisture Content

Mix Proportion Sludge: Clay		Sample No.	Weight of can (g)	Weight of wet soil +can (g)	Weight of dry soil + can (g)	Moisture Content (%)	Avg. Moisture Content (%)
Sludge 1 Kethhena WTP	10:90	1	56.235	67.317	64.214	28.002	**28.01**
		2	63.236	75.632	72.165	27.969	
		3	55.332	68.235	64.616	28.048	
	20:80	1	85.191	93.400	90.958	29.749	**30.26**
		2	48.171	62.356	57.995	30.744	
		3	63.235	71.585	69.056	30.287	
	30:70	1	53.652	62.225	59.472	32.112	**31.78**
		2	56.236	68.456	64.652	31.129	
		3	48.710	60.125	56.462	32.089	
Sludge 2 Kandana WTP	10:90	1	48.710	59.590	56.543	28.002	**28.22**
		2	53.652	63.253	60.542	28.238	
		3	56.235	68.256	64.841	28.409	
	20:80	1	55.331	65.320	62.363	29.604	**29.68**
		2	63.236	73.524	70.486	29.530	
		3	53.651	65.368	61.865	29.897	
	30:70	1	55.623	73.658	67.985	31.456	**31.32**
		2	63.235	76.235	72.185	31.154	
		3	53.651	62.130	59.472	31.348	
Control	0:100	1	63.235	76.546	73.045	26.302	**26.85**
		2	56.236	67.259	64.362	26.281	
		3	53.651	65.231	61.992	27.971	

Table D.5: Dimension of Bricks

Mix 1 of Kethhena WTP Sludge																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
1-1	194	195	194	194	**194**	96	96	96	95	96	96	**96**	57	57	56	57	57	57	**57**
1-2	194	194	193	194	**194**	96	95	96	96	95	96	**96**	57	57	57	58	57	57	**57**
1-3	193	194	194	194	**194**	96	96	96	96	96	96	**96**	57	57	57	57	58	57	**57**
1-4	194	194	194	194	**194**	96	95	96	96	95	96	**96**	57	58	57	57	57	57	**57**
1-5	195	194	194	194	**194**	96	96	96	96	96	96	**96**	57	57	57	57	57	57	**57**
1-6	194	195	193	194	**194**	96	96	96	96	96	96	**96**	56	57	57	57	57	57	**57**
1-7	194	195	194	194	**194**	96	96	96	96	96	96	**96**	57	58	57	57	57	58	**57**
1-8	193	194	194	195	**194**	95	96	96	96	96	96	**96**	57	57	57	58	57	57	**57**
1-9	194	194	194	194	**194**	96	95	96	96	95	96	**96**	57	57	57	58	57	57	**57**
1-10	194	194	193	194	**194**	96	96	96	96	96	96	**96**	58	56	57	57	58	57	**57**
	194	**194**	**194**	**194**	**194**	**96**	**96**	**96**	**96**	**96**	**96**	**96**	**57**	**57**	**57**	**57**	**57**	**57**	**57**

Mix 2 of Kethhena WTP Sludge																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
2-1	191	191	191	192	**191**	94	94	94	94	95	94	**94**	56	57	56	56	57	56	**56**
2-2	191	191	191	191	**191**	94	94	94	94	94	94	**94**	56	56	56	57	56	57	**56**
2-3	191	191	192	192	**192**	95	94	94	95	94	95	**95**	56	56	57	56	57	56	**56**
2-4	192	192	191	192	**192**	94	94	95	94	94	94	**94**	57	56	57	56	55	56	**56**
2-5	191	192	191	191	**191**	94	94	94	94	95	95	**94**	57	55	56	56	56	57	**56**
2-6	191	191	190	191	**191**	94	95	95	95	94	94	**95**	56	56	56	57	56	57	**56**
2-7	190	191	190	191	**191**	95	94	94	94	94	94	**94**	56	56	57	56	57	55	**56**
2-8	190	191	191	190	**191**	94	94	94	94	94	94	**94**	56	57	56	57	56	55	**56**
2-9	191	190	190	190	**190**	95	95	94	94	94	94	**94**	56	57	56	55	57	56	**56**
2-10	190	190	191	191	**191**	94	94	95	94	94	94	**94**	55	56	57	56	57	56	**56**
	191	**191**	**191**	**191**	**191**	**95**	**94**	**94**	**94**	**94**	**94**	**94**	**56**	**56**	**56**	**56**	**56**	**56**	**56**

Mix 3 of Kethhena WTP Sludge																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
3-1	188	189	188	189	**189**	93	94	93	94	93	93	**93**	56	55	55	56	55	55	**55**
3-2	189	188	189	188	**189**	94	93	93	94	93	93	**93**	55	55	55	56	56	55	**55**
3-3	188	189	188	189	**189**	93	94	93	93	94	93	**93**	56	55	55	56	55	55	**55**
3-4	189	188	189	188	**189**	93	93	94	93	93	94	**93**	55	56	56	55	55	55	**55**
3-5	188	189	188	189	**189**	93	93	94	93	93	94	**93**	55	56	55	55	55	56	**55**
3-6	189	188	188	189	**189**	94	93	93	94	93	93	**93**	55	55	55	55	55	56	**55**
3-7	188	189	189	188	**189**	94	93	93	93	94	93	**93**	56	55	56	55	55	55	**55**
3-8	188	189	188	189	**189**	93	93	93	94	94	93	**93**	55	55	55	56	56	55	**55**
3-9	189	188	189	188	**189**	93	94	94	93	93	94	**94**	55	55	55	55	55	55	**55**
3-10	189	188	189	189	**189**	93	94	93	93	93	94	**93**	55	56	56	55	55	55	**55**
	189	**189**	**189**	**189**	**189**	**93**	**93**	**93**	**93**	**93**	**93**	**93**	**55**	**55**	**55**	**55**	**55**	**55**	**55**

Mix 1 of Kandana WTP Sludge																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
1-1	192	192	193	193	**193**	96	96	96	97	96	96	**96**	57	57	57	57	58	57	**57**
1-2	192	193	192	192	**192**	96	96	97	96	95	96	**96**	57	57	57	57	56	57	**57**
1-3	192	192	192	192	**192**	96	97	96	96	96	96	**96**	57	57	57	56	57	56	**57**
1-4	192	192	192	193	**192**	96	95	96	97	96	96	**96**	57	57	58	57	57	57	**57**
1-5	193	193	193	192	**193**	97	96	96	96	95	96	**96**	58	57	57	57	57	57	**57**
1-6	192	192	192	192	**192**	96	96	95	96	96	96	**96**	57	57	57	57	57	57	**57**
1-7	192	192	192	192	**192**	96	96	96	96	96	95	**96**	57	57	57	58	57	57	**57**
1-8	193	192	193	192	**193**	96	96	96	96	97	96	**96**	57	57	57	57	57	58	**57**
1-9	192	192	192	192	**192**	95	96	96	96	96	97	**96**	57	57	57	57	57	57	**57**
1-10	192	192	192	192	**192**	96	96	96	95	96	96	**96**	57	57	57	58	57	57	**57**
	192	**192**	**192**	**192**	**192**	**96**	**96**	**96**	**96**	**96**	**96**	**96**	**57**	**57**	**57**	**57**	**57**	**57**	**57**

Mix 2 of Kandana WTP Sludge																				
No	**Length**					**Width**							**Height**							
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
2-1	190	189	190	190	**190**	94	95	93	94	94	93	**94**	56	57	56	56	56	57	**56**
2-2	190	190	189	190	**190**	94	94	94	93	94	94	**94**	57	56	56	56	56	56	**56**
2-3	190	190	190	189	**190**	94	94	94	95	93	94	**94**	56	56	56	57	56	56	**56**
2-4	189	190	190	190	**190**	93	94	94	94	94	95	**94**	57	56	56	56	57	56	**56**
2-5	190	189	190	190	**190**	94	93	94	94	94	94	**94**	56	56	57	56	56	57	**56**
2-6	190	190	189	190	**190**	94	93	93	94	94	94	**94**	57	56	56	56	56	56	**56**
2-7	190	190	190	189	**190**	94	94	94	93	93	94	**94**	56	57	56	57	56	56	**56**
2-8	189	190	190	189	**190**	93	94	94	94	94	94	**94**	57	56	56	56	56	56	**56**
2-9	190	189	190	190	**190**	94	94	94	94	94	93	**94**	56	56	56	56	57	56	**56**
2-10	190	190	189	190	**190**	94	93	94	94	94	94	**94**	57	56	57	56	56	56	**56**
	190	**190**	**190**	**190**	**190**	**94**	**94**	**94**	**94**	**94**	**94**	**94**	**57**	**56**	**56**	**56**	**56**	**56**	**56**

Mix 3 of Kandana WTP Sludge																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
3-1	188	189	189	188	**189**	93	93	93	92	93	92	**93**	56	56	56	56	56	56	**56**
3-2	189	188	189	188	**189**	93	92	93	93	92	93	**93**	56	56	57	56	56	57	**56**
3-3	189	188	188	189	**189**	93	93	93	93	94	93	**93**	56	56	56	57	56	56	**56**
3-4	188	189	189	188	**189**	93	93	92	93	93	92	**93**	57	56	56	56	57	56	**56**
3-5	189	188	188	189	**189**	92	93	93	94	93	93	**93**	56	57	56	56	56	56	**56**
3-6	188	188	188	189	**188**	93	92	93	93	93	93	**93**	57	56	57	56	56	56	**56**
3-7	188	189	189	188	**189**	93	93	93	92	92	93	**93**	56	56	56	56	56	57	**56**
3-8	189	188	188	188	**188**	93	93	93	93	93	94	**93**	57	56	56	56	56	56	**56**
3-9	188	189	188	189	**189**	94	93	94	93	93	93	**93**	56	56	56	57	56	56	**56**
3-10	189	188	189	188	**189**	93	93	92	92	93	93	**93**	57	56	56	56	56	56	**56**
	189	**188**	**189**	**188**	**188**	**93**	**93**	**93**	**93**	**93**	**93**	**93**	**56**	**56**	**56**	**56**	**56**	**56**	**56**

Manufacturer Original Clay (Control Sample)																			
No	**Length**					**Width**							**Height**						
	L1	L2	L3	L4	Avg	W1	W2	W3	W4	W5	W6	**Avg**	H1	H2	H3	H4	H5	H6	**Avg**
1	195	195	196	196	**196**	96	97	96	96	96	97	**96**	57	58	57	58	57	57	**57**
2	195	196	196	195	**196**	96	96	96	97	97	96	**96**	57	58	57	57	57	57	**57**
3	195	196	195	196	**196**	97	96	97	96	96	96	**96**	57	57	57	57	58	57	**57**
4	196	195	195	196	**196**	96	96	96	96	96	96	**96**	58	57	57	57	57	57	**57**
5	196	195	195	195	**195**	96	96	95	96	96	97	**96**	57	58	57	57	58	57	**57**
6	195	195	196	195	**195**	96	97	96	96	96	95	**96**	57	57	58	57	57	58	**57**
7	195	195	196	195	**195**	96	97	97	96	96	96	**96**	58	57	58	57	57	57	**57**
8	195	196	195	195	**195**	97	96	96	97	96	96	**96**	57	57	57	58	57	57	**57**
9	195	196	196	196	**196**	96	96	96	97	96	97	**96**	57	57	57	57	57	57	**57**
10	196	196	195	196	**196**	97	96	96	96	97	96	**96**	58	57	57	57	57	58	**57**
	195	**196**	**196**	**196**	**195**	**96**	**96**	**96**	**96**	**96**	**96**	**96**	**57**	**57**	**57**	**57**	**57**	**57**	**57**

Compressive Strength Results

Table D.6: Observations & Results of Moisture Content

	Mix	No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (Ton)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Kethhena WTP Sludge	**Mix 1** Clay: Sludge 90:10	1-1	195	94	18330	4.70	2.52	**2.87**
		1-2	194	94	18236	5.10	2.74	
		1-3	194	96	18624	6.14	3.23	
		1-4	198	96	19008	5.78	2.98	
		1-5	194	94	18236	4.96	2.67	
		1-6	197	97	19109	6.16	3.16	
		1-7	194	94	18236	5.36	2.88	
		1-8	196	93	18228	4.74	2.55	
		1-9	194	95	18430	5.40	2.87	
		1-10	195	97	18915	6.06	3.14	
	Mix 2 Clay: Sludge 80:20	2-1	193	94	18142	4.36	2.36	**2.49**
		2-2	193	95	18335	5.24	2.80	
		2-3	190	95	18050	5.06	2.75	
		2-4	190	93	17670	4.32	2.40	
		2-5	193	93	17949	4.18	2.28	
		2-6	193	94	18142	4.08	2.21	
		2-7	190	94	17860	4.86	2.67	
		2-8	190	94	17860	4.40	2.42	
		2-9	190	95	18050	4.76	2.59	
		2-10	190	93	17670	4.46	2.48	
	Mix 3 Clay: Sludge 70:30	3-1	189	94	17766	3.16	1.74	**1.91**
		3-2	190	94	17860	3.60	1.98	
		3-3	187	93	17391	2.90	1.64	
		3-4	188	95	17860	3.50	1.92	
		3-5	188	94	17672	3.70	2.05	
		3-6	187	93	17391	3.40	1.92	
		3-7	188	94	17672	3.36	1.87	
		3-8	190	94	17860	3.58	1.97	
		3-9	190	93	17670	3.64	2.02	
		3-10	189	93	17577	3.60	2.01	

	Mix	No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (Ton)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Kandana WTP Sludge	**Mix 1** Clay: Sludge 90:10	1-1	194	98	19012	5.5	2.84	**2.76**
		1-2	192	95	18240	5.1	2.74	
		1-3	192	95	18240	5.0	2.69	
		1-4	190	95	18050	4.9	2.66	
		1-5	191	93	17763	4.5	2.49	
		1-6	192	96	18432	5.3	2.82	
		1-7	190	95	18050	5.2	2.83	
		1-8	194	98	19012	5.6	2.89	
		1-9	195	96	18720	5.4	2.83	
		1-10	192	97	18624	5.3	2.79	
	Mix 2 Clay: Sludge 80:20	2-1	188	93	17484	3.9	2.19	**2.24**
		2-2	189	94	17766	4.3	2.37	
		2-3	191	95	18145	4.5	2.43	
		2-4	188	92	17296	3.4	1.93	
		2-5	188	92	17296	3.7	2.10	
		2-6	190	95	18050	4.4	2.39	
		2-7	192	96	18432	4.6	2.45	
		2-8	192	95	18240	4.2	2.26	
		2-9	192	96	18432	4.3	2.29	
		2-10	188	92	17296	3.5	1.99	
	Mix 3 Clay: Sludge 70:30	3-1	186	93	17298	3.1	1.76	**1.85**
		3-2	190	94	17860	3.7	2.03	
		3-3	186	91	16926	2.8	1.62	
		3-4	191	94	17954	3.9	2.13	
		3-5	188	93	17484	3.3	1.85	
		3-6	190	94	17860	3.6	1.98	
		3-7	189	93	17577	3.4	1.90	
		3-8	187	93	17391	3.0	1.69	
		3-9	189	93	17577	3.2	1.79	
		3-10	186	92	17112	3.0	1.72	

	Mix	No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (Ton)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
ManufacturerOriginal Bricks	Clay: Sludge 100:00	1	196	94	18424	8.1	4.31	**4.23**
		2	195	97	18915	8.3	4.30	
		3	198	97	19206	8.6	4.39	
		4	195	96	18720	8.2	4.30	
		5	195	97	18915	8.5	4.41	
		6	195	96	18720	7.9	4.14	
		7	197	94	18518	7.8	4.13	
		8	193	96	18528	8.3	4.39	
		9	195	97	18915	7.7	3.99	
		10	193	96	18528	7.4	3.92	

Water Absorption

Table D.7: Observations & Results of Moisture Content

	Mix	No	Oven dried Weight (g)	Weight after immersion (g)	Absorption (Percentage)	Avg. Absorption (Percentage)
Keththena WTP Sludge	**Mix 1** Clay: Sludge 90:10	1-1	1400.7	1729.2	23.45	**23.59**
		1-2	1450.2	1784.1	23.02	
		1-3	1411.6	1749.3	23.92	
		1-4	1401.1	1722.7	22.95	
		1-5	1378.9	1712.2	24.17	
		1-6	1385.2	1718.0	24.03	
	Mix 2 Clay: Sludge 80:20	2-1	1277.0	1605.5	25.72	**25.42**
		2-2	1261.0	1593.3	26.35	
		2-3	1302.0	1635.2	25.59	
		2-4	1343.5	1673.9	24.59	
		2-5	1273.2	1599.0	25.59	
		2-6	1277.0	1591.9	24.66	
	Mix 3 Clay: Sludge 70:30	3-1	1097.3	1451.5	32.28	**26.30**
		3-2	1108.1	1463.5	32.07	
		3-3	1133.6	1481.1	30.65	
		3-4	1186.1	1538.5	29.71	
		3-5	1162.5	1518.5	30.62	
		3-6	1176.4	1514.4	28.73	

	Mix	No	Oven dried Weight (g)	Weight after immersion (g)	Absorption (Percentage)	Avg. Absorption (Percentage)
Kandana WTP Sludge	**Mix 1** Clay: Sludge 90:10	1-1	1387.3	1705.2	22.92	**23.11**
		1-2	1444.0	1766.4	22.33	
		1-3	1453.1	1798.2	23.75	
		1-4	1445.4	1784.0	23.43	
		1-5	1444.5	1778.0	23.09	
		1-6	1371.6	1688.8	23.13	
	Mix 2 Clay: Sludge 80:20	2-1	1283.8	1608.3	25.28	**25.36**
		2-2	1276.2	1600.4	25.40	
		2-3	1270.1	1595.0	25.58	
		2-4	1267.0	1586.0	25.18	
		2-5	1306.3	1635.9	25.23	
		2-6	1281.4	1607.8	25.47	
	Mix 3 Clay: Sludge 70:30	3-1	1107.6	1448.0	30.73	**30.29**
		3-2	1142.7	1485.0	29.96	
		3-3	1124.3	1466.7	30.45	
		3-4	1140.4	1477.7	29.58	
		3-5	1112.4	1444.0	29.81	
		3-6	1108.2	1454.4	31.24	

	Mix	No	Oven dried Weight (g)	Weight after immersion (g)	Absorption (Percentage)	Avg. Absorption (Percentage)
Manufacturer Original Clay	Clay: Sludge 100:00	1	1504.6	1811.0	20.36	**20.22**
		2	1603.7	1926.7	20.14	
		3	1563.0	1874.1	19.90	
		4	1527.9	1849.3	21.04	
		5	1572.3	1893.4	20.42	
		6	1579.0	1886.6	19.48	

Appendix E - Test Results of Cement Mortar

Table E.1: Observation & Results of Moisture Content

Material	Sample No.	Weight of can (g)	Weight of wet soil +can (g)	Weight of dry soil + can (g)	Moisture Content (%)	Avg. Moisture Content (%)
WTP Sludge Kandana	1	23.670	38.393	36.361	13.80	13.67
	2	53.512	72.737	70.152	13.45	
	3	68.236	96.587	92.682	13.77	

Table E.2: Data and Result of Sieve Analysis Test for Sand

Sieve size (mm)	Sieve weight (g)	Mass + Sieve (g)	Mass in each Sieve (g)	Cumulative Mass Retained (g)	Cumulative Retained (%By mass)	Passing (% By mass)
4.250	1500.0	1524.3	24.3	24.3	1.62	100.00
2.800	577.9	630.4	52.5	76.8	5.12	94.88
1.180	508.2	846.8	338.6	415.4	27.69	72.31
0.850	483.1	714.3	231.2	646.6	43.11	56.89
0.600	468.5	750.4	281.9	928.5	61.90	38.10
0.300	432.1	857.6	425.5	1354.0	90.27	9.73
0.150	405.6	525.2	119.6	1473.6	98.24	1.76
pan	542.5	568.5	26.0	1499.6	99.97	0.03

Table E.3: Observation and Calculation of SpecificGravityTest

Material	Trial No	W_1	W_2	W_3	W_4	(W_2-W_1)	$(W_4-W_1) - (W_3-W_2)$	Specific gravity
Sand	1	26.553	77.185	107.773	76.314	50.632	19.173	2.64
	2	24.675	75.474	105.285	73.624	50.799	19.138	2.65
	3	26.599	77.313	107.795	76.202	50.714	19.121	2.65
	Average							**2.65**
WTP Sludge	1	24.677	46.355	82.979	74.745	21.678	13.444	1.61
	2	26.552	48.256	84.659	76.328	21.704	13.373	1.62
	3	26.597	48.321	84.853	76.521	21.724	13.392	1.62
	Average							**1.62**

Calculation

Specific gravity = $(W_2-W_1) / \{(W_4-W_1) - (W_3-W_2)\}$

Where

Weight of specific gravity bottle - W_1 (g)

Weight of specific gravity bottle and one third of aggregate - W_2 (g)

Weight of specific gravity bottle, one-third of aggregate and water - W_3 (g)

Weight of specific gravity bottle and water - W_4 (g)

Table E.4: Observation &Results of Flow Table Test of Mortar

Mix number	0.5		0.7		0.9		1.1		1.3		1.5	
	X (mm)	Y (mm)	X (mm)	Y (mm)	X (mm)	Y (mm)	X (mm)	Y (mm)	X (mm)	Y (mm)	X (mm)	Y (mm)
1-1	210	210	200	160	180	155	120	130	165	160	175	175
1-2	200	200	190	200	200	185	120	130	160	150	175	175
2-1	185	160	120	190	115	125	170	160	190	180	200	210
2-2	165	165	140	180	115	120	150	155	185	185	210	210
3-1	210	210	155	165	120	125	150	140	175	160	170	185
3-2	210	190	170	165	125	125	170	150	155	170	185	195
4-1	170	160	160	180	130	140	160	155	190	185	205	195
4-2	200	160	160	160	125	130	160	155	190	195	205	200

Table E.4: Flow Value of Mortar

Mix	Water to Cement Ratio					
	0.5	0.7	0.9	1.1	1.3	1.5
1	205.0	187.5	180.0	125.0	158.8	175.0
2	168.8	157.5	118.8	158.8	185.0	207.5
3	205.0	163.8	123.8	152.5	165.0	183.8
4	172.5	165.0	131.3	157.5	190.0	201.3

Table E.5: Flow Percentage of Mortar

Mix	Water to Cement Ratio					
	0.5	0.7	0.9	1.1	1.3	1.5
1	192.9	167.9	157.1	78.6	126.8	150.0
2	141.1	125.0	69.6	126.8	164.3	196.4
3	192.9	133.9	76.8	117.9	135.7	162.5
4	146.4	135.7	87.5	125.0	171.4	187.5

Table E.6: Observation & Results of Compressive Strength Tests of Mortar at 7days

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 1 Sand: Sludge 100: 0	1.1	1-1	70	70	4900	16.1	3.29	3.16
		1-2	71	70	4970	14.9	3.00	
		1-3	70	70	4900	15.6	3.18	
	1.3	1-1	70	70	4900	13.9	2.84	2.82
		1-2	70	70	4900	13.2	2.69	
		1-3	70	71	4970	14.5	2.92	
	1.5	1-1	71	70	4970	14.0	2.82	2.78
		1-2	70	71	4970	13.3	2.68	
		1-3	70	70	4900	14.0	2.86	
Mix 2 Sand: Sludge 90:10	0.7	2-1	70	71	4970	32.0	6.44	6.26
		2-2	70	70	4900	34.8	7.10	
		2-3	70	70	4900	25.7	5.24	
	0.9	2-1	71	70	4970	28.4	5.71	5.96
		2-2	70	70	4900	29.7	6.06	
		2-3	70	71	4970	30.4	6.12	
	1.1	2-1	71	70	4970	13.9	2.80	2.67
		2-2	70	70	4900	13.2	2.69	
		2-3	70	70	4900	12.4	2.53	
Mix 3 Sand: Sludge 80:20	0.7	3-1	70	71	4970	26.8	5.39	5.78
		3-2	71	70	4970	30.0	6.04	
		3-3	70	70	4900	28.9	5.90	
	0.9	3-1	70	70	4900	23.3	4.76	4.86
		3-2	70	71	4970	24.1	4.85	
		3-3	70	70	4900	24.4	4.98	
	1.1	3-1	70	71	4970	12.1	2.43	2.54
		3-2	70	70	4900	13.6	2.78	
		3-3	70	70	4900	11.8	2.41	

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 4 Sand: Sludge 70:30	0.7	4-1	70	70	4900	25.5	5.20	5.01
		4-2	70	70	4900	23.2	4.73	
		4-3	70	71	4970	25.3	5.09	
	0.9	4-1	70	70	4900	16.9	3.45	3.56
		4-2	71	70	4970	14.5	2.92	
		4-3	70	71	4970	21.5	4.33	
	1.1	4-1	70	70	4900	7.0	1.43	1.57
		4-2	70	70	4900	8.1	1.65	
		4-3	70	71	4970	8.1	1.63	

Table E.7: Observation & Results of Compressive Strength Tests of Mortar at 14days

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 1 Sand: Sludge 100: 0	1.1	1-1	70	70	4900	22.9	4.67	4.66
		1-2	71	70	4970	22.5	4.53	
		1-3	70	70	4900	23.4	4.78	
	1.3	1-1	70	70	4900	20.9	4.27	4.26
		1-2	71	70	4970	21.5	4.33	
		1-3	70	70	4900	20.5	4.18	
	1.5	1-1	70	70	4900	16.6	3.39	3.39
		1-2	71	70	4970	17.3	3.48	
		1-3	70	71	4970	16.4	3.30	
Mix 2 Sand: Sludge 90:10	0.7	2-1	70	70	4900	38.1	7.78	7.61
		2-2	70	70	4900	41.5	8.47	
		2-3	71	70	4970	32.8	6.60	
	0.9	2-1	70	70	4900	30.2	6.16	6.37
		2-2	70	70	4900	31.7	6.47	
		2-3	71	70	4970	32.2	6.48	
	1.1	2-1	71	70	4970	14.5	2.92	3.03
		2-2	70	70	4900	15.3	3.12	
		2-3	70	70	4900	15.0	3.06	
Mix 3 Sand: Sludge 80:20	0.7	3-1	70	70	4900	31.5	6.43	6.87
		3-2	70	70	4900	36.8	7.51	
		3-3	71	70	4970	33.1	6.66	
	0.9	3-1	70	70	4900	26.8	5.47	5.75
		3-2	70	70	4900	28.3	5.78	
		3-3	71	70	4970	29.8	6.00	
	1.1	3-1	70	70	4900	14.2	2.90	2.83
		3-2	71	70	4970	14.1	2.84	
		3-3	70	70	4900	13.5	2.76	

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 4 Sand: Sludge 70:30	0.7	4-1	70	70	4900	27.8	5.67	5.40
		4-2	71	70	4970	24.8	4.99	
		4-3	70	70	4900	27.2	5.55	
	0.9	4-1	70	70	4900	18.4	3.76	3.91
		4-2	71	70	4970	17.0	3.42	
		4-3	70	71	4970	22.6	4.55	
	1.1	4-1	70	70	4900	9.1	1.86	2.17
		4-2	70	70	4900	10.6	2.16	
		4-3	71	70	4970	12.4	2.49	

Table E.8: Observation & Results of Compressive Strength Tests of Mortar at 28days

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 1 Sand: Sludge 100: 0	1.1	1-1	70	70	4900	30.6	6.24	7.18
		1-2	71	70	4970	35.9	7.22	
		1-3	70	70	4900	39.5	8.06	
	1.3	1-1	70	70	4900	33.8	6.90	6.53
		1-2	70	70	4900	30.3	6.18	
		1-3	70	71	4970	32.3	6.50	
	1.5	1-1	71	70	4970	25.9	5.21	5.88
		1-2	70	71	4970	32.6	6.56	
		1-3	70	70	4900	28.8	5.88	
Mix 2 Sand: Sludge 90:10	0.7	2-1	70	70	4900	46.5	9.49	9.72
		2-2	71	70	4970	53.7	10.80	
		2-3	70	70	4900	43.5	8.88	
	0.9	2-1	70	70	4900	35.6	7.27	6.91
		2-2	70	70	4900	33.4	6.82	
		2-3	70	71	4970	33.1	6.66	
	1.1	2-1	71	70	4970	26.6	5.35	6.46
		2-2	70	71	4970	35.6	7.16	
		2-3	70	70	4900	33.6	6.86	
Mix 3 Sand: Sludge 80:20	0.7	3-1	70	70	4900	47.0	9.59	8.71
		3-2	71	70	4970	39.9	8.03	
		3-3	70	70	4900	41.7	8.51	
	0.9	3-1	70	70	4900	34.4	7.02	6.96
		3-2	70	70	4900	32.2	6.57	
		3-3	70	71	4970	36.2	7.28	
	1.1	3-1	71	70	4970	15.5	3.12	3.61
		3-2	70	71	4970	18.9	3.80	
		3-3	70	70	4900	19.1	3.90	

Mix	W/C ratio	Cube No	Avg. Length (mm)	Avg. width (mm)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 4 Sand: Sludge 70:30	0.7	4-1	70	70	4900	31.3	6.39	6.17
		4-2	71	70	4970	30.6	6.16	
		4-3	70	70	4900	29.2	5.96	
	0.9	4-1	70	70	4900	17.3	3.53	4.32
		4-2	70	70	4900	21.4	4.37	
		4-3	70	71	4970	25.2	5.07	
	1.1	4-1	71	70	4970	15.0	3.02	3.10
		4-2	70	71	4970	19.0	3.82	
		4-3	70	70	4900	12.0	2.45	

Appendix F - Test Results of Concrete Paving Blocks

Table F.1: Observation & Calculation of Moisture Content

Material	Trial No	Weight of can (g)	Weight of wet soil + can (g)	Weight of dry soil + can (g)	Moisture Content (%)	Avg. Moisture Content (%)
WT PSludge	1	20.980	29.459	27.466	23.51	23.87
	2	57.244	72.737	69.044	23.84	
	3	57.240	81.669	75.737	24.28	
Bottom Ash	1	53.948	61.747	60.171	20.21	20.61
	2	56.22	76.65	72.43	20.66	
	3	75.477	88.351	85.65	20.98	

Table F.2: Observation & Calculation of Specific Gravity

Material	Trial No	W_1	W_2	W_3	W_4	(W_2-W_1)	$(W_4-W_1) - (W_3-W_2)$	Specific gravity
Sand	1	26.553	77.185	107.773	76.314	50.632	19.173	2.64
	2	24.675	75.474	105.285	73.624	50.799	19.138	2.65
	3	26.599	77.313	107.795	76.202	50.714	19.121	2.65
								2.65
WT PSludge	1	24.777	37.783	77.726	74.745	13.006	10.025	1.30
	2	26.598	40.346	80.254	76.952	13.748	10.446	1.32
	3	24.68	37.856	77.668	74.736	13.176	10.244	1.29
								1.
Bottom Ash	1	26.599	37.028	79.971	76.275	10.429	6.733	1.55
	2	24.78	35.126	77.956	74.256	10.346	6.646	1.56
	3	26.534	35.524	78.836	75.632	8.99	5.786	1.55
								1.55
Coarse Aggregate	1	24.62	60.389	96.342	76.293	35.769	15.72	2.28
	2	26.595	62.429	97.231	77.325	35.834	15.928	2.25
	3	26.583	61.89	95.856	76.293	35.307	15.744	2.24
	Average							**2.26**

Specific gravity = $(W_2-W_1)/((W_4-W_1)-(W_3-W_2))$

Where

Weight of specific gravity bottle - W_1 (g)

Weight of specific gravity bottle and one third of aggregate - W_2 (g)

Weight of specific gravity bottle, one-third of aggregate and water- W_3 (g)

Weight of specific gravity bottle and water - W_4 (g)

Table F.3: Data and Result of Sieve Analysis Test

Sand						
Sieve size (mm)	**Sieve weight (g)**	**Mass + sieve (g)**	**Mass in each sieve (g)**	**Cumulative mass retained (g)**	**Cumulative retained (%By mass)**	**Passing (% By mass)**
4.250	1500.0	1524.3	24.3	24.3	1.62	100.00
2.800	577.9	630.4	52.5	76.8	5.12	94.88
1.180	508.2	846.8	338.6	415.4	27.69	72.31
0.850	483.1	714.3	231.2	646.6	43.11	56.89
0.600	468.5	750.4	281.9	928.5	61.90	38.10
0.300	432.1	857.6	425.5	1354.0	90.27	9.73
0.150	405.6	525.2	119.6	1473.6	98.24	1.76
pan	542.5	568.5	26.0	1499.6	99.97	0.03
Water Treatment Plant Sludge (Kethhena)						
Sieve size (mm)	**Sieve weight (g)**	**Mass + sieve (g)**	**Mass in each sieve (g)**	**Cumulative mass retained (g)**	**Cumulative retained (%By mass)**	**Passing (% By mass)**
3.35	546	546	0	0	0	100
2.36	527	527	0	0	0	100
2	376	377	1	1	0.1	99.9
1.18	366	400	34	35	3.5	96.5
0.6	471	820	349	384	38.4	61.6
0.425	303	700	397	781	78.1	21.9
0.3	299	395	96	877	87.7	12.3
0.212	281	380	99	976	97.6	2.4
0.15	278	280	2	978	97.8	2.2
0.075	402	417	15	993	99.3	0.7
pan	462	466	4	997	99.7	0.3

Bottom Ash						
Sieve size (mm)	**Sieve weight (g)**	**Mass + sieve (g)**	**Mass in each sieve (g)**	**Cumulative mass retained (g)**	**Cumulative retained (%By mass)**	**Passing (% By mass)**
3.35	545	546	1	0	0	100
2.36	528	625	97	97	9.7	90.3
2	376	416	40	137	13.7	86.3
1.18	365	442	77	214	21.4	78.6
0.6	470	582	112	326	32.6	67.4
0.425	304	342	38	364	36.4	63.6
0.3	300	348	48	412	41.2	58.8
0.212	281	385	104	516	51.6	48.4
0.15	277	513	236	752	75.2	24.8
0.075	401	503	102	854	85.4	14.6
pan	462	606	144	998	99.8	0.2

Table F.4: Compressive Strength of Concrete Paving Block at 7 days

Mix	No	Weight of the shape (g)	Weight of the rect. (g)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 1	1-1	5.2	4.3	24190	1153.5	56.30	53.00
	1-2	5.2	4.3	24190	871.5	42.50	
	1-3	5.5	4.3	25580	1244.8	57.40	
Mix 2	2-1	5.4	4.3	25120	732.5	34.40	40.00
	2-2	5.2	4.3	24190	858.5	41.90	
	2-3	5.4	4.3	25120	907.0	42.60	
Mix 3	3-1	5.4	4.3	25120	596.3	28.00	28.00
	3-2	5.3	4.3	24650	584.3	28.00	
	3-3	5.5	4.3	25580	596.6	27.50	
Mix 4	4-1	5.4	4.3	25120	428.8	20.10	20.00
	4-2	5.3	4.3	24650	387.2	18.50	
	4-3	5.4	4.3	25120	397.6	18.70	
Mix 5	5-1	5.0	4.0	25000	428.8	20.20	18.00
	5-2	5.0	4.0	25000	357.7	16.90	
	5-3	5.0	4.0	25000	346.9	16.40	
Mix 6	6-1	5.3	4.3	24650	689.4	33.00	31.00
	6-2	5.5	4.3	25580	637.2	29.40	
	6-3	5.4	4.3	25120	631.8	29.70	
Mix 7	7-1	5.3	4.3	24650	569.3	27.30	28.00
	7-2	5.3	4.3	24650	597.8	28.60	
	7-3	5.9	4.3	27440	624.3	26.80	
Mix 8	8-1	5.3	4.3	24650	416.3	19.90	22.00
	8-2	5.4	4.3	25120	549.3	25.80	
	8-3	5.4	4.3	25120	380.4	17.90	
Mix 9	9-1	5.3	4.3	24650	410.5	19.70	20.00
	9-2	5.4	4.3	25120	380.7	17.90	
	9-3	5.4	4.3	25120	420.6	19.80	

Table F.5: Compressive Strength of Concrete Paving Block at 14 days

Mix	No	Weight of the shape	Weight of the rect.	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength
Mix 1	1-1	4.9	4.3	22790	1098.9	56.90	61.00
	1-2	4.8	4.3	22330	1280.0	67.60	
	1-3	5.1	4.3	23720	1158.5	57.60	
Mix 2	2-1	5.0	4.3	23260	927.7	47.10	50.00
	2-2	4.7	4.3	21860	962.3	51.90	
	2-3	4.8	4.3	22330	924.1	48.80	
Mix 3	3-1	5.1	4.3	23720	729.1	36.30	37.00
	3-2	5.0	4.3	23260	675.6	34.30	
	3-3	5.0	4.3	23260	791.2	40.10	
Mix 4	4-1	5.0	4.3	23260	601.4	30.50	29.00
	4-2	5.1	4.3	23720	578.7	28.80	
	4-3	5.1	4.3	23720	538.3	26.80	
Mix 5	5-1	5.0	4.3	23260	565.1	28.70	27.00
	5-2	4.9	4.3	22790	518.9	26.90	
	5-3	5.1	4.3	23720	484.2	24.10	
Mix 6	6-1	5.0	4.3	23260	996.3	50.50	49.00
	6-2	5.1	4.3	22720	920.0	47.80	
	6-3	4.9	4.3	22790	885.0	45.80	
Mix 7	7-1	5.0	4.3	23260	663.7	33.70	39.00
	7-2	4.9	4.3	22790	782.8	40.50	
	7-3	5.1	4.3	23720	842.7	41.90	
Mix 8	8-1	5.0	4.3	23260	556.2	28.20	32.00
	8-2	5.0	4.3	23260	657.2	33.30	
	8-3	4.9	4.3	22790	630.2	32.60	
Mix 9	9-1	5.0	4.3	23260	580.0	29.40	28.00
	9-2	5.1	4.3	23720	510.5	25.40	
	9-3	5.0	4.3	23260	565.6	28.70	

Table F.6: Compressive Strength of Concrete Paving Block at 28 days

Mix	No	Weight of the shape (g)	Weight of the rect. (g)	Area (mm2)	Failure Load (kN)	Compressive Strength (N/mm2)	Avg. Compressive Strength (N/mm2)
Mix 1	1-1	5.2	4.3	24190	1406.8	68.60	70.00
	1-2	5.2	4.3	24190	1476.6	72.00	
	1-3	5.5	4.3	25580	1456.5	67.20	
Mix 2	2-1	5.4	4.3	25120	1190.7	55.90	56.00
	2-2	5.2	4.3	24190	1123.0	54.80	
	2-3	5.4	4.3	25120	1191.0	55.90	
Mix 3	3-1	5.4	4.3	25120	973.2	45.70	45.00
	3-2	5.3	4.3	24650	976.0	46.70	
	3-3	5.5	4.3	25580	910.2	42.00	
Mix 4	4-1	5.4	4.3	25120	655.4	30.80	34.00
	4-2	5.3	4.3	24650	730.1	35.00	
	4-3	5.4	4.3	25120	735.6	34.60	
Mix 5	5-1	5.0	4.0	25000	655.8	31.00	32.00
	5-2	5.0	4.0	25000	622.0	29.40	
	5-3	5.0	4.0	25000	696.9	32.90	
Mix 6	6-1	5.0	4.0	25000	1155.5	54.50	54.00
	6-2	5.0	4.0	25000	1122.4	53.00	
	6-3	4.9	4.0	24500	1096.9	52.80	
Mix 7	7-1	5.1	4.0	25500	909.5	42.10	46.00
	7-2	5.0	4.0	25000	996.9	47.10	
	7-3	5.0	4.0	25000	971.4	45.90	
Mix 8	8-1	4.9	4.0	24500	747.5	36.00	37.00
	8-2	5.0	4.0	25000	774.5	36.60	
	8-3	5.0	4.0	25000	752.3	35.50	
Mix 9	9-1	4.9	4.0	24500	735.2	35.40	34.00
	9-2	5.0	4.0	25000	710.5	33.50	
	9-3	5.0	4.0	25000	680.0	32.10	

Table F.7: Unpolished Slip Resistance Value of Paving Block

Mix	No	USRV – (Unpolished Slip Resistance for Paving Blocks)					Average of each	Avg. USRV
Mix 1	1-1	95	90	90	90	90	91	90
	1-2	90	90	90	95	90	91	
	1-3	90	85	90	90	90	89	
Mix 2	2-1	90	85	90	85	85	87	86
	2-2	85	90	85	85	85	86	
	2-3	85	85	85	80	85	84	
Mix 3	3-1	80	80	85	85	85	83	80
	3-2	75	80	80	85	80	80	
	3-3	80	75	75	80	80	78	
Mix 4	4-1	80	80	80	75	80	79	78
	4-2	80	75	75	80	75	77	
	4-3	75	80	80	80	75	78	
Mix 5	5-1	75	75	80	75	70	75	76
	5-2	80	80	80	75	70	77	
	5-3	75	80	80	80	70	77	
Mix 6	6-1	75	75	75	75	75	75	75
	6-2	75	75	75	70	75	74	
	6-3	80	75	75	70	75	75	
Mix 7	7-1	75	70	70	70	75	72	72
	7-2	70	75	75	70	70	72	
	7-3	75	75	70	75	70	73	
Mix 8	8-1	65	65	70	70	70	68	68
	8-2	70	70	65	65	70	68	
	8-3	65	70	70	65	70	68	
Mix 9	9-1	65	60	60	65	65	63	63
	9-2	60	65	65	65	60	63	
	9-3	65	65	65	60	65	64	

Table F.8 : Water Absorption of Paving Block

Mix	No	Dry Weight (kg)	Wet Weight (kg)	Water Absorption (%)	Avg. Water Absorption (%)
Mix 1	1-1	4803.4	4991.4	3.91	4.06
	1-2	4787.9	4996.5	4.36	
	1-3	4811.0	4999.0	3.91	
Mix 2	2-1	4718.2	4952.6	4.97	4.93
	2-2	4696.1	4912.6	4.61	
	2-3	4727.7	4973.9	5.21	
Mix 3	3-1	4639.0	4877.5	5.14	5.22
	3-2	4664.0	4909.8	5.27	
	3-3	4663.0	4907.8	5.25	
Mix 4	4-1	4395.0	4560.0	3.75	6.23
	4-2	4488.0	4782.0	6.55	
	4-3	4490.0	4867.0	8.40	
Mix 5	5-1	4062.2	4451.0	9.57	9.41
	5-2	4013.7	4386.0	9.27	
	5-3	4133.9	4522.0	9.39	
Mix 6	6-1	4642.0	4964.0	6.94	6.48
	6-2	4686.7	4952.0	5.66	
	6-3	4363.0	4662.0	6.85	
Mix 7	7-1	4563.0	4913.0	7.67	6.77
	7-2	4684.0	4961.0	5.91	
	7-3	4634.0	4945.0	6.71	
Mix 8	8-1	4356.0	4733.0	8.65	8.48
	8-2	4437.0	4784.0	7.82	
	8-3	4388.0	4781.0	8.96	
Mix 9	9-1	4022.0	4451.0	10.67	10.51
	9-2	3974.0	4386.0	10.37	
	9-3	4093.0	4522.0	10.48	