Study on the Decentralized Wastewater Treatment Plants in Khulna

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A thesis submitted to the department of Civil Engineering of Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh in partial fulfillment of the requirements for the degree of

"Master of Science in Civil Engineering"

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Declaration

This is to certify that the thesis work entitled "Study on the Decentralized Wastewater Treatment Plants in Khulna" has been carried out by Shuma Rani Saha in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by Shuma Rani Saha entitled "Study on the Decentralized Wastewater Treatment Plants in Khulna" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in July 2014.

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Abstract

Khulna is the third largest city of Bangladesh and situated at the Southwest region of the country having 1.4 million populations living in 45.65 square kilometres area. It has been facing growing urban environmental problems due to daily generated wastewater. There is no sewerage network or any central treatment system in Khulna city. Conventional wastewater treatment plant needs large space for treating vast quantities of wastewater and also requires very high initial as well as operation and maintenance cost.

This study is concerned about the two decentralized wastewater treatment (DEWAT) plants constructed at the 'Peoples Panchtola Colony' at Khalishpur in Khulna. DEWAT system may be defined as the collection, treatment, and disposal or reuse of wastewater from individual homes, clusters of homes, isolated communities, industries or industrial facilities at or near the point of waste generation. It consists of septic tank, anaerobic baffled reactors (ABR), anaerobic filter bed baffled reactors (AFBBR), planted gravel filter (PGF) and polishing pond (PP). The specific objectives of this study were to (1) study the performance of two DEWAT plants regarding its technical and socio-economic acceptance by ordinary population in Panchtola Colony; (2) compare the performance of two DEWAT plants based on field and laboratory investigations; (3) identify the technical problems in the operation and maintenance of two DEWAT plants; and (4) recommend the modified DEWAT plants which will reduce construction cost and require small space above ground and low maintenance.

To conduct necessary investigation both in field and laboratory, wastewater samples were collected from six different points such as in and out point of settler tank, middle of AFBBR, out of ABR, out of PGF, out of PP of two DEWAT plants at once a month for about one year. Different parameters such as BOD_5, COD, pH, Nitrate, Phosphate, Temperature, Oil and Grease, Total Dissolve Solid (TDS), Faecal Coliform (FC), Dissolve Oxygen (DO), Total Suspended Solid (TSS), etc. were determined of the collected samples. The results show that the concentration of all harmful parameters were reduced significantly and lowered to an acceptable level. The results also indicate the effectiveness of ABR and AFBBR over the planted gravel filter considering the area required for PGF and the associated cost. The clogging is also a problem in the filter bed. Finally, it can be concluded that the modified DEWAT system can be practiced in low incoming developing countries as a mid-term solution to improve the sanitation condition.

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INTRODUCTION

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Introduction

1.1 Background

Now a days, sanitation and wastewater management are currently considered as one of the most immediate and serious environmental issues, both nationally and globally. Due to the increase of the worldwide population, rapid urbanization and industrialization, the problem of sewage disposal, domestic and industrial wastewater management has become more and more critical issue for any city authority. To have a clean, hygiene and environment-friendly city, the generated wastewater must be managed in an appropriate way, which is absent in most of the cities of developing countries. According to the World Health Organization (WHO) and UNICEF, there are over 2.6 billion people facing various types of water crises and sanitation problems [1]. Inappropriate use and improper management of water resources have an increasingly negative impact on environment, on economic growth, on social welfare and on the world's eco-systems. A major challenge faced by the developing countries like Bangladesh is that human waste as well as human faeces, urine, gray water and other types of domestic wastewater collection, treatment and safely disposal to natural streams. In developing countries, almost half of the urban populations have inadequate waste disposal facilities.

For a long time, the need for efficient wastewater treatment was ignored by many public authorities. As a result, the performance of existing treatment technologies and the conditions of sanitation facilities are rather poor. At many locations the sewage is just drained to surface or ground waters without adequate handling causing a serious risk to public health [2].

To solve sanitation and wastewater management problems, two types of treatment facilities are available such as centralized and decentralized. Centralized wastewater treatment plants require conventional (intensive) systems, which rely on sophisticated technologies and plants operation by highly skilled personnel [3]. Conventional wastewater treatment plant needs large space for treating vast quantities of wastewater and also requires very high initial as well as operation and maintenance cost that countries face structural and financial adjustment problems. DEWAT System rather than a centralized system might be especially beneficial in developing countries and allow locals to deal with their situation when there is a lack of action or capacity by the central governing body [4].

Bangladesh is a dense populated country with total population of 150 million where sewerage system has been developed and maintained by Dhaka Water Supply and Sewerage Authority (DWASA) to serve the inhabitants of the nation's capital only. The coverage of sewerage network is only 18% of the city and the central treatment plant of DWASA is not sufficient for treating vast quantities of wastewater to a satisfactory level.

1.2 Statement of the Problem

Khulna is the third largest city of Bangladesh and situated at the Southwest region of the country having 1.4 million populations living in 45.65 square kilometres area. It has been facing growing urban environmental problems due to daily generated wastewater. Due to the management of large amount of wastewater, there is no sewerage network or any central treatment system in Khulna city.

Most of the industries like Jute mills, Newsprint mills, and Hardboard mills are situated in Khalispur, Khulna. To meet up the accommodation problem of mills employees, a total number of eight buildings were built at Peoples jute mill area in 1982. Every building has double units and five floors. For this reason, it is known as Peoples Panchtala colony. Approximately, three hundred and forty people lives in each building. Prior to the implementation of the Nabolok Enhancing Environmental Health by Community organization (EEHCO) project, Residential wastewater even sewage and wastes were dumped beside their residence and near about the premises of their residence because there was no any sewerage systems or damping place for management of daily waste. Due to unaffordable cost of construction, most of the drains in the towns and cities are open and as a result they are misused, sometimes serving as defecating sites for homes without adequate toilet facility [6]. Blockage of drainage systems occurred for wastewater overflow during rainy season. In consequence, self-purification capacity of receiving water bodies is overloaded and it causes surface and ground water pollution, impacting directly to the health of community, reducing the value of environment [7]. Moreover, wastes were spread by birds and animals.

To improve water and sanitation situation, a new wastewater treatment plant was therefore needed. But the Municipality could not afford a centralized system for its entire area. Very often centralized wastewater treatment systems comprising sewerage networks and sewage treatment plants are not feasible for the rapidly growing cities like Khulna. Conventional wastewater treatment plant needs large space for treating vast quantities of wastewater and also requires very high initial as well as operation and maintenance cost that Khulna municipality faces structural and financial adjustment problems. For these circumstances, a small scale DEWAT system would be suitable to reduce the pollution to an acceptable level.

Nowadays, the decentralized approach is very popular system for sustainable wastewater management especially for developing country like Bangladesh, where neither central sewer network systems nor large centralized wastewater treatment systems are suitable. Decentralized wastewater management may be defined as the collection, treatment, and disposal or reuse of wastewater from individual homes, clusters of homes, isolated communities, industries or industrial facilities, as well as from portions of existing communities at or near the point of waste generation (Tchobanoglous, 1998). It is the combinations of aerobic and anaerobic treatment process. The anaerobic treatment process comprise of settlers, anaerobic baffle reactors (ABR) and anaerobic filters (AF). The aerobic treatment process has horizontal planted gravel filters (PGF) and a polishing pond (PP). The basic idea of that is to treat the wastewater/sewage on-site by means of low-cost and low maintenance treatment systems, and reuse the treated water.

Recently, two DEWAT plants were constructed by Nabolok with the assistance of Water Aid Bangladesh for improving water and sanitation situation of Peoples Panchtala Colony. Treated waste water can be mixed with natural water bodies or used for gardening and flushing in toilet. The use of treated wastewater can also support agricultural production, which in turn contributes towards better food security and livelihoods.

1.3 Objectives of this Study

The main objective of the study is to investigate the feasibility of a decentralized wastewater treatment and its possibility for reclamation and reuse of wastewater. The details of the study can be described in below:

a) To study the performance of two DEWAT plants regarding its technical and socio-economic acceptance by ordinary population in Panchtola Colony in Khulna, Bangladesh;

b) To compare the performance of two DEWAT plants based on field and laboratory investigations;

c) To identify the technical problems in the operation and maintenance of two DEWAT plants;

d) To recommend the modified DEWAT plant which will reduce construction cost, require small space above ground and low maintenance and prevent the deteriorating health conditions, pollution of nearby water bodies and surrounding environment.

1.4 Scope of this Study

This study is focused on two aspects. The first is evaluation of the performance of two DEWAT plants based on field and laboratory investigations. The second is recommendation of a modified DEWAT plant in order to improve its effluent quality and encourage reuse and reclamation of wastewater.

In this study, two DEWAT plants at Panchtola Colony in Khalishpur, Khulna was selected to review. Wastewater quality, design and operation of DEWAT plants were mentioned. The duration of monitor DEWAT plants was about one year, from February 2013 to November 2013.

Different filter media such as gravel, brick khoa and sand were applied in planted gravel filter to treat effluent which passed through the anaerobic baffled reactors. The wastewater samples of various parts of DEWAT plants were collected for investigation purposes. Water quality in influent and effluent was analyzed to evaluate efficiency of treatment plants.

Two alternative designs for modification of DEWAT plant are recommended regarding the treatment of wastewater by natural biological means. The first option is fully elimination of the planted gravel filter from DEWAT system for minimizing construction and maintenance cost. The second option is addition of biogas collector unit with the first option for the collection of biogas used as fuel and for removal pollutant from wastewater.

1.5 Thesis Outline

This study consists of five chapters as follows:

Chapter One: Introduces and defines the problem, specifies the objectives of this study and clarifies the scope of it.

Chapter Two: This chapter reviews the relevant literature with regard to the subject of this thesis. The sanitation and wastewater, classification of wastewater, characteristic of wastewater, necessity of wastewater treatment, and benefit of reused wastewater are focused. The wastewater treatment systems, the problems of conventional wastewater treatment systems in Bangladesh and the suitability of DEWAT practice are mainly discussed in this chapter. The anaerobic and aerobic process and the anaerobic-aerobic treatment system and its benefits are addressed. The mechanisms of DEWAT system i.e. different components of DEWAT plant are also described. The biogas, biogas sanitation systems are introduced in this chapter. The advantages and disadvantages of the biogas sanitation systems are highlighted. The biogas settler or biogas septic tank is also described in this discussion.

Chapter Three: This study included four main parts: survey, performance study of the two DEWAT plants, identification of technical problems in the operation and maintenance and to recommend a modified DEWAT plant.

Chapter Four: This chapter includes four parts. The first part is Data Analysis of the wastewater from existing two DEWAT plants at the Panchtola Colony in Khalishpur, Khulna. Second, presents comparison of DEWAT plants. The third part is Identification Technical

Problems in existing DEWAT Plants based on experimental results. The final goal is to recommend a modified DEWATS which will prevent the deteriorating health conditions, pollution of nearby water bodies and surrounding environment.

Chapter Five: Conclusions and recommendations for further studies are presented in this chapter.

CHAPTER II

LITERATURE REVIEW

CHAPTER II

Literature Review

2.1 General

This chapter reviews the relevant literature with regard to the subject of this thesis. Sanitation and wastewater, classification of wastewater, characteristic of wastewater, necessity of wastewater treatment, and benefit of reuse of wastewater are focused. The wastewater treatment systems, the problems of conventional wastewater treatment systems in Bangladesh and the suitability of decentralized wastewater treatment (DEWAT) practice are mainly discussed in this chapter. The anaerobic and aerobic process and the anaerobic-aerobic treatment system and its benefits are addressed. The mechanisms of DEWAT system i.e. different components of DEWAT plant are also described. The biogas, biogas sanitation systems are introduced in this chapter. The advantages and disadvantages of the biogas sanitation systems are highlighted. The biogas settler or biogas septic tank is also described in this discussion.

2.2 Sanitation and Wastewater

Sanitation is the principles and practices relating to the collection, treatment and proper disposal or reuse of sewage wastewater and domestic wastewater. The aim of a sanitation system is to protect human health and environment from the hazardous wastes. Poor sanitation leads to the contamination of freshwater sources which is a major cause of disease and death, and affects the health of ecosystems.

Wastewater is any liquid waste discharged by domestic residences, commercial properties, industry, agriculture, which often contains some contaminants that has been adversely affected in quality by anthropogenic influence. Term wastewater need to be separated from the term sewage. Sewage is subset of wastewater that is contaminated with feces or urine though many people use term sewage referring to any waste water.

2.2.1 Sewage

Generally, the wastewater discharged from domestic premises like residences, institutions and commercial establishments is termed as "Sewage/Community wastewater". It comprises of 99.9% water and 0.1% solids and is organic because it consists of carbon compounds like human waste, paper, vegetable matter etc [9].

2.2.2 Classification of wastewater

Classification of wastewater is in two main categories namely, grey and black water. While, grey water is the term used for water from kitchen, baths, laundries and sinks and black water is wastewater contaminated by faeces or urine, and includes wastewater arising from toilet, urinal, or bidet. Both require different degree of treatment and require different treatment mechanisms. Wastewater treated in appropriate technology can be reused for a large number of uses and reduce intake of freshwater from the supply systems or groundwater [10]. Classifications of wastewater are shown in figure 2.1.

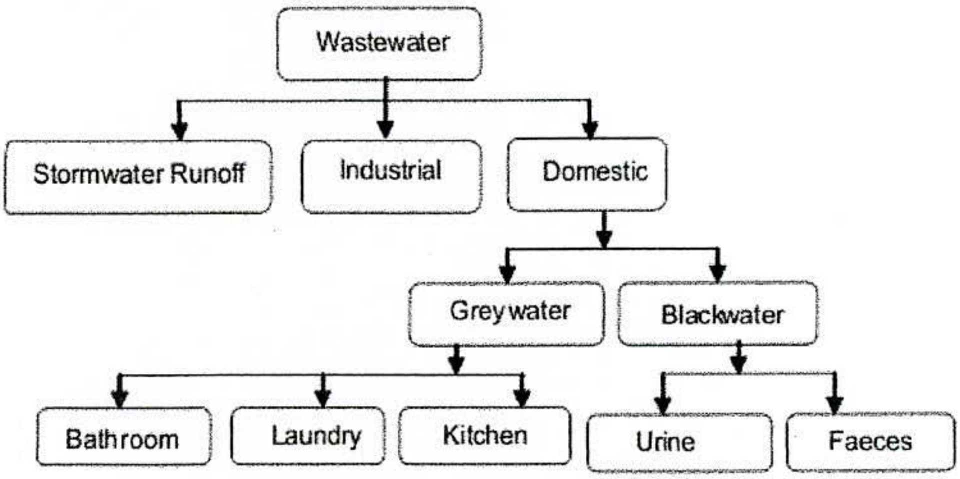

Figure2.1: Classification of wastewater [11].

Based on its origin wastewater can be classed as:

- Sanitary,
- Commercial
- Industrial
- Agricultural or
- Surface runoff

2.2.3 Characteristics of wastewater

Depending on its source, wastewater has peculiar characteristics [11]. In general, the contaminants in wastewater are categorized into physical, chemical and biological. Some indicator measured to ascertain these contaminants include [12, 13]:

Physical

- Electrical Conductivity (EC) indicates the salt content
- Total Dissolved Solids (TDS) comprise inorganic salts and small amounts of organic matter dissolved in water
- Suspended solids (SS) comprises solid particles suspended (but not dissolved)in water

Chemical

- Dissolved Oxygen (DO) indicates the amount of oxygen in water
- Biochemical oxygen demand (BOD) indicates the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water in a defined time period.
- Chemical oxygen demand (COD) indicates the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant
- Total Organic Compound (TOC)
- NH4-N and NO3-N show dissolved nitrogen (Ammonium and Nitrate, respectively).
- Total Kjeldhal Nitrogen is a measurement of organically-bound ammonia nitrogen.
- Total-P reflects the amount of all forms of phosphorous in a sample.

Biological

- Total Coliforms (TC) is encompassing faecal coliforms (FC) as well as common soil microorganisms, and is a broad indicator of possible water contamination.

- Faecal Coliforms (FC) is an indicator of water contamination with faecal matter. The common lead indicator is the bacteria Escherichia coli or E. coli.
- Helminth analysis looks for worm eggs in the water.

2.2.4 Why should Sewage/Wastewater be treated before disposal?

Sewage/Wastewater treatment involves breakdown of complex organic compounds in the wastewater into simpler compounds that are stable and nuisance-free, either physico-chemically and or by using micro-organisms (biological treatment) [14]. The adverse environmental impact of allowing untreated wastewater to be discharged in groundwater or surface water bodies and/or land is as follows [9]:

- The decomposition of the organic materials contained in wastewater can lead to the production of large quantities of malodorous gases,

- Untreated wastewater (sewage) containing a large amount of organic matter, if discharged into a river/stream, will consume the dissolved oxygen for satisfying the biochemical oxygen demand (BOD) of wastewater and thus, deplete the dissolved oxygen of the stream; thereby, causing fish kills and other undesirable effects [15],

- Wastewater may also contain nutrients, which can stimulate the growth of aquatic plants and algal blooms; thus, leading to eutrophication of the lakes and streams and

- Untreated wastewater usually contains numerous pathogenic, or disease causing microorganisms and toxic compounds, that dwell in the human intestinal tract or may be present in certain industrial waste. These may contaminate the land or the water body, where such sewage is disposed. For the above-mentioned reasons, the treatment and disposal of wastewater, is not only desirable but also necessary [15].

2.2.5 Benefits of Reuse of wastewater

The major benefits are as follows [10]:

- Helps save water, since it reduce the demand for freshwater for various uses, thus it helps to supplement potable water for non potable uses
- Helps reduce pollution in the water bodies, since water is being recycled and treated
- Recharges ground water and replenishes surface water bodies
- Provision to develop and use a reliable in-house water source availability
- Reduction in fresh water cost and reduction in disposal cess-pools
- An approach towards zero liquid discharge
- A low-cost method for sanitary disposal of municipal wastewater
- Reduces pollution of rivers and other surface water bodies
- Conserves nutrients, thereby reducing the need for artificial fertilizer
- Provides a reliable water supply to farmers
- Protection of environment and effectively combat the water scarcity

2.3 Wastewater Treatment Systems

In developing countries sewage and wastewater management is still a major problem. Increase in population, rapid urbanization and less availability of natural resources makes sewage a major concern of health hazard and environmental pollution. According to the World Bank, "The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes" [16]. There are two types wastewater treatment facilities namely, centralized wastewater treatment system and decentralized wastewater treatment system. Flow chart of wastewater treatment process is shown in figure 2.2.

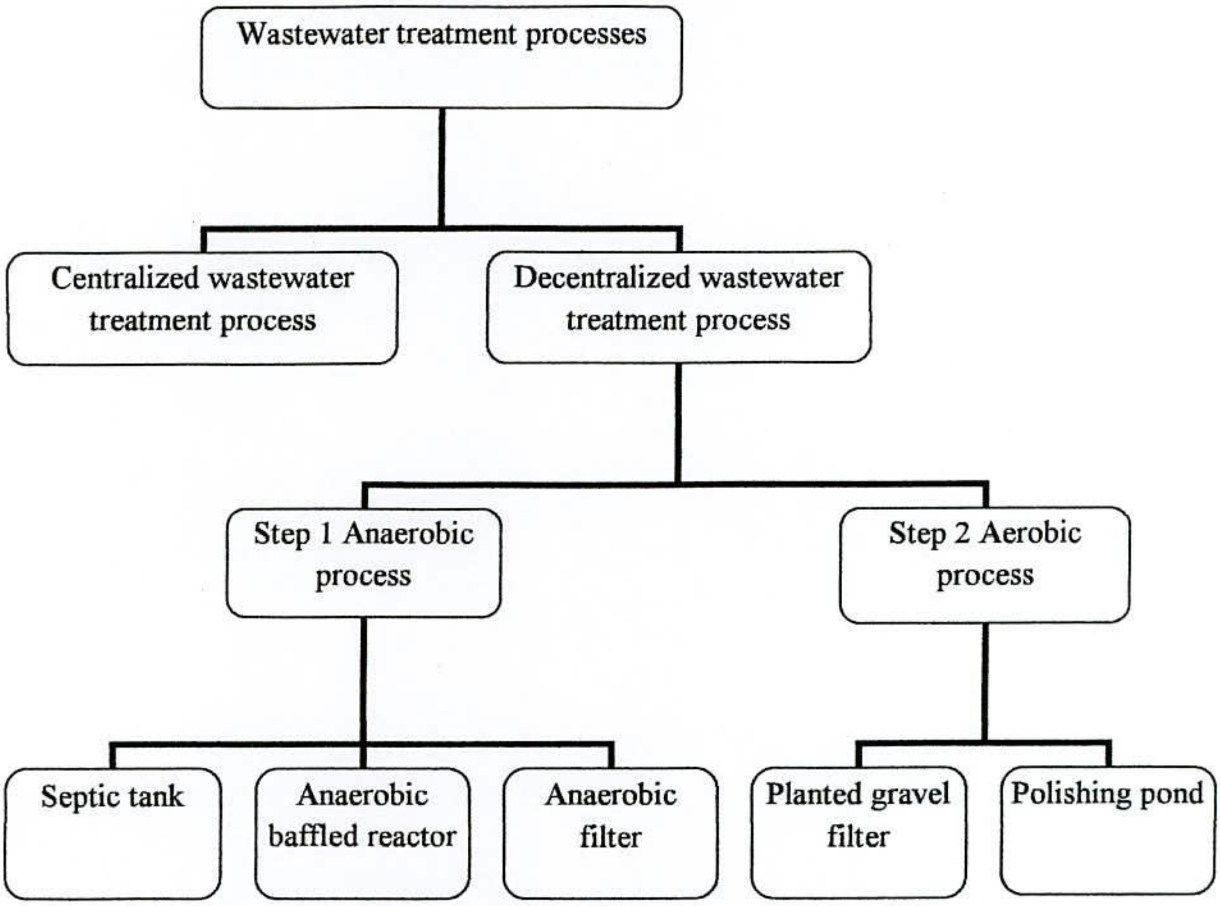

Figure2.2: Flow chart of wastewater treatment process

2.4 Centralized Wastewater Treatment System

Centralized wastewater treatment plants require conventional (intensive) systems, which rely on sophisticated technologies and plants operation by highly skilled personnel [17]. Centralized wastewater management consists of: (1) centralized collection system (sewers) that collects wastewater from many wastewater producers: households, commercial areas, industrial plants and institutions, and transports it to (2) centralized wastewater treatment plant in an off-site location outside the settlement, and (3) disposal/reuse of the treated effluent, usually far from the point of origin [18.19]This approach was developed in the middle of the nineteenth century and it is connected to the development of urbanization and urban life style. A network of sewer pipes carries generated wastewater from many homes and commercial areas to a central municipal treatment plant. For this reason it is also known as Off-site treatment system. Large diameter deep pipes, large excavations, and frequent manhole accesses are required to collect generated wastewater.

The first comprehensive sewer network was built in the Hamburg, starting 1842, and soon other cities followed. European cities were constructing large-scale centralized waste-carriage sewer systems, and proving them successful for removing wastewater from urban areas. This technology was transferred to the USA as well and by the end of the nineteenth century most of the major cities in the USA had also constructed some form of a central sewer. In Germany, for example, over 95% of the population is currently connected to sewer systems; In Israel 96% of the population is connected to sewer systems, etc. [20]. Tunisia's main cities and secondary towns are served with wastewater collection systems and central wastewater treatment plants; in Jordan 65% of the population is connected to collection systems and the largest towns are served by central treatment plants, etc. [21]. In other developing countries there is also a tendency to copy and apply the same collection and treatment technologies as applied in the industrialized countries, although these are expensive solutions and many believe that applying them as standard solution for developing countries, is not feasible [22].

Centralized system has been only applied very successfully in developed countries because of their financial ability for high cost investment for construction of sewer systems. It requires so much money for operation, maintenance, and collection wastewater from generate point to central treatment plant. This system also needs very good infrastructure support for its operation. In the developing and lower incoming countries, it is very difficult to build this system because lack of money. Therefore, they have to look towards alternative options such as decentralized system.

2.4.1 Classification of Conventional Wastewater Treatment

There are several types of conventional methods for wastewaters treatment such as

- active sludge process (ASP),
- rotating biological contactor (RBC),
- stabilization ponds,
- oxidation ditch,
- trickling filter (TF),
- sequence batch reactors (SBR),
- lagoons and up flow anaerobic sludge blanket (UASB),
- Micro-algae techniques etc.

These methods having the limitations like energy, economic, need for large land, complex construction and operation, sensitive to temperature and excessive sludge [23, 24, 25]. In developing countries, restricted local budgets, lack of local expertise, lack of funding, shortage of natural resources and lack of space are responsible for inadequate operation of conventional wastewater treatment plants. Considering these aspects, it is revealed that the decentralized wastewater treatment system (DEWATS) can play a major role in water pollution abetment with multifaceted benefits for treating wastewater.

2.5 Decentralized wastewater treatment system

Nowadays the global attention has been developed for simple, safe, cost effective and green technology. Decentralized wastewater treatment system (DEWATS) as a natural process, environmentally friendly, eco-friendly with simple construction, low maintenance and cost effective is one of the interested technique for sustainable wastewater and sewage management especially for developing countries like Bangladesh, where the water and sanitation issues are becoming a more and more important issue. This approach is an effective, efficient, affordable and sustainable wastewater treatment solution for a small or medium community.

Decentralized wastewater management may be defined as the collection, treatment, and disposal or reuse of wastewater from individual homes, clusters of homes, isolated communities, industries or industrial facilities, as well as from portions of existing communities at or near the point of waste generation [19]. Decentralization emphasizes a more holistic approach that considers the benefits of reducing the amount of waste at source and the option of recycling or reuse at the site [26]. It is also known as onsite wastewater treatment system. It not only reduces the effects on the environment and public health but also increases the ultimate reuse of wastewater

Decentralized system is used in rural and urban for long time in both developed and developing countries [27]. In the United States, about 60 million people use some form of onsite wastewater treatment systems of which about 20 million use the conventional septic tank system [28]. Australia is of no difference, where about 12 percent of the population uses septic tank systems to get rid of its wastewater [29]. In Canada, decentralized systems are employed in a number of locations. Around 14 percent of the population in Greece might be served by decentralized systems due to their location in rural areas [30]. Turkey tries to avoid centralized treatment due to the high cost of construction and operation. Of all the Turkish municipalities, up to 28 percent are served by septic systems. In other areas, the cluster systems and the package systems also exist [31]. Moreover, some countries encouraged wastewater reuse through some special programs. For instance, Cyprus initiated a subsidy program to the households that opted to install gray water recycling and reuse systems [32].

The major advantages of the DEWATS with extensive systems are as follows [33, 34, and 35]:

- Reliable, robust and buffer shock loads;
- No (or very little) energy is required;
- Limited sludge production;
- O&M does not require highly skilled personnel;
- Very low O&M cost;
- Reduces the risks associated with system failure;
- Increases wastewater reuse opportunities;

2.6 Centralized VS. Decentralized system

Collection, treatment and disposal are three basic components of any wastewater management system of which collection is the least important for treatment and disposal of wastewater [35]. Centralized wastewater treatment system in developing countries is not a convenient one, since these systems are costly to build and operate. It requires a sewer network for collection of wastewater from all homes to treatment point. Nonetheless, collection costs more than 60 percent of the total budget for wastewater management in a centralized system, particularly in small communities with low population densities [36]. It also for disposal requires disproportionately large investments for disposal which are unaffordable to the government of low incoming countries. Decentralized systems keep the collection component of the wastewater management system as minimal as possible and focus mainly on necessary treatment of wastewater.

Decentralized wastewater systems allow for flexibility in wastewater management, and different parts of the system may be combined into "treatment trains," or a series of processes to meet treatment goals, overcome site conditions, and to address environmental protection requirements [37]. It is a long-term alternative to centralized wastewater treatment system, particularly in small or medium communities.

A comparison between centralized and decentralized systems is shown in Table 2.1. From this table we can see that decentralized systems offer competitive operating and management costs, better source contamination control, better environmental outcomes however this emerging paradigm faces legislative challenges [38].

Table 2.1: Comparison of benefits and shortcomings between centralized and decentralized wastewater systems [38, 39, 40, 41, 42, and 43]

Centralized	Decentralized
Ownership: The water service provider controls ownership of unit: designing, constructing, operating or maintaining systems are considered too complicated to be in the control of homeowners. Not much flexibility in delivery and disposal options.	Ownership: Ownership and management are options available to the homeowner. Units can be altered to be site specific to allow for environmental factors and can be effective solutions for ecologically sensitive areas. For example, in the USA town of Jericho, 95% of homeowners rely on individual on-site sewage systems to help protect groundwater and surface water quality.
Cost: Initial cost average Aus$ 5,000 to 10,000 per property, with the majority (up to 80%) of the cost is in the set up of pipes and pumps. $/unit decreases as number of units increases economies of scale. $/unit would increase if deep sewage with pumping over long distances was needed.	Cost: Initial cost average Aus$ 5,000 to 10,000 per system. (Mainly in the treatment unit and reuse or disposal land area). $/unit decreases as number of units increases economies of scale.

Operation & maintenance costs: Aus$ 500 to 1,000 /property/ year (costs in operation and maintenance of the sewerage system).	Operation & maintenance costs: Aus$ 500 to 1,000 /property/year by a service provider (costs in operation and maintenance of treatment unit and reuse or disposal land area costs).
Nutrients: Safe disposal of treated wastewater is primary objective. This may leave nutrients within the wastewater that can cause problems for the receiving water bodies; further treatment is increasingly being required. To reuse this treated water additional plumbing at additional cost will be necessary.	Nutrients: Onsite reuse of treated wastewater is generally the objective of onsite systems with nutrients being recycled back onto land. The opportunity to reuse the sludge residue on-site via additional processes such as vermi-composting is possible, with the end product becoming a useful garden fertilizer.
Source: The wastewater comes from various origins, including industry, which contains various contaminants that increase the costs of treatment and disposal.	Source: Communities have a certain amount of control over the inputs into the systems and contamination by toxic substances can be limited, whilst wastewater reuse onsite can further reduce costs.
Stormwater can cause sewerage overflow, this may cause health or environmental harm.	Stormwater management incorporated into a system can recharge local groundwater supplies, reducing the risk of environmental harm.
Standard System: This is the standard type of wastewater system and there are clear policies and regulatory framework, responsible for its management.	Alternative Systems: Alternative wastewater options do not have clearly defined policies. In the past decentralized has meant individual septic tanks with local government being responsible for approvals and landowners being responsible for management, sometimes with detrimental environmental impacts. The evolution of alternative wastewater technologies has highlighted the need for clear policies and regulatory frameworks. In Finland, the rapid development of decentralized systems caused

	confusion amongst authorities, manufacturers and homeowners; in an emerging industry it is important to get the governance in place to guide future developments.

2.7 Anaerobic Process

In anaerobic process, bacteria decompose the organic wastes in the absence of oxygen to produce carbon dioxide (CO_2) and methane (CH_4) with the production of less quantities of extra bacterial mass (sludge) [44]. The methane (CH_4) can be reused as an alternative energy source named as biogas. Other benefits include a reduction of total bio-solids volume of up to 50-80% and a final waste sludge that is biologically stable can serve as rich humus for agriculture [45].

Anaerobic microorganisms work together to degrade the organic sludge and waste in three steps such as hydrolysis of high-molecular-mass compounds, acidogenesis and methanogenesis. Anaerobic process fully depends on the temperature of the wastewater. The activity of anaerobic microorganisms at temperatures below 20°C is very low. Therefore, anaerobic treatment of domestic sewage becomes much more attractive for tropical and subtropical climate countries, which are mainly developing countries [46].

The anaerobic process is efficient for the removal of organic material and suspended solids from municipal wastewater [47]. However, the anaerobic process has little effect on the concentrations of nitrogen and phosphorus; whereas pathogenic organisms are only partially removed [48]. Pathogens are reduced during digestion and to which extent depends on the temperature and retention times used [49]. The treated water from anaerobic process should never be discharged directly into water bodies without further treatment, unless the carrying capacity of the receiving water body is not exceeded. The main advantages of the anaerobic treatment process compared to the aerobic treatment process are the generation of biogas and significantly less sludge production [50]. However the treatment efficiency of anaerobic process is not as high as it is for aerobic processes.

Advantages of Anaerobic Digestion Treatment [45]:

- No, or very low energy demand.
- Production of valuable energy in the form of methane.
- Low investment costs and low space requirement.
- Applicable at small as well as large scale.
- Low production of excess sludge, which is well stabilized.
- Low nitrogen and phosphorus requirements.
- High treatment efficiencies.
- High loading capacity (5-10 times that of aerobic treatment).
- Suitable for camps with long term periods without discharge of wastewater.
- Effluents contain valuable fertilizers (ammonium salts).

2.8 Aerobic Process

In aerobic process, bacteria break down the organic waste by using oxygen to produce carbondioxide (CO_2) and water with the production of quantities of extra bacterial mass (sludge). Most aerobic processes require the mechanical addition of oxygen and that can be expensive [44]. Sludge production may be high in aerobic process due to dead bacterial cells sinking to the bottom. The existence of oxygen can avoid the bad smell due to the anaerobic activity by microorganism. Suspended solids concentrations are also significant reduced compared to anaerobic systems and, with the addition of disinfection devices, reduction in pathogenic organisms is also obtained [51].

Aerobic wastewater treatment systems generally consist of two main treatment processes. The first system type utilizes fully aerobic processes, consisting of either suspended or fixed growth media for allowing aerobic bacteria to digest wastewater materials. The second type of system is where an anaerobic chamber is employed as an initial pre-treatment process. The anaerobic treatment process always precedes the aerobic treatment [52]. Each system has its own advantages and limitations, but in general, the same common features of oxygen transfer to the wastewater, contact between microorganisms and wastes, and solid separation and removal are utilized by each system [53].

Other disadvantages associated with aerobic wastewater treatment system are: [54, 55]

- Increased susceptibility to shock loadings, due to sudden high loading or intermittent loading
- Sludge bulking and periodic solids washout, which causes high variations in effluent quality
- Large volume of sludge produced when compared to anaerobic systems

However, compared to anaerobic systems, aerobic systems achieve higher removal of soluble biodegradable organic matter material and the produced biomass is generally well flocculated, resulting in lower effluent suspended solids concentration [56].

In general, aerobic systems are suitable for the treatment of low strength wastewaters (biodegradable COD concentrations less than 1000 mg/L) while anaerobic systems are suitable for the treatment of high strength wastewaters (biodegradable COD concentrations over 4000 mg/L) [57]. A comparison between aerobic and anaerobic treatment is shown in Table 2.2.

Table 2.2: Comparison of aerobic and anaerobic treatment [56, 58, and 59]

Feature	Aerobic	Anaerobic
Process Principle	• Microbial reactions take place in the presence of molecular/ free oxygen • Reactions products are carbon dioxide, water and excess biomass	• Microbial reactions take place in the absence of molecular/ free oxygen • Reactions products are carbon dioxide, methane and excess biomass
Applications	Wastewater with low to medium organic impurities (COD < 1000 ppm) and for wastewater that are difficult to biodegrade e.g. municipal sewage, refinery wastewater etc.	Wastewater with medium to high organic impurities (COD > 1000 ppm) and easily biodegradable wastewater e.g. food and beverage wastewater rich in

		starch/sugar/alcohol
Reaction Kinetic	Relatively fast	Relatively slow
Organic removal efficiency	High	High
Effluent quality	Excellent	Moderate to poor
Organic loading rate	Moderate	High
Sludge production	High	Low
Nutrient requirement	High	Low
Alkalinity requirement	Low	High for certain industrial waste
Energy requirement	High	Low to moderate
Temperature sensitivity	Low	High
Start up time	2-4 weeks	2-4 months
Odor	Less opportunity for odors	Potential odor problems
Bioenergy and nutrient recovery	No	Yes
Mode of treatment	Total(depending on feedstock characteristics)	Essentially pretreatment
Capital Investment	Relatively high	Relatively low with pay back
Post Treatment	Typically direct discharge or filtration/disinfection	Invariably followed by aerobic treatment

2.9 Anaerobic – Aerobic Treatment System

When treating high organic strength wastewater, aerobic or anaerobic treatment alone does not produce effluents that comply with effluent discharge limit. The use of anaerobic–aerobic processes can also lead to a factor eight cost reduction in operating costs when compared with aerobic treatment alone [60], while simultaneously resulting in high organic matter removal efficiency, a smaller amount of aerobic sludge and no pH correction [57]. The three main types of anaerobic–aerobic system are available as shown in figure 2.3.

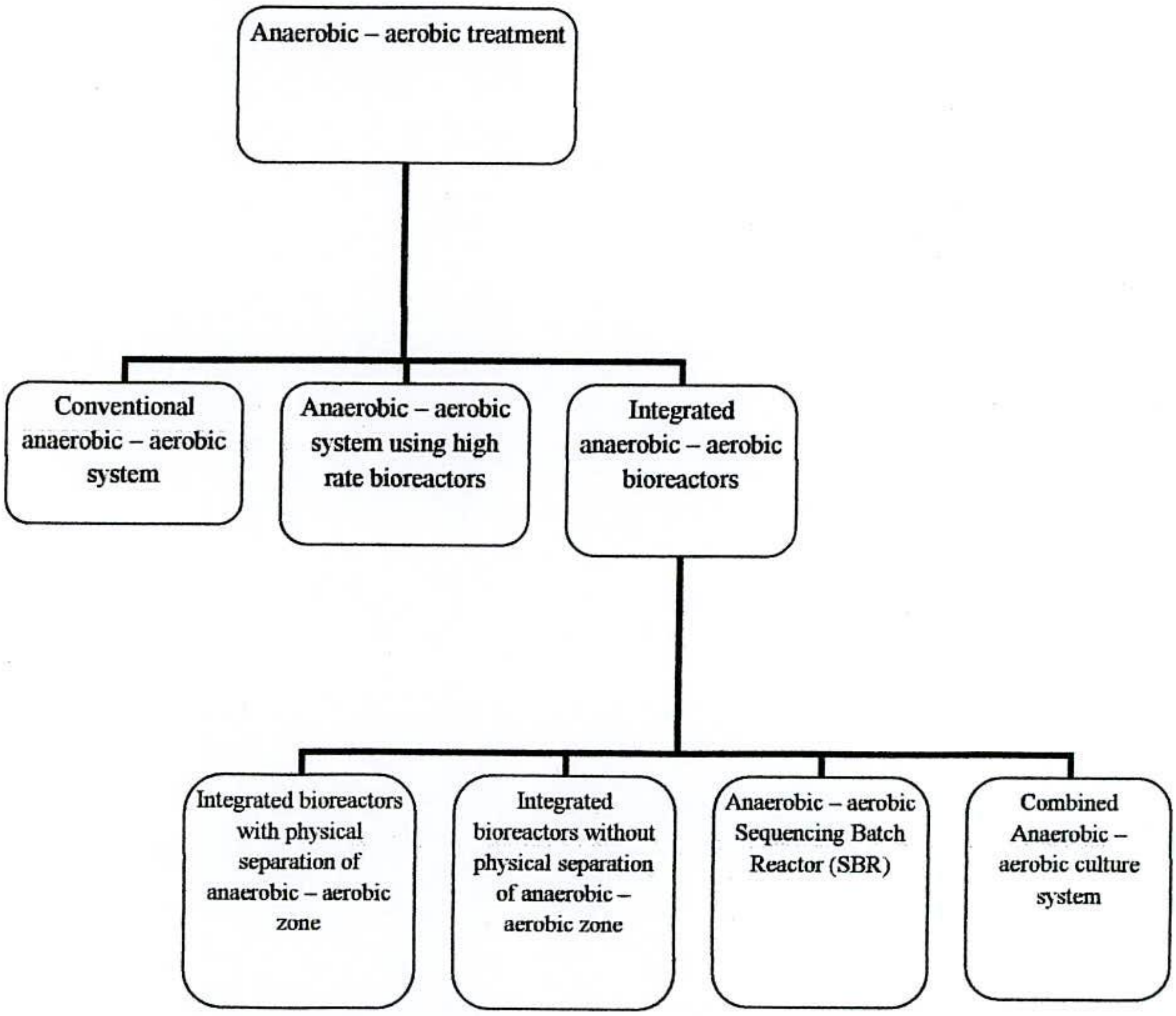

Figure2.3: Types of combined anaerobic–aerobic system.

Benefits of the anaerobic–aerobic process are listed below: [57]

- Great potential of resource recovery: Anaerobic pretreatment removes most of the organic pollutants and converts them into a useful fuel, biogas.

- High overall treatment efficiency: Aerobic post-treatment polishes the anaerobic effluent and results in very high overall treatment efficiency. The aerobic treatment also smoothes out fluctuations in the quality of the anaerobic effluent.

- Less disposal of sludge: By digesting excess aerobic sludge in the anaerobic tank, a minimum stabilized total sludge is produced which leads to a reduction in sludge disposal cost. As an additional benefit, a higher gas yield is achieved.

- Low energy consumption: anaerobic pretreatment acts as an influent equalization tank, reducing diurnal variations of the oxy-gen demand and resulting in a further reduction of the required maximum aeration capacity.

- When volatile organics are present in the wastewater, the volatile compound is degraded in the anaerobic treatment, removing the possibility of volatilization in the aerobic treatment.

2.10 Mechanism of DEWAT System

Decentralized system is the combination of aerobic and anaerobic treatment process. The anaerobic treatment process comprises of settlers, baffle reactors and anaerobic filters. The aerobic treatment process has horizontal planted gravel filters and a polishing pond.

2.10.1 Septic Tank/Settler

A septic tank is referred as a watertight chamber made of concrete, fiberglass, PVC or plastic, for the storage and treatment of blackwater and greywater. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate (Figure 2.4). A Septic Tank should typically have at least two chambers [61]. It is the most common method for onsite treatment of sewage used in the worldwide.

Septic tank is most well known form for small scale and decentralized treatment plants and accomplishes approximately 50% of the ultimate treatment within the tank [62]. The purpose of a septic tank is to provide a receiving vessel for all wastewater generated from domestic dwelling and to afford primary treatment that wastewater [27]. This tank separates settleable and floatable materials from raw sewage and functions as an anaerobic bioreactor that promotes partial digestion of retained organic matter. It removes about 60-70% of the dissolved matter from it [63]. Effluent of septic tank contains significant concentrations of pathogens, suspended and dissolved solid particles, and nutrients has traditionally been discharged to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils. Nowadays, many alternative treatment technologies are applied to treat wastewater when they exit the septic tank.

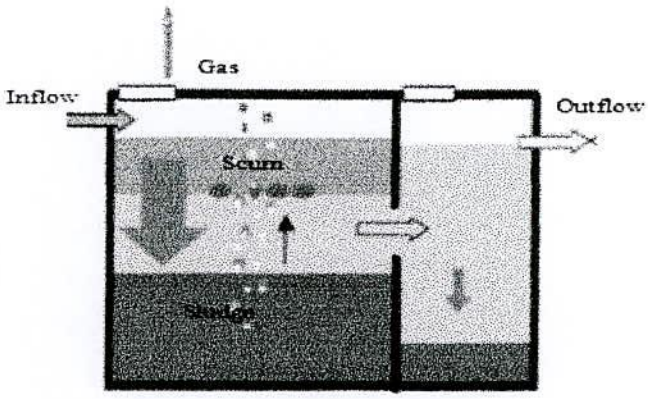

Figure2.4: Schematic diagram of a septic tank

Technology of Septic Tank

There are different types of septic tanks. The septic tank may be rectangular or cylindrical container made of concrete or polyethylene. Normally, septic tank is an underground constructed tank having one or multiple compartments. These compartments can be separated in to different tanks but its function is not difference. The wastewater from the toilet, bath, kitchen, etc., enters the tank. Velocity of flow is reduced providing relatively quiescent conditions. That allows portions of the heavy solids to settle to the bottom. The lighter substances such as grease, oil and other floatable materials rise to the top and form a scum layer [27]. Within septic tank two main treatment processes take place, first sedimentation and second a stabilization and anaerobic digestion of the settled sludge through biological treatment.

Anaerobic bacteria break down wastes and the solids that are not decomposed remain in the tank called sludge. The settled sludge must be pumped out periodically and the period for pumping sludge depends on tank size, types of solid enter the tank, etc. Usually, this period can be 3 – 5 years.

In a study carried out in Vietnam, it was shown that septage (content of septic tank) contains high level of E. Coil, Salmonella spp., Enterococcus spp., and Helminth eggs [64]. So, it should be required very careful handling. Some characteristics of septage from various countries are established by Koné and Strauss (Table 2.3).

Table 2.3: Characteristics of septage from various countries [65]

	Accra (Ghana)	Ouagadougou (Burkina Faso)	Bangkok (Thailand)	Alcorta (Argentina)
TS, mg/l	12000	19000	15350	6000-35000
COD, mg/l	7800	13500	15700	4200
BOD_5, mg/l	840	2240	2300	750-2600
NH_4-N, mg/l	330	-	415	150

***General information:* [44]**

Effluent Quality

- This is rough primary treatment prior to secondary or tertiary treatment
- 25-50% COD removal
- 40% BOD reduction of raw sewage
- 65% Suspended Solids reduction
- Effluent still contains pathogenic bacteria, cysts and worm eggs.

Water Information

- Both greywater and blackwater can be flushed through the system
- Since only accepts liquid waste must be connected to a flush toilet. Not suitable where water supply scarce or unreliable.

Operation and Maintenance

- Construction of septic tank requires skilled labour
- Little maintenance however requires regular desludging.

Table 2.4: Advantage and Disadvantages of septic tank [27]

Advantages	Disadvantages
• Simple operation • Little space requirements (underground) • Low maintenance requirement • Nutrients are returned to the soil • Cost-efficiency regarding treatment • Long-lasting	• Low treatment efficiency • Enrichment of nutrients and disease caused microorganisms in effluent. • Foul-smelling emissions created by anaerobic digestion

2.10.2 Anaerobic Baffled Reactor

The baffled reactor also known as "baffled septic tank", consists of several tanks in series (Figure 2.5). The tanks in series are to assist in the digestion of difficult degradable substances especially towards the end part of the process. Baffle walls or down-flow PVC pipes direct the waste water flow between the compartments from top to bottom and up again. Biological and natural chemical processes are used to digest and remove most of the organic matter into the baffled reactor. Sludge settles at the bottom of each compartment. During this process the fresh Influent upon entering the process is mixed with active sludge present in the reactor. It is used for treatment of wastewater with a high percentage of non-settleable suspended solids and low COD/BOD ratio. It is also suitable for all kinds of wastewater including domestic.

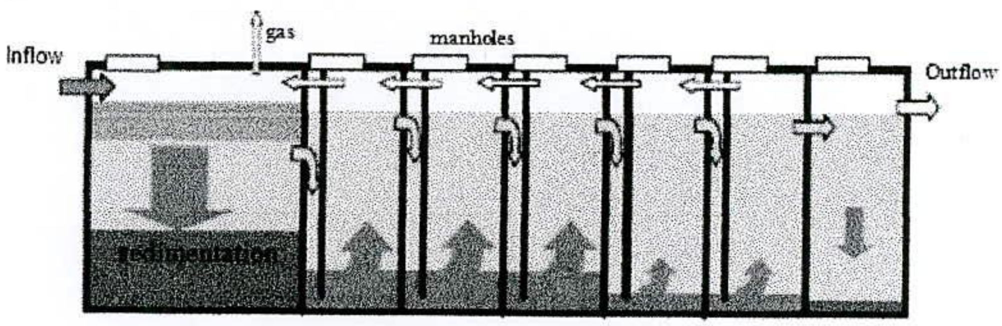

Figure2.5: Schematic diagram of a baffled reactor

General information: **[44]**

Effluent quality:

- Treatment Efficiency 70-95% BOD removal, 65-95% COD removal.

- Moderate Effluent Quality

Water Information

- Both greywater and blackwater can be flushed through the system
- Since they only accept liquid waste must be connected to a flush toilet. Not suitable where water supply scarce or unreliable.

Operation and Maintenance

- Requires skilled labor for construction.
- Sludge removal is important and must be done regularly
- Flow regulation is also important as up-flow velocity should not exceed 2m/h.
- Moderate operation and maintenance requirements

Table 2.5: Advantage and Disadvantages of baffled septic tank [66]

Advantages	Disadvantages
• Low cost • No electrical requirements • Construction material locally available • Low land space required • High treatment efficiency • Simple to build and operate • Hardly any blockage • Durable system • Relatively cheap • Low affect due to shock load and shock hydraulic.	• Needs skilled contractors for construction • Less efficient with weakly polluted wastewater • Long start-up phase • Large volume requirement

2.10.3 Anaerobic Filters

Anaerobic filters, also known as fixed bed or fixed film reactor, can be used for pre-settled domestic and industrial wastewater of narrow COD/BOD ratio and low SS concentrations [27]. One or more chambers can be fitted out at the end of the last chamber of the baffled reactor as an anaerobic filter in order to improve further the treatment efficiency (Figure 2.6). Anaerobic filters are constructed below ground level. They are suitable for domestic wastewater and all industrial wastewater that have a lower content of suspended solids. Preliminary treatment should be required to remove larger size solid particles.

Anaerobic filters treat non – settleable and dissolved solids by bringing them in close contact with active bacterial mass on a filter media. The filter media should be rough for bacterial growth. Surface of filter material should be from 90 to 300 m2/m3of reactor volume [27]. The materials such as gravel, rocks, cinder or specially formed plastic pieces are used as filter media which provide additional surface area for bacterial growth and digestion of dissolved organic matter.

The problem of encountering clogging is minimized due to the digestion and treatment that occurred already in the baffled tank treatment. The effluent passing out of the anaerobic filters will have a 90% of the original pollution load removal. The Central Pollution Control Board's (CPCB) standards are met and the wastewater can be, if required, safely used for infiltration into the soil and subsequently recharge the ground water table [67].

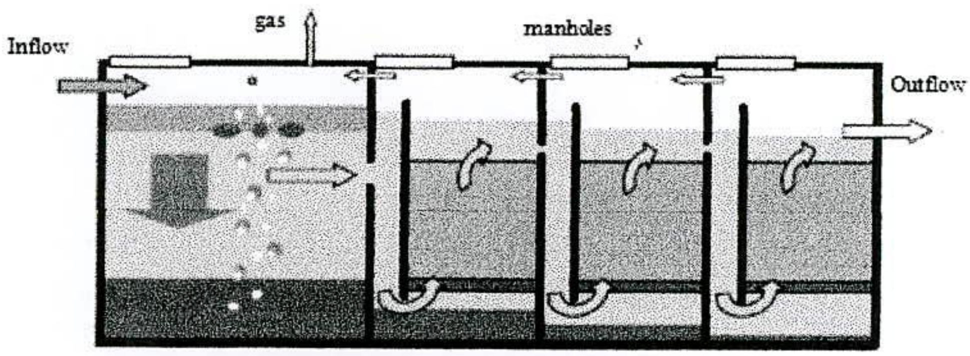

Figure2.6: Schematic diagram of anaerobic filters

General information: [44]

The requirement tank volume should be 0.5 to 1 m3/capita. Biogas utilization should be considered in the case of BOD concentration is higher than 1.000 mg/L. The hydraulic retention time should be higher than 24 hours [27].

Effluent quality:

- 70-90% BOD removal in a well operated anaerobic filter.
- Moderate effluent quality

Water Requirement

- Since only receive liquid waste not suitable where water scarce or unreliable.
- Both greywater and blackwater can be flushed through the system

Operation and Maintenance

- High operation and maintenance
- Desludging required at regular intervals
- Cleaning of filter material required

Table 2.6: Advantage and Disadvantages of Anaerobic filters [66]

Advantages	Disadvantages
• Little space requirements • Simple and durable system • High treatment efficiency	• High construction costs (filter media) • High operation and maintenance requirements • Blockage of filter possible • Effluent can smell

2.10.4 Planted Gravel Filters

Planted gravel filter is an aerobic unit which treats wastewater by adding air into water to break down organic matters, reduce pathogens, and transform nutrients (Figure2.7). It functions through the combined effects of the filter material, the plants and their roots growing in the filter media. The reed bed system is 1m deep basin sealed with clay or some other form of lining to prevent percolation into groundwater with the basin itself being filled with soil in which reeds are then planted [44]. When wastewater passes through the root zone soil, organic compounds and other impurities are eliminated by micro-organisms in the soil. A properly operating system can produce high-quality effluent with less than 30 mg/L BOD, 25 mg/L TSS, and 10,000 cfu/mL faecal coliform bacteria [27]. The effluent coming out is also odor free.

Since the planted filter becomes less prominent in the overall design due to the excellent treatment taking place in the baffled tank reactor and anaerobic filter, the minimizing of the planted filter results in cost reduction, less needed space above ground and with an additional benefit of having reusable treated waste water.

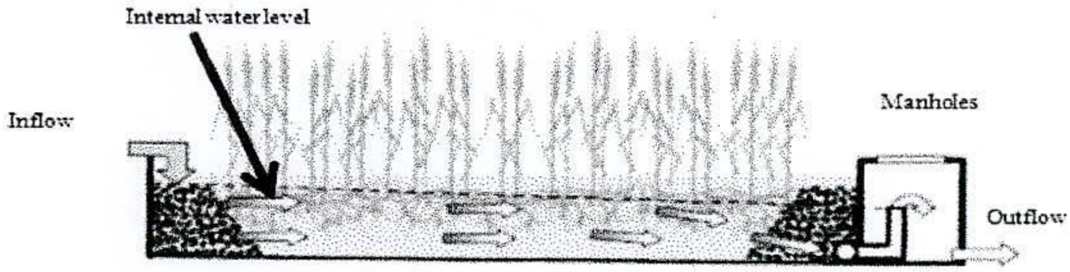

Figure2.7: Schematic diagram of a planted gravel filter

General information: [44]

Effluent quality:

- 84% COD removal rates
- 86% BOD removal rate

Water Information

- Since only receive liquid waste not suitable where water scarce or unreliable.

- Requires high volumes of water for transportation to treatment site

Operation & Maintenance

- Low operation and maintenance required.
- Regular maintenance of erosion trenches

Table 2.7: Advantage and Disadvantages of planted gravel filter [68, 69]

Advantages	Disadvantages
• Provide higher level of treatment than a septic tank • Helps to protect valuable water resources where septic system is failed. • Low operation and maintenance • No electrical requirement • Construction material locally available • High effluent quality	• More expensive to operate than a septic system. • Require more frequent maintenance components. • Release more nitrates to groundwater than a septic system

2.10.5 Polishing Pond

After passing through the different devices, with both anaerobic and aerobic treatment, the first full exposure of the treated water with air and nature is in the polishing tank, the treated effluent becomes "living water again" (Figure2.8). Through natural ultraviolet (UV) exposure, it undergoes further biological treatment. At this stage the recycled wastewater can be safely reused without posing any threat to human hygiene. It is extremely valuable for irrigation; the water is high in nutrient contents and beneficial to plant growth.

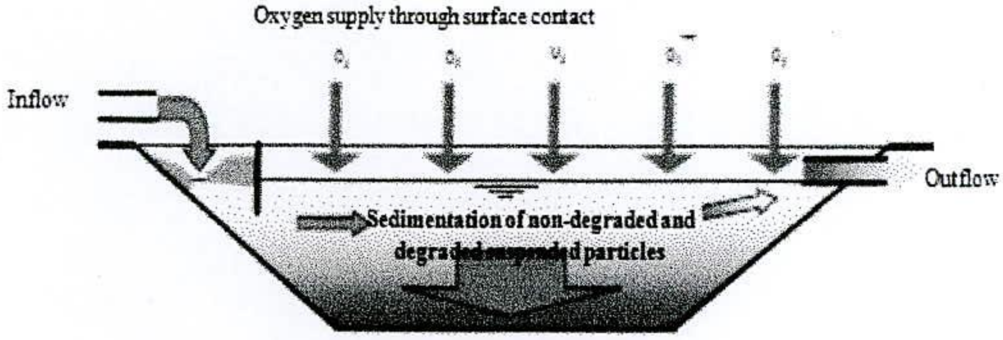

Figure2.8: Schematic diagram of a polishing pond

Table 2.8: Advantage and Disadvantages of polishing pond

Advantages	Disadvantages
• Low operation and maintenance • No electrical requirement • Low Construction cost • High effluent quality	• Require land above ground

2.11 Bio-Gas

Biogas is a byproduct of the decomposition of organic waste by anaerobic bacteria [70]. It is a clean and renewable energy that may be substituted to natural gas for cooking or to generate electricity. Biogas is typically composed of 60% methane and 40% CO2. It is similar to natural gas which is composed of 99% CH_4 gas.

2.11.1 Biogas composition

Biogas comprises of methane, carbon dioxide, hydrogen sulfide, water vapour etc. It is almost 20% lighter than air. Typical compositions of biogas are shown in table 2.9.

Table 2.9: Typical compositions of biogas [71]

Component	Formula	Concentration (% by vol.)
Methane	CH_4	55-70
Carbon dioxide	CO_2	30-45
Nitrogen	N_2	0-5
Oxygen	O_2	<1
Hydrocarbons	C_nH_{2n+2}	<1
Hydrogen sulfide	H_2S	0-0.5
Ammonia	NH_3	0-0.05
Water (vapour)	H_2O	1-5
Siloxanes	$C_nH_{2n+1}SiO$	0-50 mg/m^3

2.11.2 What can 1 m^3 biogas do? [72]

- It can illuminate a gas lamp equivalent of 60W non-electricity saving bulb for about 7 hours, resulting in a light performance efficiency of only 7%, 93% of the energy content is transformed in heat.
- It can cook 3 meals for a family of 5-6 persons.
- It can generate 2 kW of electricity, the rest turns into heat which can also be used for heating applications.
- It is average equivalent to 5.5 kg of firewood.
- It is equivalent to 1.5 kg of charcoal.
- It is equivalent to 0.45 liter of petrol, 0.55 liter of diesel, 0.60 liter of kerosene or of gasolene, or 0.5 kg of LPG

2.12 Biogas Sanitation Systems

Biogas sanitation systems are defined as ''engineered systems designed and constructed to utilise biological processes which break down solids and soluble organics in the liquid by anaerobic bacterial action under exclusion of free oxygen in treating organically loaded sludge, excreta or wastewater''[73]. Biogas sanitation systems have been used to treat domestic wastewater, organic waste, brown water, blackwater, excreta, faeces, and faecal sludge. Flow chart of biogas sanitation systems is shown in figure (Figure2.9).

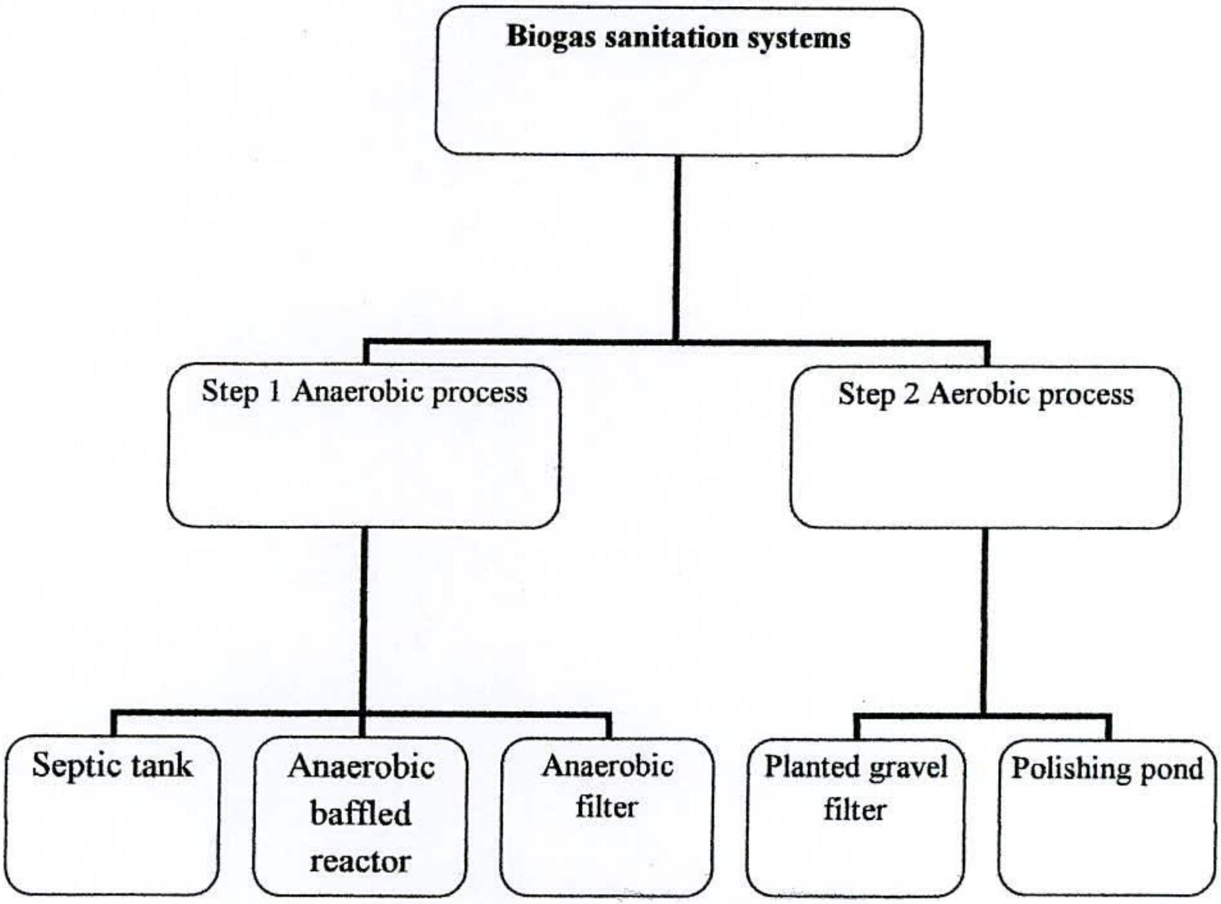

Figure2.9: Flow chart of biogas sanitation systems

Biogas sanitation systems are usually designed as: [73]

- primary treatment for removal of settleable and digestable solids and organic matter (biogas settler, biogas septic tank), the primary treatment could be divided in multiple anaerobic steps i.e. as "biogas settler followed by anaerobic baffled reactor",

- secondary treatment for nutrient removal (nitrogen), hygienisation, and reduction of chemical oxygen demand (COD) and biological oxygen demand (BOD) – (anaerobic filter, upflow anaerobic sludge blanket reactor). Secondary treatment could further be carried out in a separate aerobic treatment process with natural aerated trickling filters, constructed wetlands or aerobic polishing pond systems.

Table 2.10: Overview on biogas sanitation systems [73]

Type of digester	Expected BOD reduction	Hydraulic retention time (HRT), days	OLR, (kg COD/m^3)	Sludge retention time (SRT), days	Optimal application
Biogas septic tank (BST)/bio gas settler (BS)	25-60%	Min 20, optimum 60 (limited by construction costs, but longer HRT for sanitization required)	0.5 – 2	Min 10 days, max 7 years (as higher to lower sludge volume handling challenges)	Pretreatment, energy optimized with organic waste, baffle in BS required if built as main treatment system with post composting, post-wetland, or drying bed
Anaerobic baffled reactor	70-90%	2 - 4	1 - 12	At least 2 years	Post-treatment after BS (than without baffle)
Anaerobic filter (AF)	70–95%	0.5 - 4	5 - 15	Theoretically no, but sludge may accumulate at the bottom	Post-treatment after BST or after ABR
Upflow Anaerobic sludge blanket (UASB)	55-90%	0.5 - 10	15 - 32	more than 365 days	Main-treatment after grid chamber, energy optimized with organic waste, or post-treatment after BS or BST, with post-wetland, or post-lagoon

2.12.1 Advantages of biogas sanitation systems

The advantages of biogas sanitation systems include: [73]

- Generation of clean energy for household use: after an initial investment in the system, there is less or no need to spend money on fuel, and no more smoke from wood or charcoal in the kitchen.

- Cooking on biogas is quicker and easier than cooking with firewood.

- Destruction of bacteria, viruses and helminth eggs in human and animal excreta. A farm with a biogas system is a cleaner and safer place.

- Production of safe fertilizers for use on the farm containing plant nutrients in an easy absorbable liquid form.

- Support the fight against global warming by facilitating to burn methane from organic waste, instead of escaping into the atmosphere where it adds to the greenhouse effect; supports also efforts to restrict deforestation.

- Cost effectiveness: Biogas septic tanks have at least the same investment as a conventional septic tank, and capture the biogas for further use. Operation and maintenance expenses (energy and supplies) are low and require only low skilled labour. For financial consideration the energy source that is replaced by biogas is important (wood, kerosene, LPG).

- Low-tech system: Anaerobic technology does not rely on complex machines and processes (such as aeration systems); systems, such as the anaerobic pre-treatment units (settler, baffled reactors or filters) of a complex decentralized wastewater treatment system, require low but adequate maintenance.

- Low space requirement: underground construction does not occupy valuable space especially in urban areas; only 0.5-1m^2per m^3 daily flow are needed, compared to 25-30 m2/m3/d flow in aerobic ponds and constructed wetlands. The space above a biogas plant could also be built on as parking area, as long as the system remains accessible.

- Treatment capability for a wide variety of domestic and industrial effluents, especially suitable for wastewater high in organic matter.

- Multi-step decentraliced wastewater treatment systems does not need electricity if there is suitable slope for gravity flow, saving a large amount of investment into the sewerage system. Low energy and maintenance cost, low total lifetime cost.

- If well designed, constructed and operated, calculated sewage sludge production is five times less compared to aerobic systems. The sludge yield from anaerobic treatment is approximately 0.1kg VSS/kg COD removed; by contrast aerobic activated sludge treatment results in 0.5kg VSS/kg COD removed.

- As the anaerobic treatment alone can not meet the requirements of direct discharge into water bodies, a post-treatment with an aerobic process is necessary. But even this combination reduces the specific sludge production by 40% [74].

2.12.2 Disadvantages of biogas sanitation systems

The disadvantages of biogas sanitation systems include: [73]

- ***Incomplete pathogen removal:*** Human excreta are contaminated with all kinds of pathogens and hence a reliable technology is necessary for their inactivation. During anaerobic digestion an inactivation of most animal and plant pathogens is obtained under thermophillic conditions (>55°C for several days). Several studies on wet fermentation report that also mesophilic and lower temperature operation inactivates pathogens; further findings indicate that reactors with retention times of at least 60 days at 20°C to 15 days and 35-55°C reduce significantly any type of pathogens [75]. Many studies reveal also that under fully mixed mesophilic conditions, pathogens are not completely inactivated.

- ***Temperature dependence:*** Organic material degrades more rapidly at higher temperatures because all biological processes operate faster at higher temperatures up to 65°C. The three ranges of temperature in which methanogens work are called psychrophilic (8-25°C), mesophilic (30-42°C) and thermophilic (50-65°C).

Biogas sanitation is often applied in countries where the ambient average temperature ranges above 15°C. In temperatures below 8°C digestion capability is much reduced. The process is also sensitive to temperature variations of more than 3°C; therefore variations have to be kept in a limited range to ensure a steady biogas production. The higher the process temperature the more sensitive is the process (bacteria).

- ***Variable performance:*** Performance may be less consistent than in conventional (aerobic) treatments. In terms of removal of organic matter and nutrients, biogas sanitation is mainly a primary or secondary treatment step, which may need post-treatment depending on the disposal or reuse strategy. The biological components are sensitive to toxic chemicals, such as ammonia and pesticides. Flushed pollutants or surges in water flow could temporarily reduce treatment effectiveness. Therefore buffer tanks or biogas-settler as pre-treatment units for wastewater flow equalization should be built.

- ***Experienced constructions, design and maintenance staff required:*** People with experience to design, build and maintain biogas sanitation systems are required at local level. A biogas sanitation system is technically more complicated as it includes more components than just a (urine diversion dehydration) toilet.

- ***Risk of explosion:*** As methane is flammable, there is always a small but manageable risk of explosion if methane escapes. The Flammable Range (Explosive Range) is the range of a concentration of a gas or vapor that will burn (or explode) if an ignition source is introduced.

2.13 Biogas settler or biogas septic tank

The biogas settler (with or without baffle(s), depend of the further treatment step chosen) or biogas septic tank (always with integrated baffles) is mainly applied as on-site household based system with secondary treatment of effluents in compost (solids) and drainages/subsurface irrigation (liquid) [73]. The biogas settler is used as a pretreatment step in combined anaerobic/aerobic multi-step systems or as pretreatment in combination with constructed wetlands or as pretreatment in combination with DEWAT plant (Figure2.10). The accumulated settled sludge must be removed from the base of the biogas settler periodically, based on experiences this will be necessary every 5-7 years [73]. There are different forms of biogas settler such as fixed-dome plant, bag digester, glass fiber (half) bowl plant, water jacked floating drum, PE or PVC predesigned tanks, covered anaerobic lagoons. Main parameters for the choice of construction material and for the basic design are [76]:

- Technical suitability (stability, gas- and liquid tightness);
- Cost-effectiveness;
- Availability in the region and transport costs;
- Availability of local skills for working with the particular building material.

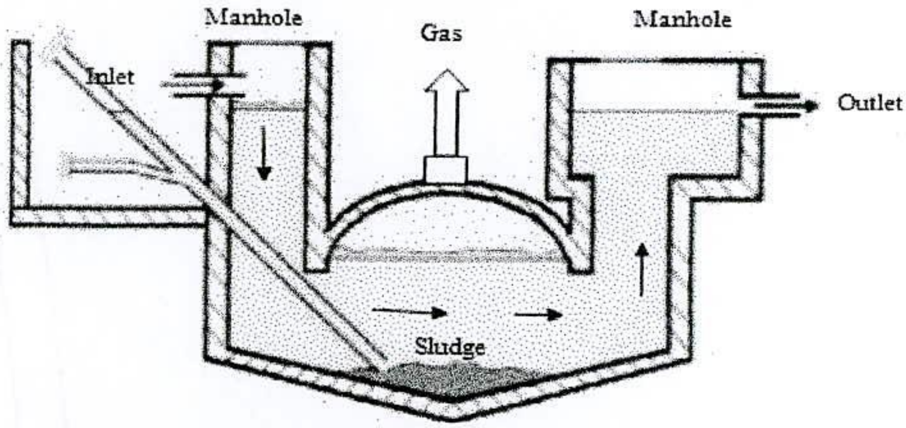

Figure2.10: Schematic diagram of a biogas settler

General information: [73]

Effluent quality:

- 65% solids removal rates
- 60% BOD removal rate
- 1-log E. coli removal rate

Operation & Maintenance

- Efficiencies vary greatly depending on operation, maintenance, and climatic conditions.
- No electrical requirement.

Table 2.11: Advantage and Disadvantages of biogas settler [73]

Advantages	**Disadvantages**
• Provide higher level of treatment than a septic tank • Helps to protect valuable energy resources where conventional septic tank is failed. • No electrical requirement • Construction material locally available.	• More expensive to operate than a conventional septic tank. • Require regular maintenance. • It is gas and watertight, it should not be constructed in areas with frequent flooding. • The efficiency will be low in cold climates

Table 2.12 shows the cooking fuel savings over 10 years outweigh the added infrastructural costs of a biogas settler over a conventional settler.

Table 2.12: Financial comparison of conventional settler and biogas settler (for 10 m^3 wastewater/day) [77]

	Settler	Biogas settler	Costs/Benefit for biogas settlers
Construction costs (INR)	79,000 (~1740 USD)	1,50,000 (~3300 USD)	-71,000 (~1560 USD)
Running cost (INR/year)	1000 (~22 USD)	2500 (~55 USD)	-1500 (~33 USD)
Income/savings in 10 years at Friends of camphill		Bogas as cooking fuel 1,20,000	+1,20,000 (~2640 USD)
Repayment period			Approx. 6 years
Income/savings in 10 years at Ullalu		Bogas as fuel for heating bathing water 3,65,000	+3,65,000 (8022 USD)
Repayment period			Approx. 2 years

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

Materials and Methods

3.1 General

Based on the objectives listed in the chapter 1, this study included four main parts: survey, performance study of the two DEWAT plants, identification of technical problems in the operation and maintenance and to propose the modified design of DEWAT plant. The chronological activities of this study are delineated in Figure 3.1.

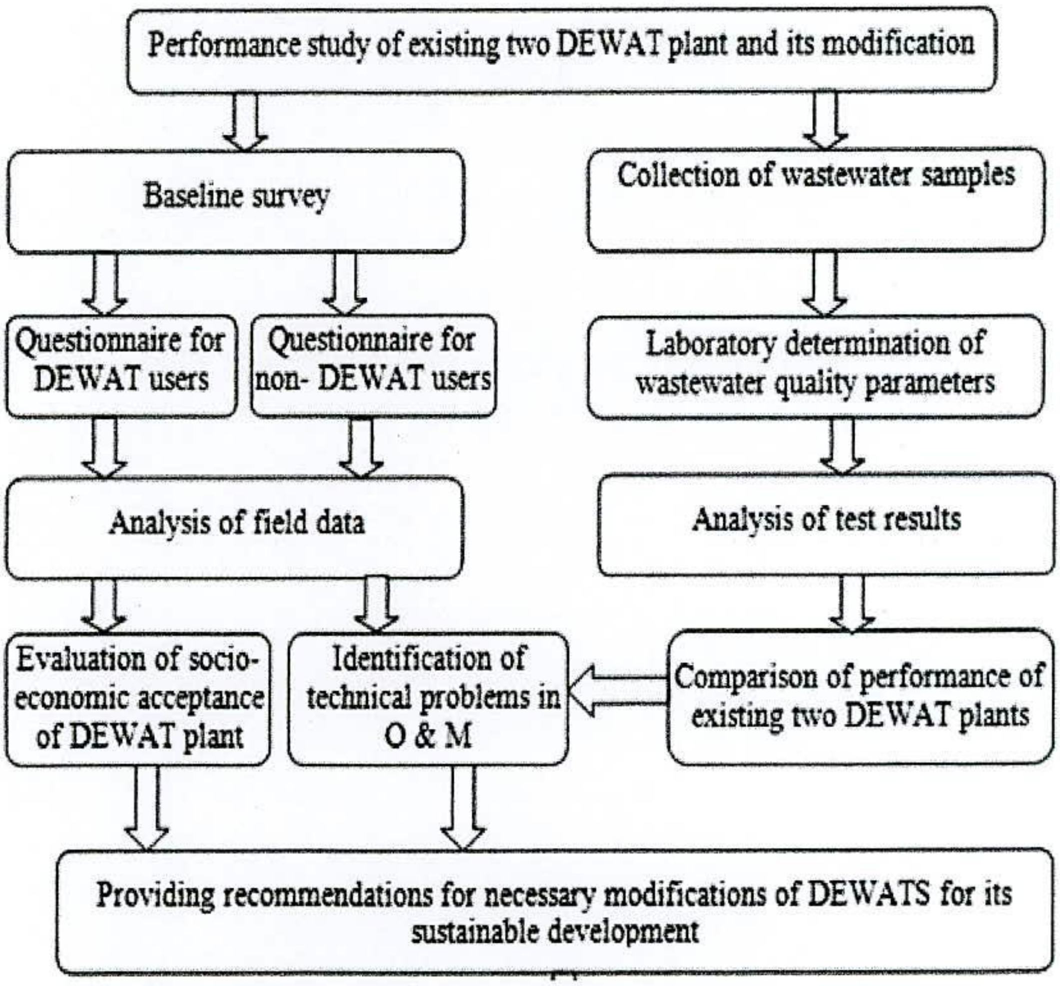

Figure 3.1: Flowchart showing the sequential steps in the research works

3.2 Study Area

Khulna is the third largest industrial city of Bangladesh, has a total area of 45.65 km² out of 4394.46 km² district area. Most of its industries like Jute mills, News print mill, and Hardboard mill are situated in Khalispur area. Khalishpur is situated at 22.8500°N 89.5361°E. There is no sewer network or no any central treatment system. Recently, two DEWAT plants were constructed at the Peoples Panchtola Colony at Khalishpur in Khulna City Corportaion (KCC) Area. Figure 3.2 shows the location of Peoples Panchtola Colony at Khalishpur in Khulna City.

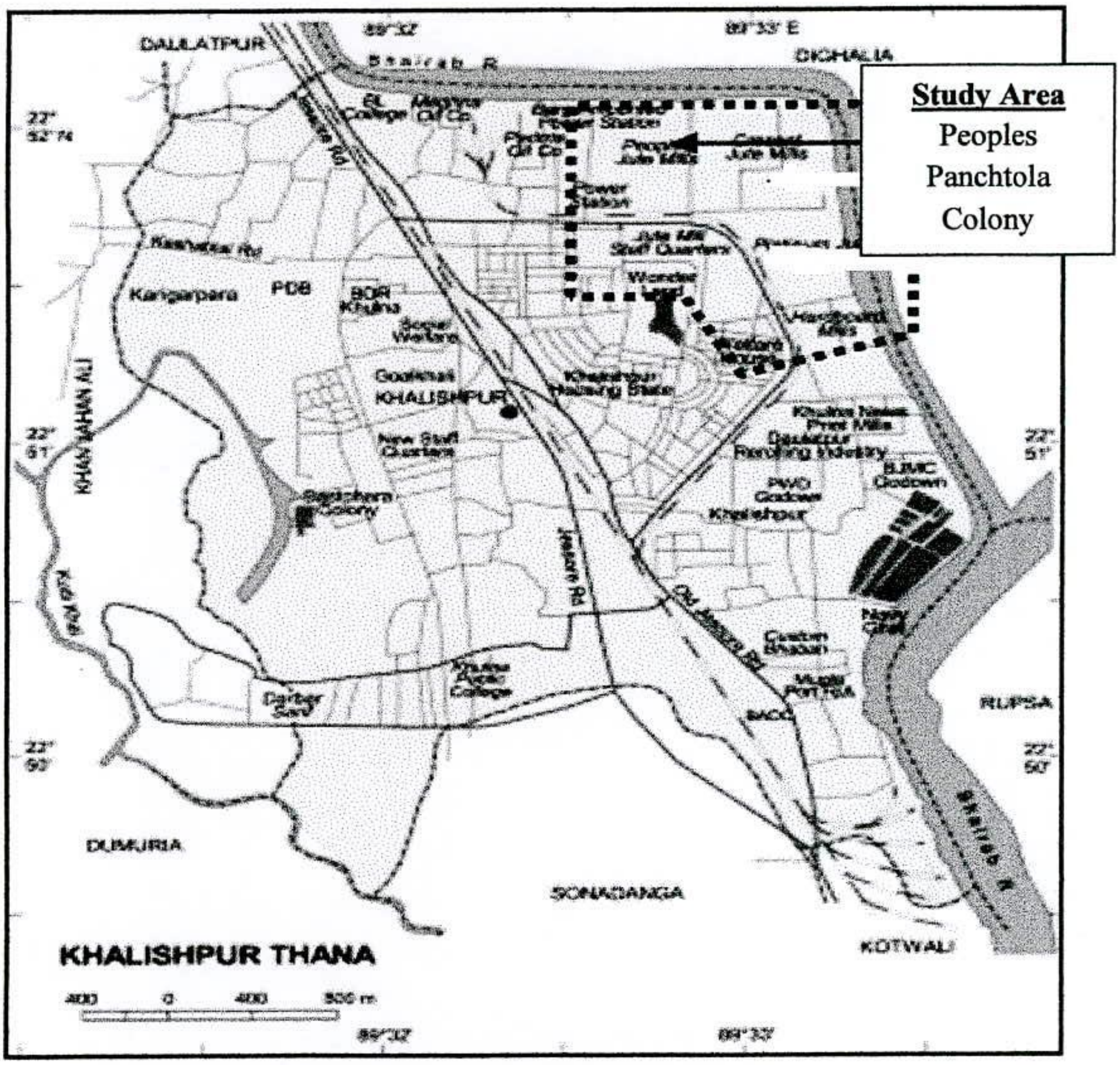

Figure 3.2: Location of study area [78]

3.3 Baseline Survey

Two DEWAT plants have been already constructed in Panchtola Colony at Khalishpur in Khulna by a local NGO named as Nabolok. A field survey was carried out to investigate the performance of the existing DEWAT plants. A sample of 166 families who are users of DEWAT plants was selected. Family interviews were conducted in the families of the colony. This was done with assistance of a Nabolok staff. One questionnaire was prepared for the users of DEWAT plants considering much information such as general, socio-economic, environmental condition, hygiene practice, benefits of DEWAT plant, maintenance of DEWAT plants, and aesthetic view of DEWAT plant, and recommendation on existing DEWAT plants. The aim of this survey was to find out the socio-economic acceptance and technical problems of existing DEWAT plant.

3.3.1 Survey before implementation of DEWAT plant

Before implementation of the Nabolok EEHCO project, Residential wastewater even sewage and Wastes were dumped beside their residence and near about the premises of their residence because there were not any sewerage systems or damping place for management of daily waste (Figure 3.3).

As a result, the place covered with full of wastage and polluting the environment. On the other hand all septic tanks were over flow due to lack of proper maintenance. Human excreta were mixing with mud, water and foot path. The open drains were breeding ground for infected disease germs. Colony peoples suffered from contaminated diseases like diarrhea, cholera, hookworms etc. Foul odour were emitted from waste garbage surrounded the buildings. Blockage of drainage systems occurred for wastewater overflow during rainy season. For that reason, surface water bodies and groundwater was polluted. Clogged drainage ditches along roads were productive mosquito breeding sites.

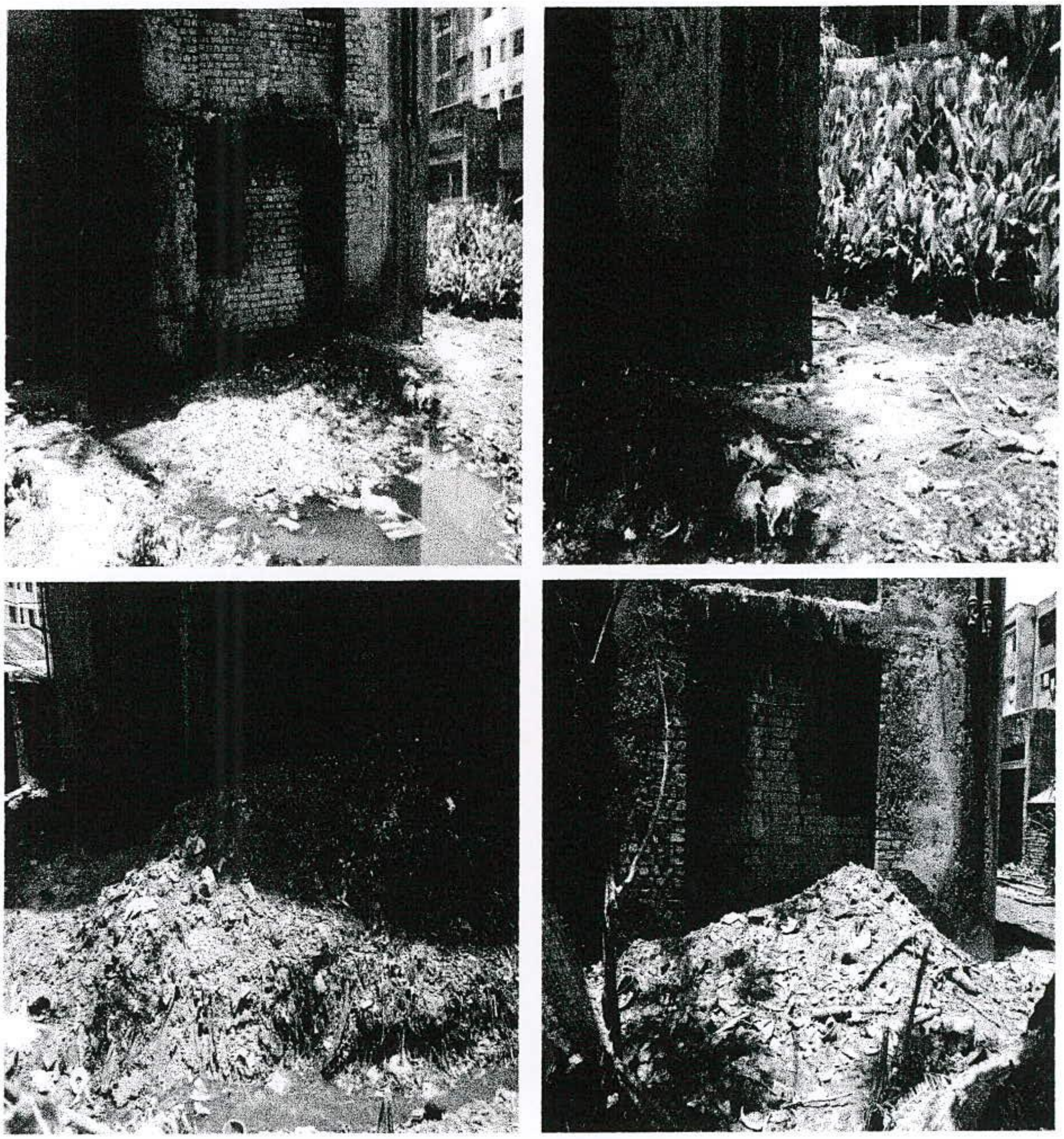

Figure 3.3: Waste and wastewater including sewage dumping practices before the Nabolok EEHCO project implementation.

3.3.2 Survey after implementation of DEWAT plant

Sanitation, hygiene and safe water supply need to be integrated to meet public health and environmental goals. DEWAT plant creates a linkage between sanitation and health. It gives a standard, prosperous and luxurious life to colony peoples.

DEWAT plant has created clean, hygienic and aesthetic environment (Figure 3.4). The open drain which was a breeding ground for disease germs is now safe space for colony people. Foul odor emitted from waste garbage surrounded the building is controlled. Water logging, one of major cause of infected diseases is managed. Colony peoples release from contaminated diseases like diarrhea, cholera, hookworms etc. Groundwater and surface water bodies are protected from wastewater/sewage.

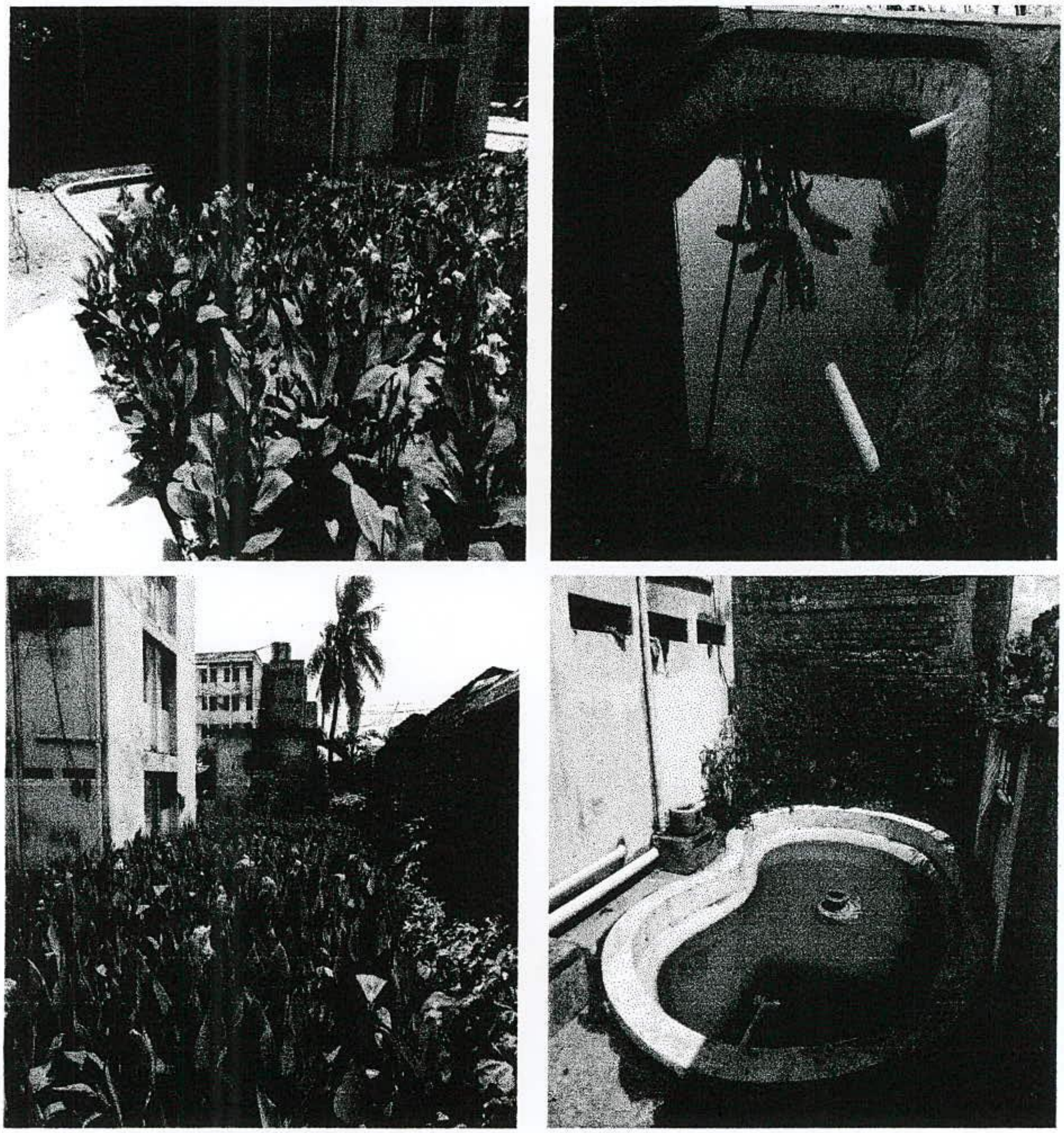

Figure 3.4: After implementation of the Nabolok EEHCO project

3.4 Necessary Information of the DEWAT System

3.4.1 Detail Design of DEWAT Plants

To solve long standing sanitation problems, two Decentralized Wastewater Treatment (DEWAT) plants were constructed at People's Panchtola Colony in Khalishpur, Khulna by Nabolok, a local NGO with the technical and financial supports received from Water Aid Bangladesh. The first one was constructed on last February 2012, while second one was constructed on last April 2013. The constructed DEWAT consists of (i) Septic Tank, (ii) Anaerobic Baffled Reactor (ABR), (iii) Anaerobic Filter Bed Baffled Reactor (AFBBR), (iv) Planted gravel filter (PGF) and (v) Polishing pond (PP). The schematic diagram of the system is shown in the Figure 3.5.

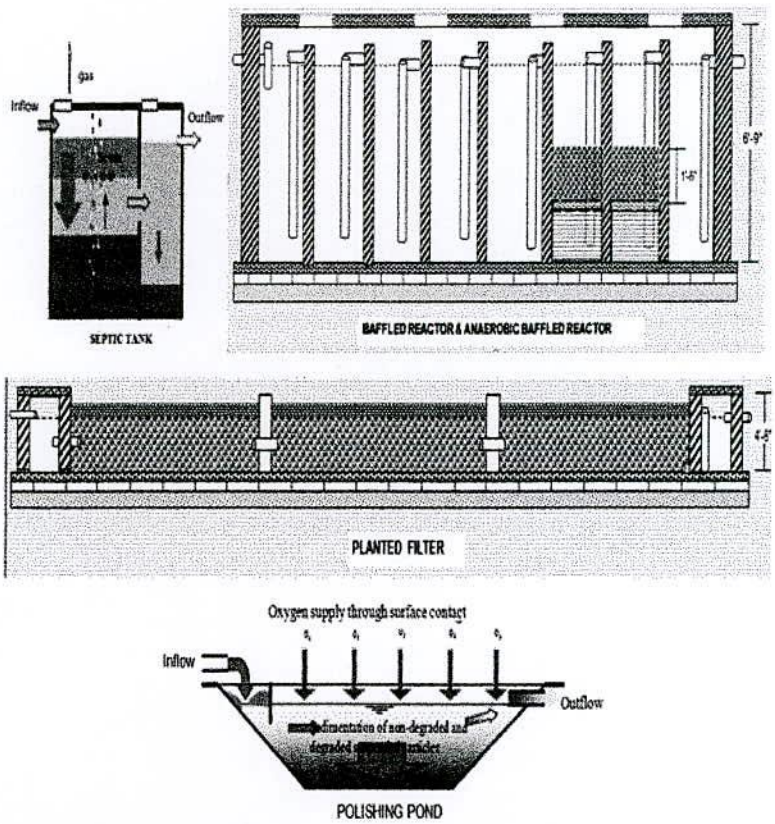

Figure 3.5: Existing DEWAT plant at the Panchtola Colony at Khalishpur, Khulna.

The septic tank has two compartments with the size of 2.0x2.25x2.75m and 1.0x2.25x2.75m having an opening at the middle of the partition wall between these two compartments. The

ABR has six compartments having same dimensions (1.0x1.58x2.0m) and functions, five in a series and the rest one placed after AFBBR and just before the PGF.

Two AFBBR, each has same capacity with gross dimensions of 1.0x1.58x2.0m, were fabricated. Each unit was packed by different types of packing materials, i.e. bamboo pieces, plastic pipe disc and cap of pet bottles placed on perforated slab, installed in series to particularly remove organic solids and other harmful materials. Packing materials served as adsorbent media and provided the niche for the growth and development of anaerobic microorganisms. Bacterial colonization of filter media often results in high degradation of organic substances in the system during the anaerobic fermentation period [79]. Wastewater loading was done in an up flow mode.

The last compartment of ABR is followed by PGF having a size of (21.6x5.0x1.25m) while sand and brick aggregates are used in PGF of first DEWAT plant and stone aggregate is used as filter media in the second DEWAT plant. The PP having the size of (4.5x4.5x1.25m) is constructed. However, for increasing treatment quality of wastewater, an external aeration device is used in polishing pond in the second DEWAT plant. Detail design descriptions of existing DEWAT plants are shown in Appendix A, B, and C.

3.4.2 Cost of DEWAT Plants

Construction cost of second DEWAT plant was high than first DEWAT plant due to variation of filter material in PGF. The contraction cost of first DEWAT plant was BDT 900000, while second one was BDT 1500000. Detail cost estimations of existing DEWAT plants are shown in Appendix D and E.

Table 3.1: Cost of existing DEWAT plants

Components	Cost (BDT)	
	First DEWAT Plant	Second DEWAT Plant
Septic Tank	63184	97560
ABR and AFBBR	149675	209350
PGF	343112	834762
PP	14981	21955
Others	329048	336373

3.5 Wastewater Collection

A total of 1 liter sample was collected in 6 bottles from six different points such as inlet and outlet of settler tank, middle of AFBBR, outlet of ABR, PGF and PP of two existing DEWAT plants of the Panchtola Colony as shown in figure 3.6. Wastewater samples were collected from the DEWAT plants once a month. Then the sample bottles were put in a cool box with ice cubes before being transported to the environment laboratory at KUET campus. This was to prevent any change of wastewater quality which could occur between the time of collection and analysis in the laboratory. Some parameters which were determined immediately upon arrival in the laboratory included Faecal Coliform, DO and BOD_5.

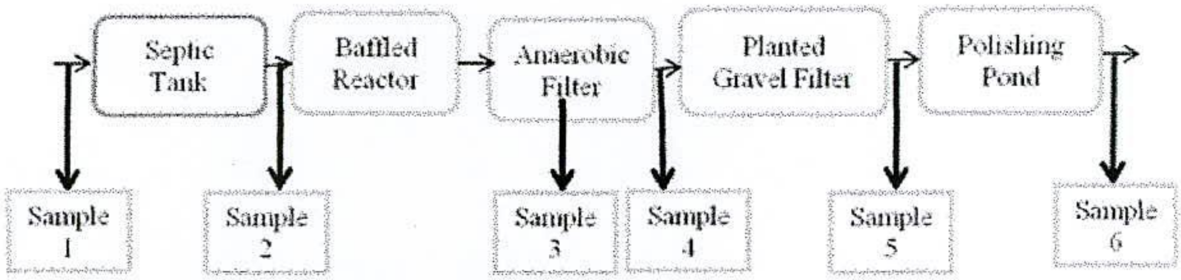

Figure 3.6: Flow diagram of DEWAT plant with indicating points of collected samples

3.6 Laboratory Experiments

The experiment was carried out in the Environmental Laboratory in KUET campus. The wastewater samples were characterized in terms of BOD, COD, DO, TSS, TDS, nitrate (NO_3^-), phosphate (PO_4^{3-}), FC, temperature, Oil and Grease and pH. Quality of collected wastewater samples was measured in order to find out removal efficiency. Target of this study is to improve effluent quality of DEWAT plant before discharge or reuse for other purposes.

Biological and chemical tests were conducted in lab employing Standard Methods for Water and Wastewater Analysis. BOD_5 and DO were determined by using membrane electrode DO meter (HACH, USA). For the determination of COD, closed reflux method using $K_2Cr_2O_7$ oxidizing agent was used. The determination of pH and Temperature were done by using electrodes (HACH, USA). For TDS and TSS in wastewater sample was determined at 105^0C using laboratory oven. For determination of Nitrate (NO_3^-) and phosphate (PO_4^{3-}), Nitrover and Phosver reagents were used [80]. For determination of Faecal Coliform (FC), Membrane Filter procedure was used. For determination of Oil and Grease Partition-Gravimatric method was used.

3.7 Analysis and Synthesis of the Experimental Findings

Almost analytical analysis use in this study is mentioned in the standard methods. Those parameters use to monitor DEWAT plants and check effective removal of experiment processes. Comparison of performance of existing two DEWAT plants is the second objective of this study. Various data were analyzed and the performances of the existing two DEWAT plants were compared with Recommended Values (Table 3.2).

Table 3.2: Recommended values of wastewater are usually allowed for irrigation purposes and disposal in water bodies.

Parameters	Irrigation purposes		Bangladesh Standard Limits for disposal in water bodies (ECR, 1997)
	Typical ranges	allowable ranges	
P^H	6.5 -8.5	-	6-8.5
BOD_5, mg/l	10 - 20	≤100	40
COD, mg/l	25 - 50	≤400	-
TSS, mg/l	10- 20	≤100	100
TDS, mg/l	-	-	2100
DO, mg/l	-	-	-
Total nitrogen, mg/l	10 - 20	-	-
Phosphorus, mg/l	2 -6	-	-
FC, (No./ 100ml)	≤200 /100ml		1000
Oil and Grease, mg/l	max 10		10
Temperature, ^{0}C	-		30
Phosphate, mg/l	-		35
Nitrate, mg/l	-		250

Identification of technical problems in existing DEWAT plants is the third objective of this study. Through the questionnaire survey and data analysis, technical problems in operation and maintenance of DEWAT plants were identified. Aesthetic view including surrounding environment of DEWAT plants was noted. Suitability of DEWAT plants was evaluated depending on user's recommendation. Natural decomposition of wastewater, low construction and maintenance cost, environmental condition, socio-economic acceptance, etc. are the key factors to be considered to propose modified design of DEWAT plant for its long-term sustainability.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

Results and Discussion

4.1 General

This chapter includes four parts. The first part is Data Analysis of the wastewater from existing two DEWAT plants at the Panchtola Colony in Khalishpur, Khulna. Secondly presents comparison of DEWAT plants. The third part is Identification Technical Problems in existing DEWAT Plants based on experimental results. The final goal is to recommend a modified DEWATS which will prevent the deteriorating health conditions, pollution of nearby water bodies and surrounding environment.

4.2 Field inspection of DEWAT plants

To get a broad view of community acceptance and management of the system, interviews were carried out with key stakeholders. The interviewees were local people, relevant stakeholders and authorities. This work gave few answers and evidences. Total 166 families were using the DEWAT plants. During the field inspection, the users were asked only how much money they spent when they had been suffering from diarrhea, cholera, hookworms etc. before implementation of DEWAT plants.

All interviewees are satisfy for DEWAT system and aware about worrying situation which was created before implementation of DEWAT system. So, they are frankly participate management of DEWAT system. Local peoples bore 10-15% of total fund of construction of DEWAT plant. They become more conscious about clean environment. Every family pays Tk. 40 per month for dumping their daily waste to the KCC dumping area.

However, the interviews of the president of social service development committee (Munshi Abdul wyadud), the secretary of social service development committee (Abdul Razzak Khan), the joint secretary of social service development committee (Sarder Ali Ahmed), the

Nabolok NGO staff (Sk Shaker Ahmed) provided useful information about the organization and the responsibilities of each about DEWAT management. Those activities are help to keep environment clean and hygienic. Detail questionnaire survey is shown in Appendix F.

4.3 Sampling Points at Different Parts of the DEWAT System

In this study, six sampling points of the two DEWAT plants and eleven experimental parameters were selected as stated by Nabolok with the assistance of Water Aid Bangladesh. Those points are in and outlet of settler tank, middle of anaerobic filter bed baffled reactor, outlet of anaerobic baffled reactor, planted gravel filter and polishing pond, shown in figure 3.6.

4.4 Data Analysis

The laboratory experiment to evaluate the changes of wastewater quality in order to judge the performance of the plants was started on February 2013 for the 1st DEWAT plant, while the second one was started in the same year of month June. Treatment results were calculated as a mean of all values measured throughout the observation period of two DEWAT plants. Wastewater samples of second DEWAT plant were collected few months after startup of the system, where DEWAT plant needs about three to six months for the growth of microbial biomass on the media to be developed. The laboratory results conducted on the wastewater collected at influent and effluent from the settler tank, anaerobic baffled reactor (ABR), planted gravel filter (PGF) and polishing pond (PP) while middle of anaerobic filter bed baffled reactor (AFBBR) of two DEWAT plants.

4.5 Performance of the 1st DEWAT plant

4.5.1 Variation of pH in 1st DEWAT plants

The laboratory test results of pH of the collected wastewater samples from the 1st DEWAT plant are presented in Figures 4.1. Based on Figure 4.1 the value of pH at influent of settler tank of 1st DEWAT plant was in the range of 6.62 to 7.23, but the value of pH at effluent of polishing pond was in the range of 6.81 to 7.13. The standard limit of pH for sewage disposal in water bodies (ECR, 1997) is 6-8.5. The results of pH between monitoring times of each location are not much different, they were around ±0.6. This variation was normal because pH is very sensitive to temperature and influent quality. Between locations, pH values is also considerably different, this is due to habit of the user.

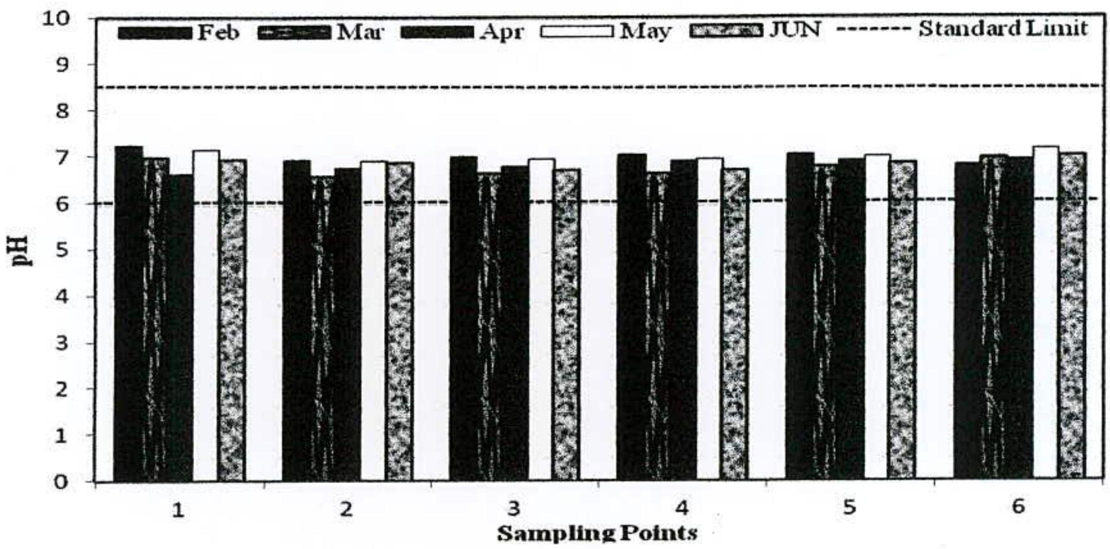

Figure 4.1: Variation of pH in 1st DEWAT plant

4.5.2 Variation of Temperature in 1st DEWAT plant

For 1st DEWAT plant, the recorded temperature at influent of settler tank varied from21.1°C to 26.3°C, but temperature at effluent of polishing pond varied from21.2°C to 26.1°C. It is close to 25°C. The laboratory test results of temperature of the collected wastewater samples from the 1st DEWAT plant are presented in Figures 4.2. The standard limit of temperature for sewage disposal in water bodies (ECR, 1997) is 30°C. The variation of temperature was relatively constant during the experiment. The aim of this test was to see the variation of temperature which can effect on the growth of microorganisms. The temperature has a great influence on the microbial metabolism, thereby affecting the oxidation rates for the carbonaceous and nitrogenous matters [81]. The relation between temperature and reaction coefficient can be expressed by the following equation [82]:

$$\mu_{maxT} = \mu_{max20} \cdot \Theta^{(T-20)}$$

Where

μ_{maxT} = maximum growth rate at a temperature T (d^{-1})

μ_{max20} = maximum growth rate at a standard temperature of 20°C T (d^{-1})

Θ = temperature coefficient (=1.07)

T= temperature of the medium (°C)

N.B: this equation is only valid in the temperature range from 4 to 30°C

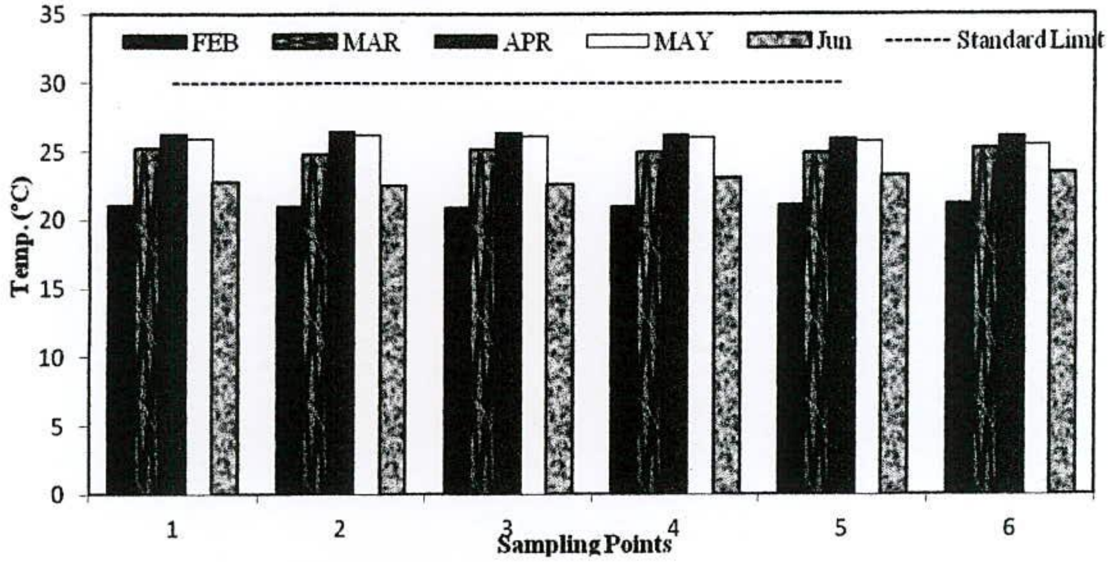

Figure 4.2: Variation of temperature in 1st DEWAT plant

4.5.3 Variation of BOD_5 of 1st DEWAT plant

BOD_5 is an essential parameter when evaluating effluent quality of a DEWAT plant. The results of BOD_5 of 1st DEWAT plant are described in Figure 4.3. In case of 1st DEWAT plant, BOD_5 values of treated wastewater samples in outlet of polishing pond were 34, 28.2, 38, 10.8 and 24mg/l throughout the observation periods. The DEWAT plant had brought BOD_5 levels down from 510 mg/l to less than 40 mg/l (Standard limit). From analysis of experimental result, it is found that high concentration of organic matter is skillfully decomposed when wastewater passed through the outlet of polishing pond.

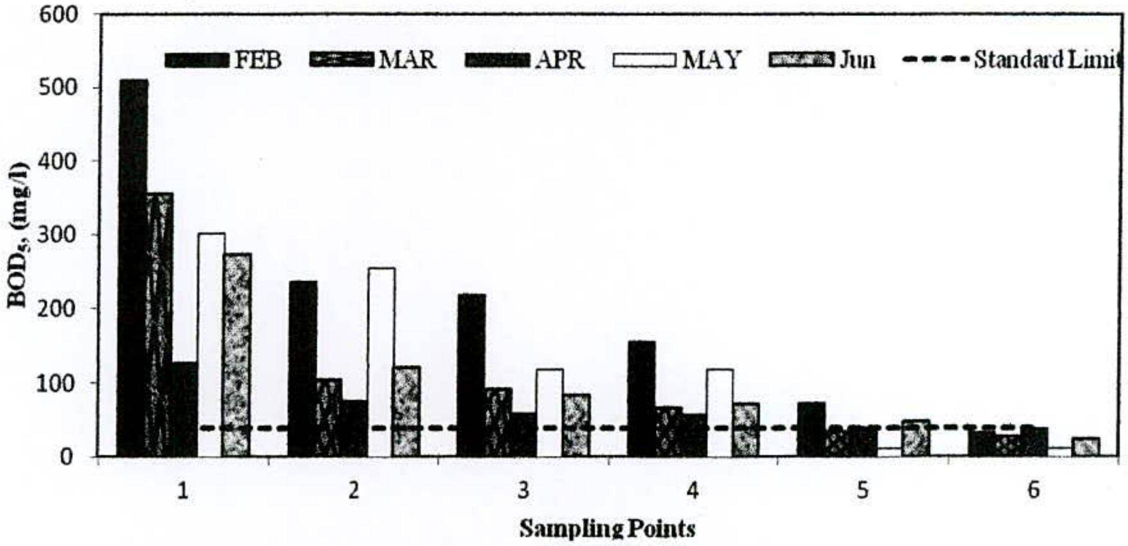

Figure 4.3: Variation of BOD_5 in 1st DEWAT plant

4.5.4 Variation of COD of 1st DEWAT plant

The COD monitoring results of 1st DEWAT plants were presented in Figure 4.4. The observed concentration of COD at influent varied between 8960 mg/L and 1820 mg/L for 1st DEWAT plant. This high concentration could be due to difference in quantity of water use. Since the wastewater percolated through the DEWAT plant there was considerable reduction of COD concentration. The mean removal efficiency for 1st DEWAT plants was 75%.

The difference occurred from DEWAT to DEWAT and between monitoring times. Some samples had wide range of COD, such as 1st DEWAT plant that could be affected by influent quality and suspended solids content.

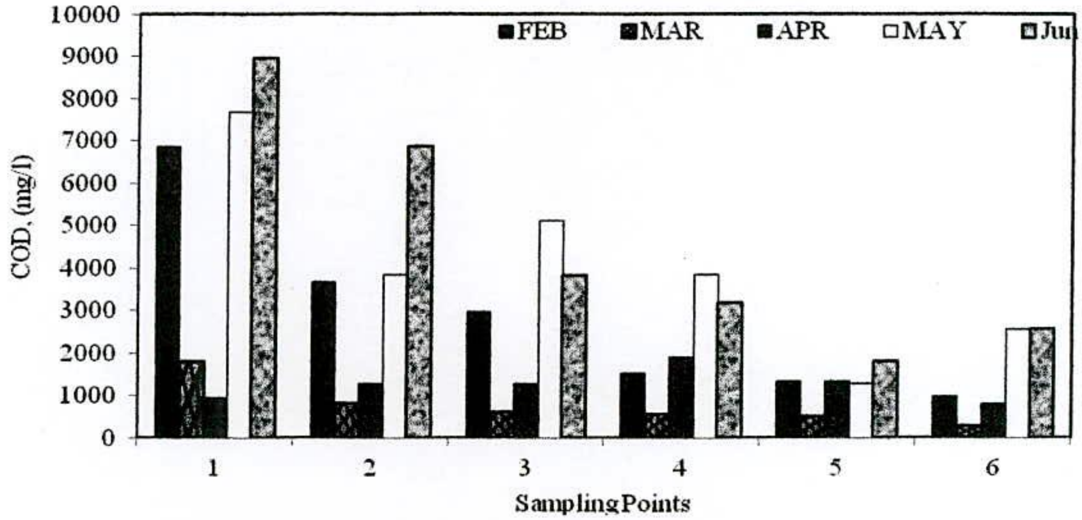

Figure 4.4: Variation of COD in 1st DEWAT plant

4.5.5 Variation of TSS of 1st DEWAT plant

Inside DEWAT plant, anaerobic and aerobic degradation of organic matter occurred and suspended solids were results of this process. Figure 4.5 depicts the results of TSS concentration in the monitored 1st DEWAT plants. As the wastewater flows through the DEWAT plant there was a significant drop (more than 95% removal) of suspended solids. TSS dropped from 2450 mg/l to 40 mg/L in the effluent of 1st DEWAT plant. It can be seen that the average effluent concentrations were below standard value (100 mg/l). After heavy rainfall or rapid snow melt, the effluent could be turbid [83]. Therefore, the high concentration of TSS could be due to the high rainfall leading to mixing of trapped solids from the adjacent area of DEWAT plant, and also due to the high concentration at the influent.

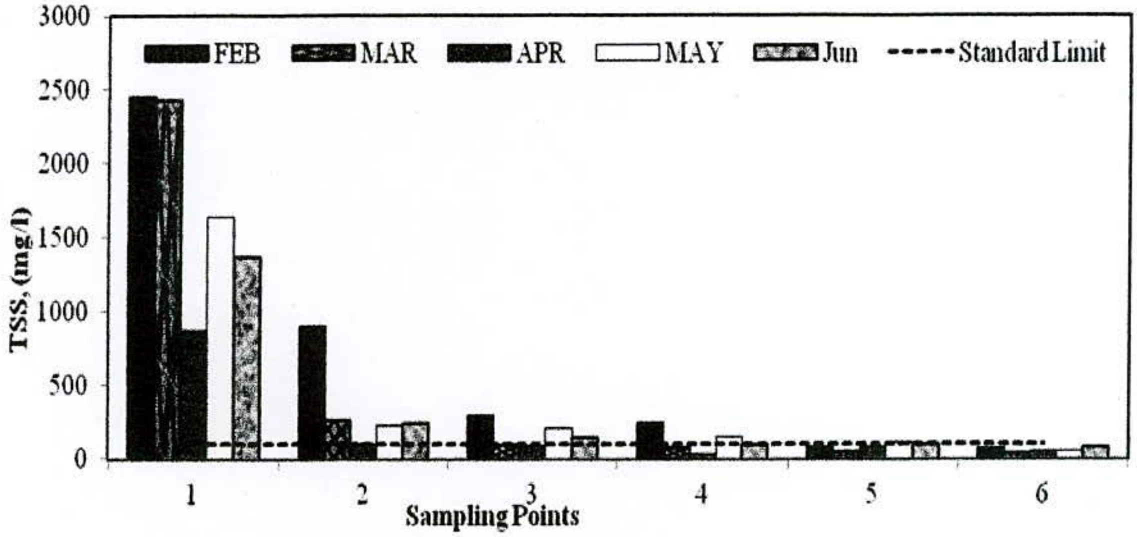

Figure 4.5: Variation of TSS in 1st DEWAT plant

4.5.6 Variation of TDS of 1st DEWAT plant

The laboratory test results of TDS of the collected wastewater samples from the 1st DEWAT plant are presented in Figures 4.6. During the monitoring period, the inlet TDS concentration of the 1st DEWAT plant varied between 1410mg/L and 4580 mg/L. The fluctuation in influent TDS concentration could be related to changes in the sewage characteristics due to the varying water use pattern. The value of TDS at effluent of polishing pond was in the range of 1020 mg/L to 1570 mg/L. It can be seen that the average effluent concentrations were below standard value (2100 mg/l).

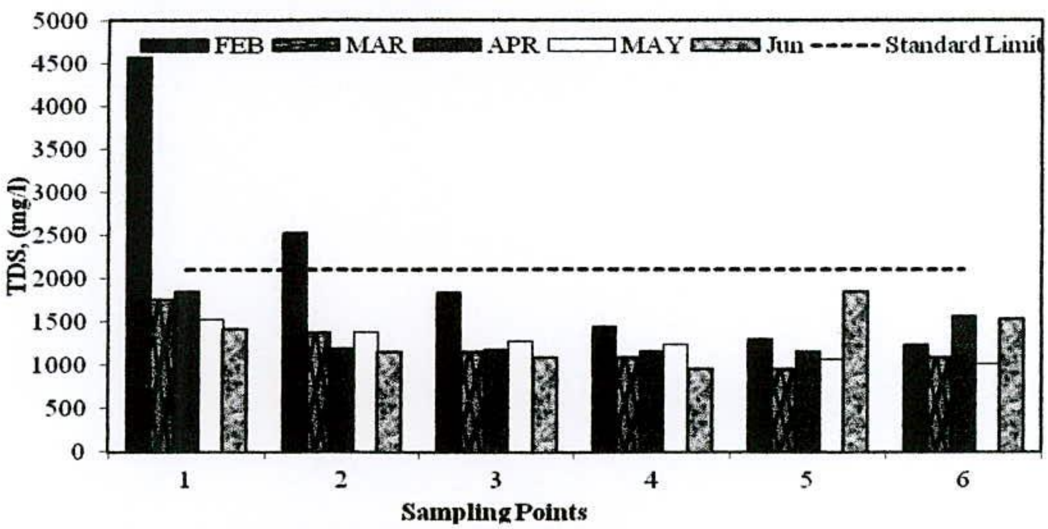

Figure 4.6: Variation of TDS in 1st DEWAT plant

4.5.7 Variation of FC of 1st DEWAT plant

The obtained test results of FC of the collected wastewater samples from the 1st DEWAT plant are presented in Figures 4.8. As seen in figure 4.7, the value of FC at influent of settler tank was in the range of 800/100ml to 2800/100ml. The concentrations of Faecal Coliform Bacteria increase in the anaerobic baffled reactor. When the wastewater got in touch with activated sludge, anaerobic bacteria decomposed organic matters and produced methane gas and new microorganisms. The growth of new cells is at its maximum when the concentration of substrates is higher. For this reason, the values of FC were increased than raw sewage in the anaerobic baffled reactor. Then, the growth of new cells will be constant as the concentration of substrates gradually decreases. At the end of anaerobic process a decrease of substrate concentration will be noticed as shown in figure.

As the wastewater flows through the planted gravel filter there was a significant drop. The values of FC at effluent of polishing pond were less than 1000/100ml (standard limit) except the April month value. Oxygen will be consumed during aerobic process, which explains the decrease of FC concentration. The activity of microorganisms is higher at high concentration of substrates and the activity decreases when the available oxygen had been consumed. Thus it can be concluded that the 1st DEWAT plant is a promising solution for the treatment of bacteria.

The values of FC show very large variance between each measuring throughout the treatment process. The influent values are also very varying. It is partly the reason for the large variations in effluent values. Thus it can be concluded that the 1st DEWAT plant is a promising solution for the treatment of bacteria. Another reason is filter media. Main removal mechanisms will be occurred by filtration especially in the sections where biofilm is well developed.

As inflow wastewater is sometimes diverted due to blockage of filter media of DEWAT plant will sometimes not receive flow. This might harm the biofilm in the DEWAT plant, and the following treatment will show lower removal rates of Faecal Coliform bacteria.

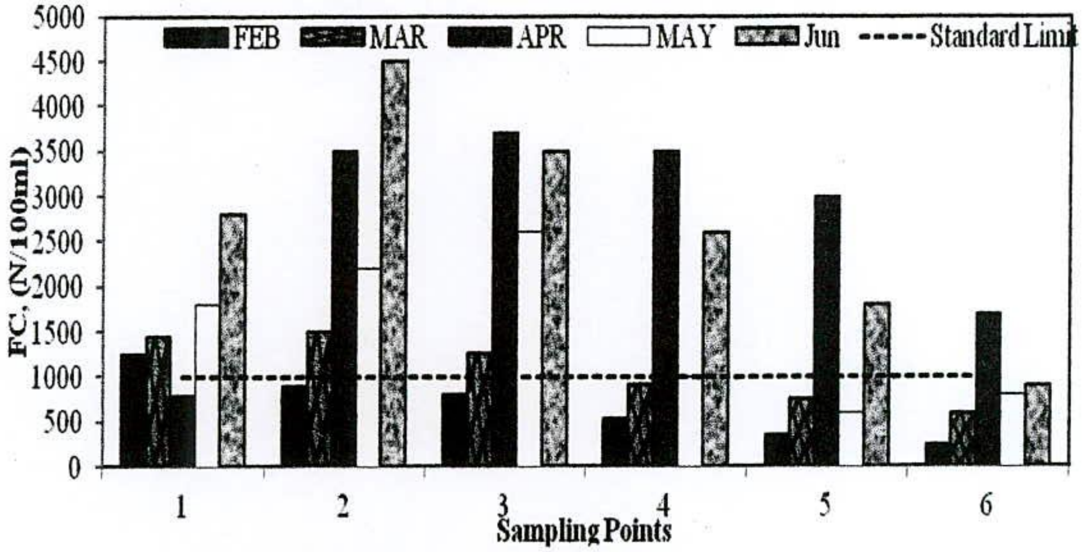

Figure 4.7: Variation of FC in 1st DEWAT plant

4.5.8 Variation of DO of 1st DEWAT plant

Normally, DO was measured immediately after samples taken in the lab. The results of DO in Figure 4.8 shown that influent of septic tank are lower than 0.5 mg/L. This is due to the anaerobic condition and high concentration of organic matter. DO values were increased when wastewater passed through the planted gravel filter and polishing pond. Mean influent concentration 0.8 mg/L increased to 1.5 mg/L at the effluent of 1st DEWAT plant. The high concentration of oxygen at the effluents could be due to the fact that the planted gravel filter and polishing pond are aerobic units. Oxygen is transferred from the atmosphere to the Root Zone of the plant in planted gravel filter. Polishing pond is also fully exposed in the air. The values of DO were increasing which indicate that the oxygen level was increased in treated wastewater samples. So the treated wastewater can be discharged into the natural water bodies or used for irrigation purposes.

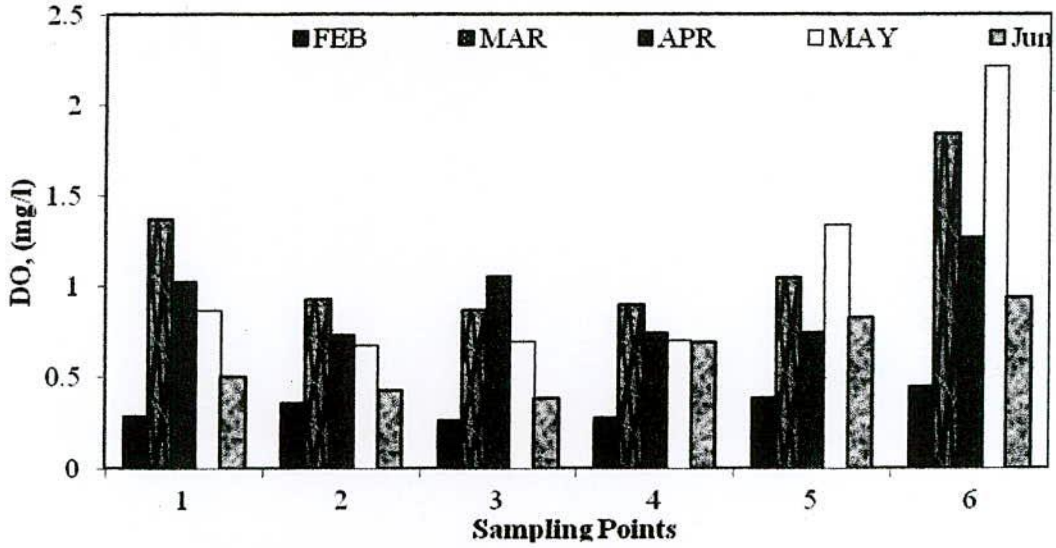

Figure 4.8: Variation of DO in 1st DEWAT plant

4.5.9 Variation of Phosphate of 1st DEWAT plant

Phosphorus can occur in wastewater and natural waters in the form of phosphates such as orthophosphates, condensed phosphates and organically bound phosphates, and can be found in either particulate form or in solution [84]. Organic phosphorus will be present in the wastewater as residues of food and human waste, while inorganic phosphorus may originate from cleaning products [84].

Phosphate is dropped significantly throughout the process as shown in figure 4.9. For 1st DEWAT plants, mean influent and effluent concentration of Phosphate were 52.75 mg/L and 22.5 mg/L respectively. It can be seen that the average effluent concentrations were below standard value (35 mg/l). Effluent concentration was strongly dependent on the influent concentration. Phosphate is mainly removed in the anaerobic baffled reactor, and increases slightly again in the planted gravel filter according to Figure 4.9. This rise is also not significant. The largest removal happens in the polishing pond. The media needs to be selected specifically for Phosphate removal in order to achieve high removal rate. The media of the planted gravel filter consists of brick khoa and sand that are not expected to have high Phosphate sorption capacity. However it is expected that some is taken up by plants, which are later removed. This would give a permanent removal but only a small amount is removed in this way.

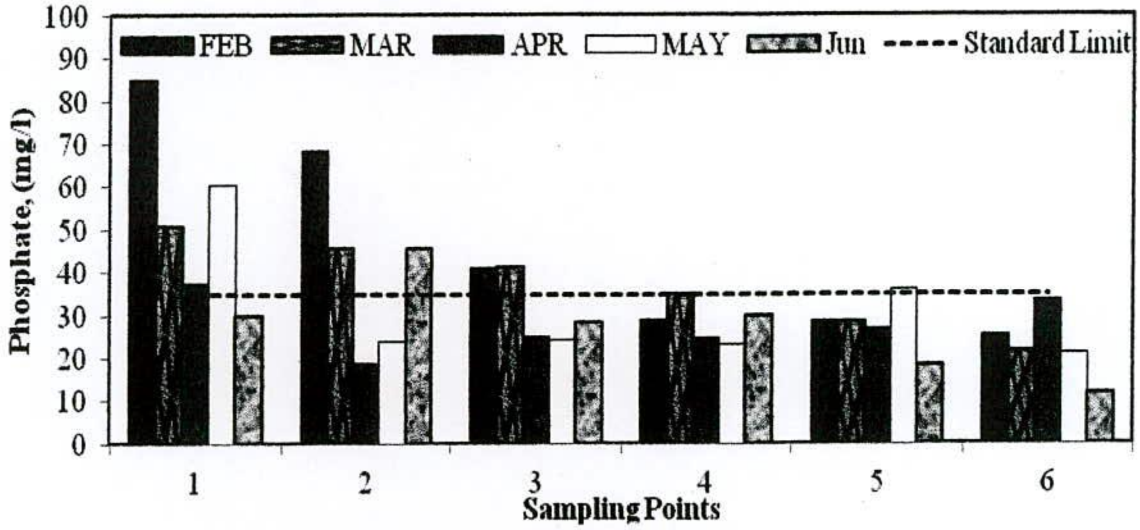

Figure 4.9: Variation of Phosphate in 1st DEWAT plant

4.5.10 Variation of Nitrate of 1st DEWAT plant

The laboratory test results of nitrate of the collected wastewater samples from the 1st DEWAT plant are presented in Figures 4.10. Based on Figure 4.10 the value of nitrate at influent of settler tank of 1st DEWAT plant was in the range of 18 mg/L to 46 mg/L, but the value of Nitrate at effluent of polishing pond was in the range of 4mg/L to 24 mg/L. It can be seen that the average effluent concentrations were below standard value (250mg/l). Effluent concentration was strongly dependent on the influent concentration. Due to the anaerobic nature of the influent wastewater, nitrate concentration was expected to be low. After passing the wastewater through the planted gravel filter, due to nitrification of NH4 -N, the NO3-N concentration increased its mean low removal rate of nitrate.

Discharging nitrogen to surface and ground waters is undesirable for several reasons; it can lead to eutrophication, it can be toxic to fish and other aquatic life, nitrate and nitrite may reduce quality of drinking resources, and ammonia may deplete oxygen levels through nitrification [84].

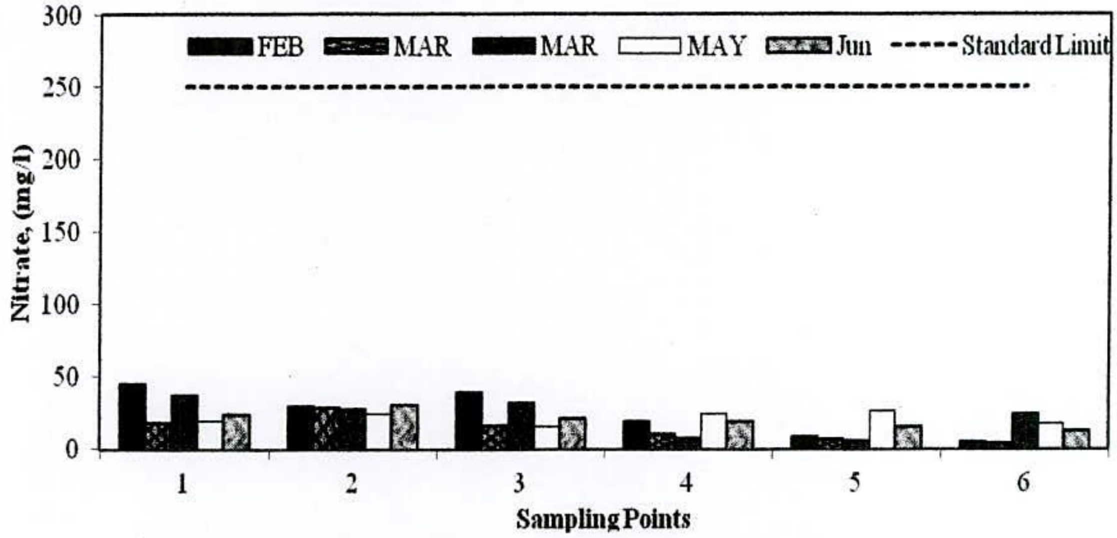

Figure 4.10: Variation of Nitrate in 1st DEWAT plant

4.6 Performance of the 2nd DEWAT plant

4.6.1 Variation of pH in 2nd DEWAT plants

The laboratory test results of pH of the collected wastewater samples from the 2nd DEWAT plant are presented in Figures 4.11. Based on Figure 4.11 the value of pH at influent of settler tank of 2nd DEWAT plant was in the range of 6.84 to 7.35, but the value of pH at effluent of polishing pond was in the range of 6.87 to 7.31. The standard limit of pH for sewage disposal in water bodies (ECR, 1997) is 6-8.5. The results of pH between monitoring times of each location are not much different, they were around ±0.6. This variation was normal because pH is very sensitive to temperature and influent quality. Between locations, pH values is also considerably different, this is due to habit of the user.

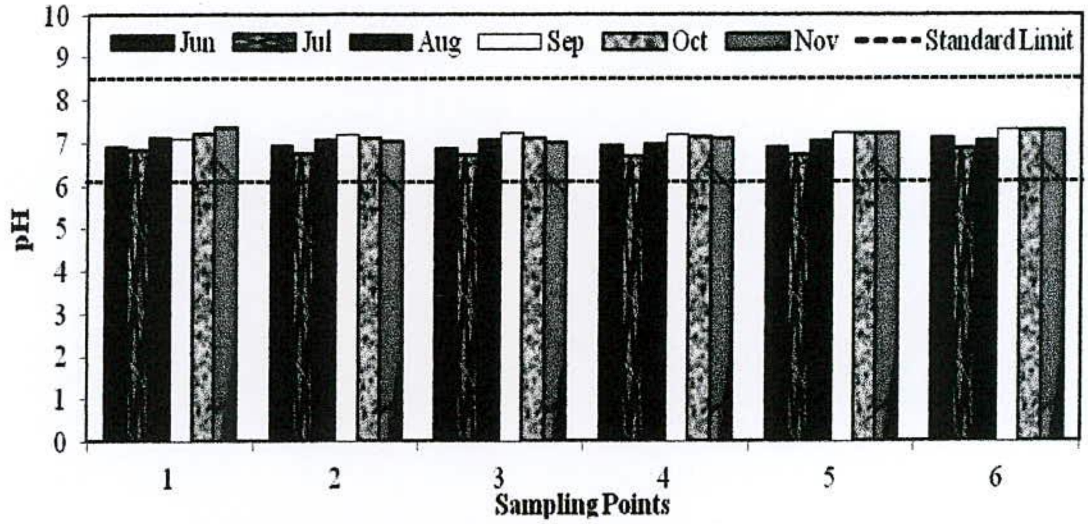

Figure 4.11: Variation of pH in 2nd DEWAT plant

4.6.2 Variation of Temperature in 2nd DEWAT plants

For 2nd DEWAT plant, the recorded temperature at influent of settler tank varied from 23°C to 28°C, but temperature at effluent of polishing pond varied from 23°C to 27.6°C. It is close to 30°C. The laboratory test results of temperature of the collected wastewater samples from the 2nd DEWAT plants are presented in Figures 4.12. The standard limit of temperature for sewage disposal in water bodies (ECR, 1997) is 30°C. The variation of temperature was relatively constant during the experiment. The aim of this test was to see the variation of temperature which can effect on the growth of microorganisms. The temperature has a great influence on the microbial metabolism, thereby affecting the oxidation rates for the carbonaceous and nitrogenous matters [81]. The relation between temperature and reaction coefficient can be expressed by the following equation [82]:

$$\mu_{maxT} = \mu_{max20} \cdot \Theta^{(T-20)}$$

Where

μ_{maxT} = maximum growth rate at a temperature T (d^{-1})

μ_{max20} = maximum growth rate at a standard temperature of 20°C T (d^{-1})

Θ = temperature coefficient (=1.07)

T= temperature of the medium (°C)

N.B: this equation is only valid in the temperature range from 4 to 30°C

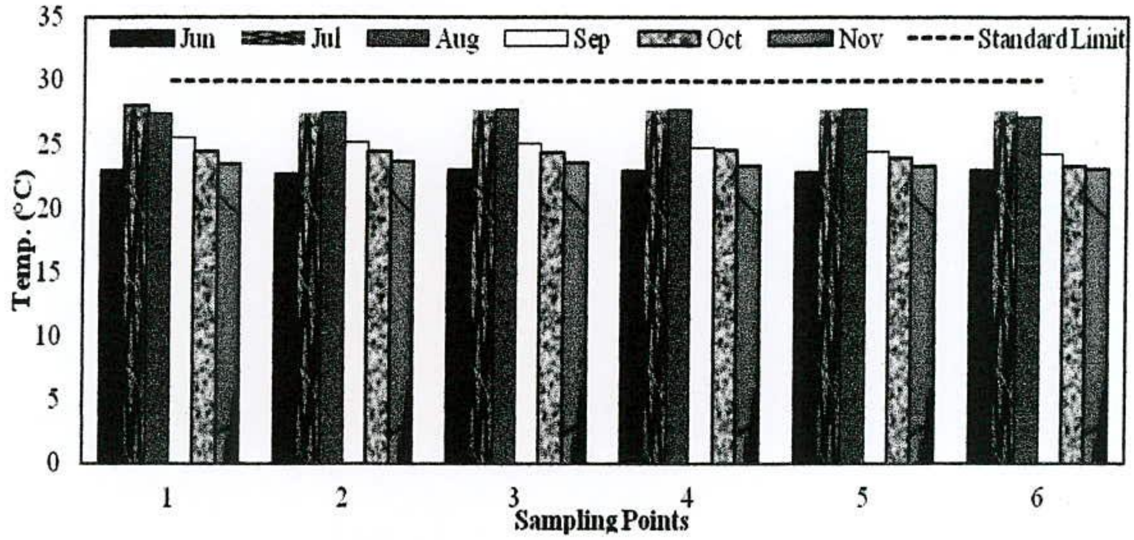

Figure 4.12: Variation of temperature in 2nd DEWAT plant

4.6.3 Variation of BOD_5 of 2nd DEWAT plant

BOD is an essential parameter when evaluating effluent quality of a DEWAT plant. The results of BOD of 2nd DEWAT plants are described in Figure 4.13. For 2nd DEWAT plant, BOD_5 values were 16.8, 14.8, 36.6, 31.6, 31 and 30.4 mg/l throughout the observation periods when wastewater passed through the outlet of polishing pond. This result indicates that 2nd DEWAT plant had brought BOD_5 levels down from 280 mg/l to less than 40 mg/l (Standard limit). From analysis of experimental result, it is found that high concentration of organic matter is skillfully decomposed when wastewater passed through the outlet of polishing pond.

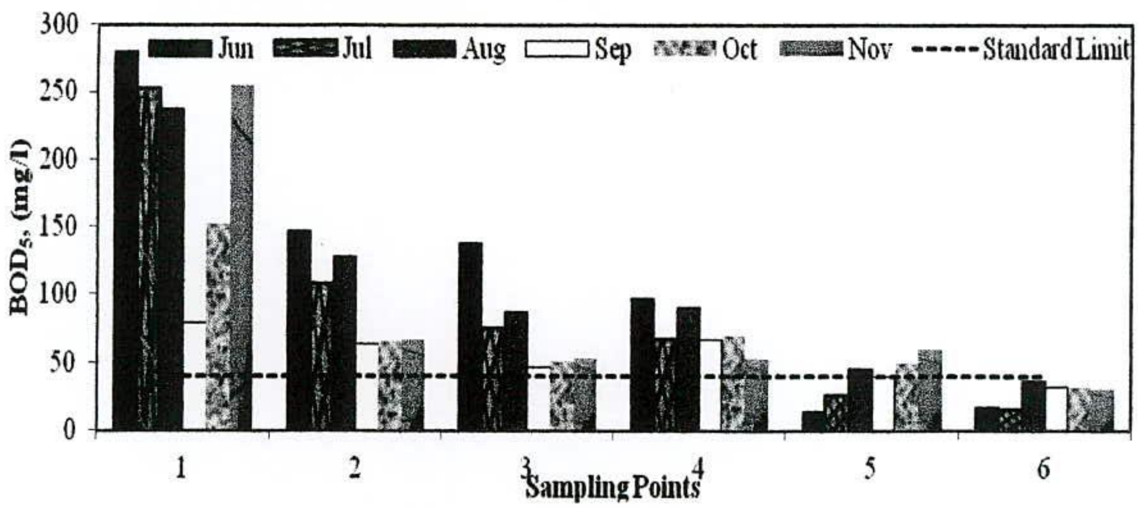

Figure 4.13: Variation of BOD_5 in 2nd DEWAT plant

4.6.4 Variation of COD of 2nd DEWAT plant

The COD monitoring result of 2nd DEWAT plants were presented in Figure 4.14. The observed concentration of COD at influent varied between 11520 mg/L and 3840mg/L for 2nd DEWAT plant. This high concentration could be due to difference in quantity of water use. Since the wastewater percolated through the DEWAT plant there was considerable reduction of COD concentration. The mean removal efficiency for 2nd DEWAT plants was 60%.

The difference occurred from DEWAT to DEWAT and between monitoring times. Some samples had wide range of COD, such as 2nd DEWAT plant that could be affected by influent quality and suspended solids content.

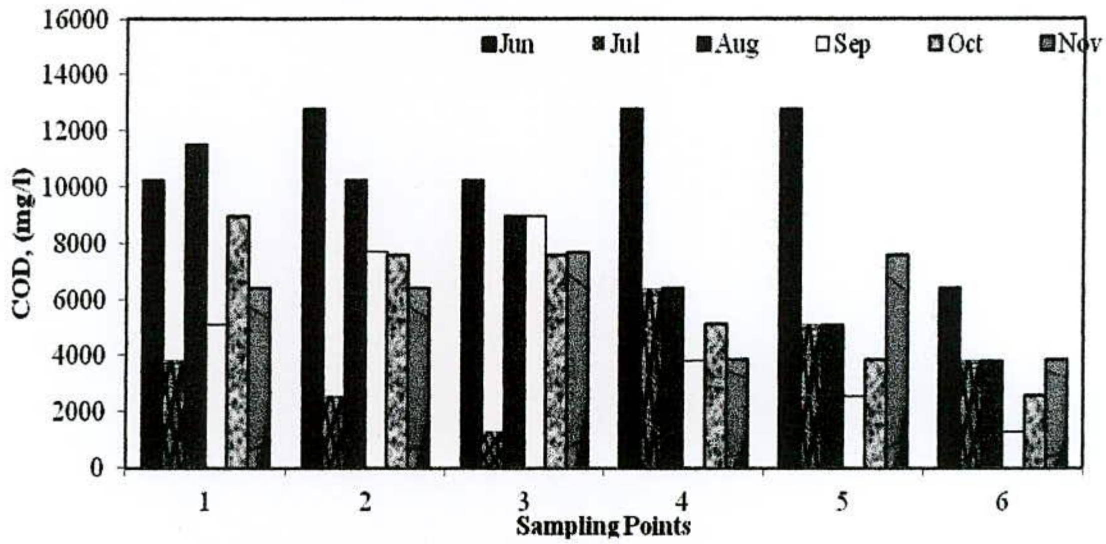

Figure 4.14: Variation of COD in 2nd DEWAT plant

4.6.5 Variation of TSS of 2nd DEWAT plant

Inside DEWAT plant, anaerobic and aerobic degradation of organic matter occurred and suspended solids were results of this process. Figure 4.15 depicts the results of TSS concentration in the monitored DEWAT plants. As the wastewater flows through the DEWAT plants there was a significant drop (more than 95% removal) of suspended solids in the 2nd DEWAT plants. TSS dropped from 1310 mg/L to 20 mg/L in the effluent of 2nd DEWAT plant. It can be seen that the average effluent concentrations were below standard value (100 mg/l). After heavy rainfall or rapid snow melt, the effluent could be turbid [83].

Therefore, the high concentration of TSS could be due to the high rainfall leading to mixing of trapped solids from the adjacent area of DEWAT plant, and also due to the high concentration at the influent.

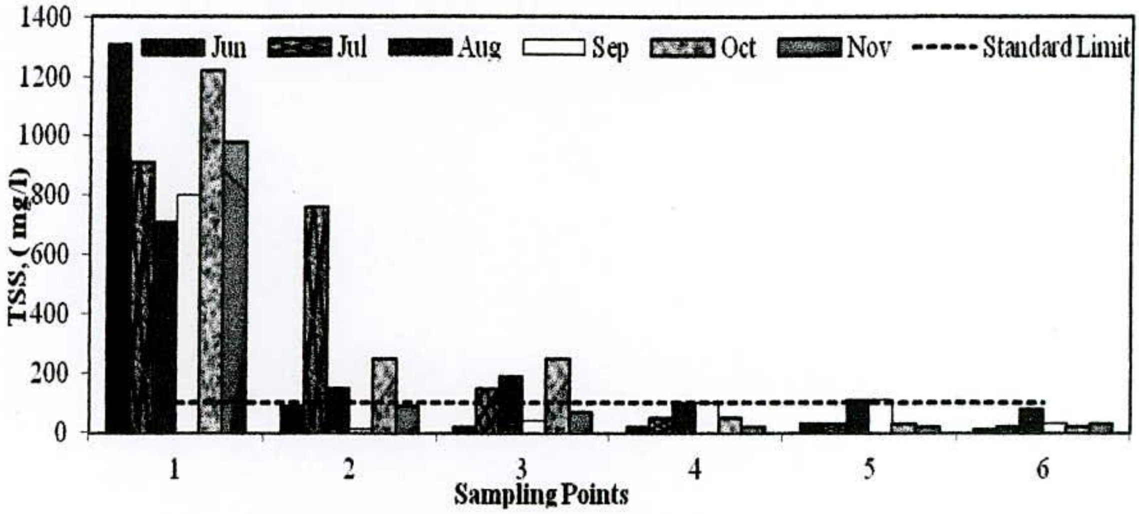

Figure 4.15: Variation of TSS in 2nd DEWAT plant

4.6.6 Variation of TDS of 2nd DEWAT plant

The laboratory test results of TDS of the collected wastewater samples from the 2nd DEWAT plant are presented in Figures 4.16. During the monitoring period, the inlet TDS concentration of the 2nd DEWAT plant varied between 1070mg/L and 1670 mg/L. The fluctuation in influent TDS concentration could be related to changes in the sewage characteristics due to the varying water use pattern. The value of TDS at effluent of polishing pond was in the range of 1020 mg/L to 1810 mg/L. It can be seen that the average effluent concentrations were below standard value (2100 mg/l).

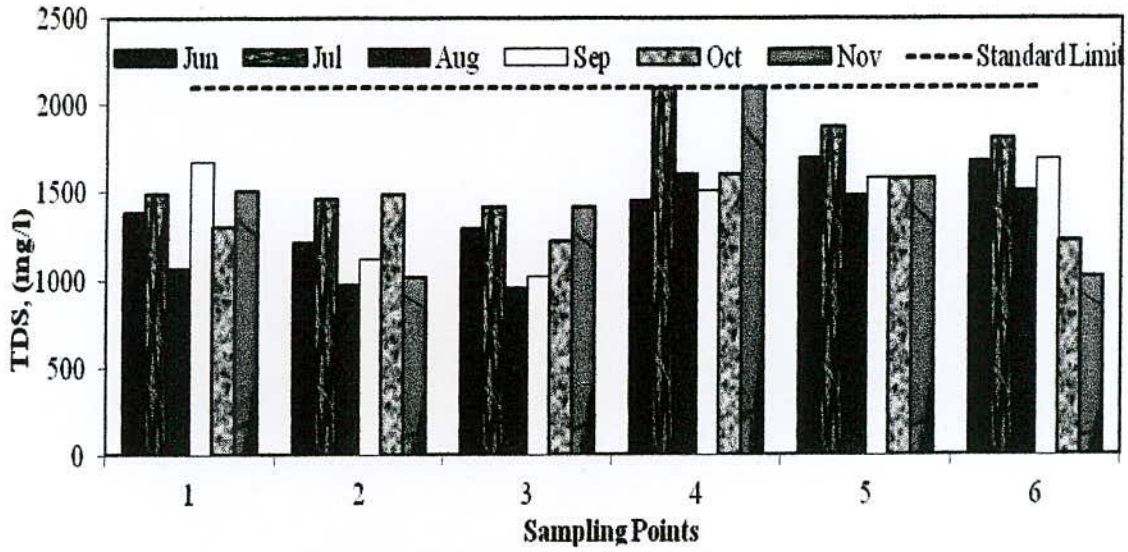

Figure 4.16: Variation of TDS in 2nd DEWAT plant

4.6.7 Variation of FC of 2nd DEWAT plant

The obtained test results of FC of the collected wastewater samples from the 2nd DEWAT plant are presented in Figures 4.17. As seen in figure 4.17, the value of FC at influent of settler tank was in the range of 4800/100ml to 22500/100ml. The concentrations of Faecal Coliform Bacteria increase in the anaerobic baffled reactor. When the wastewater got in touch with activated sludge, anaerobic bacteria decomposed organic matters and produced methane gas and new microorganisms. The growth of new cells is at its maximum when the concentration of substrates is higher. For this reason, the values of FC were increased than raw sewage in the anaerobic baffled reactor. Then, the growth of new cells will be constant as the concentration of substrates gradually decreases. At the end of anaerobic process a decrease of substrate concentration will be noticed as shown in figure 4.17 except June month value.

As the wastewater flows through the planted gravel filter there was a significant drop. Oxygen will be consumed during aerobic process, which explains the decrease of FC concentration. The activity of microorganisms is higher at high concentration of substrates and the activity decreases when the available oxygen had been consumed. The value of FC at effluent of polishing pond was in the range of 5000 /100ml to 18000 /100ml.

The values of FC show very large variance between each measuring throughout the treatment process. The influent values are also very varying. It is partly the reason for the large variations in effluent values. Another reason is filter media. Main removal mechanisms will be occurred by filtration especially in the sections where biofilm is well developed.

As inflow wastewater is sometimes diverted due to blockage of filter media of DEWAT plant will sometimes not receive flow. This might harm the biofilm in the DEWAT plant, and the following treatment will show lower removal rates of Faecal Coliform bacteria.

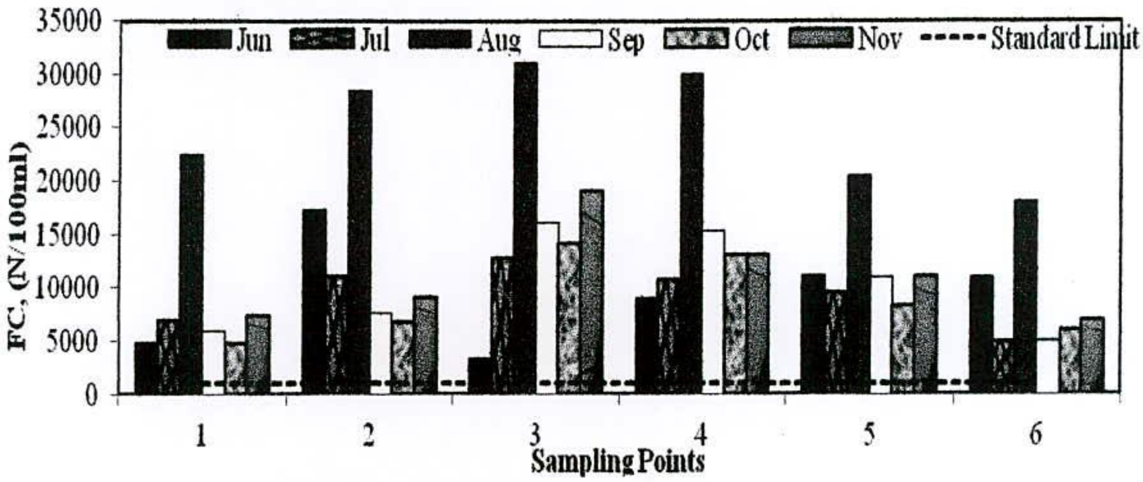

Figure 4.17: Variation of FC in 2[nd] DEWAT plant

4.6.8 Variation of DO of 2nd DEWAT plant

Normally, DO was measured immediately after samples taken in the lab. The results of DO in Figure 4.18 shown that influent of septic tank are lower than 0.9 mg/L. This is due to the anaerobic condition and high concentration of organic matter. DO values were increased when wastewater passed through the planted gravel filter and polishing pond. Mean influent concentration 0.50 mg/L increased to 3.30 mg/L at the effluent of 2[nd] DEWAT plant. The high concentration of oxygen at the effluents could be due to the fact that the planted gravel filter and polishing pond are aerobic units. Oxygen is transferred from the atmosphere to the Root Zone of the plant in planted gravel filter. Polishing pond is also fully exposed in the air. The values of DO were increasing which indicate that the oxygen level was increased in treated wastewater samples. So the treated wastewater can be discharged into the natural water bodies or used for irrigation purposes.

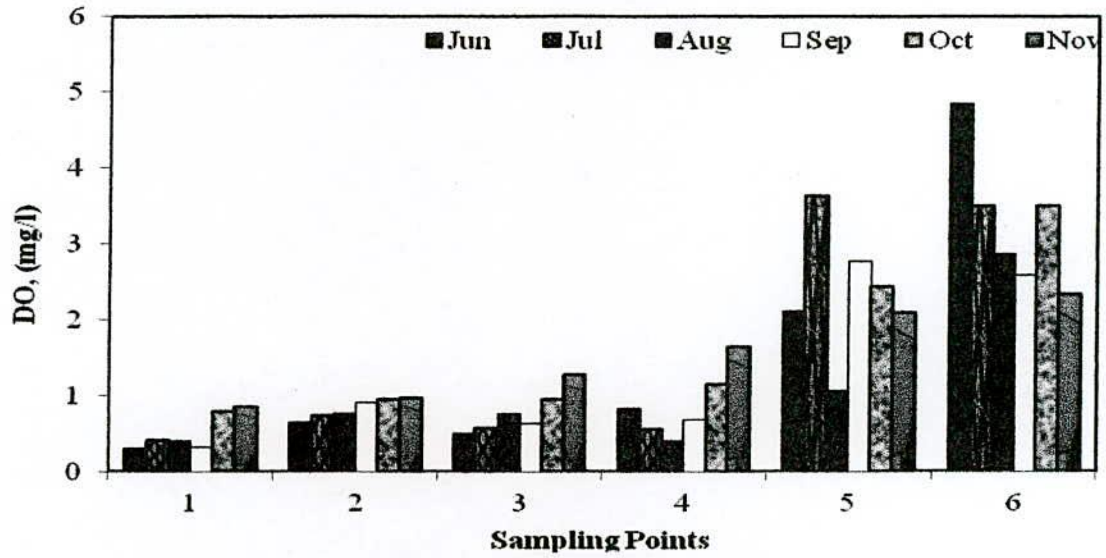

Figure 4.18: Variation of DO in 2nd DEWAT plant

4.6.9 Variation of Phosphate of 2nd DEWAT plant

Phosphorus can occur in wastewater and natural waters in the form of phosphates such as orthophosphates, condensed phosphates and organically bound phosphates, and can be found in either particulate form or in solution [84]. Organic phosphorus will be present in the wastewater as residues of food and human waste, while inorganic phosphorus may originate from cleaning products [84].

Phosphate is dropped significantly throughout the process as shown in figure 4.19. For 2nd DEWAT plants, mean influent and effluent concentration of Phosphate were 23 mg/L and 16.5 mg/L respectively. It can be seen that the average effluent concentrations were below standard value (35 mg/l). Effluent concentration was strongly dependent on the influent concentration. Phosphate increases slightly in the anaerobic baffled reactor and decreases in planted gravel filter according to Figure 4.19. The largest removal happens in the polishing pond. The media needs to be selected specifically for Phosphate removal in order to achieve high removal rate. The media of the planted gravel filter consists of only broken stone that are expected to have Phosphate sorption capacity. However it is expected that some is taken up by plants, which are later removed. This would give a permanent removal but only a small amount is removed in this way.

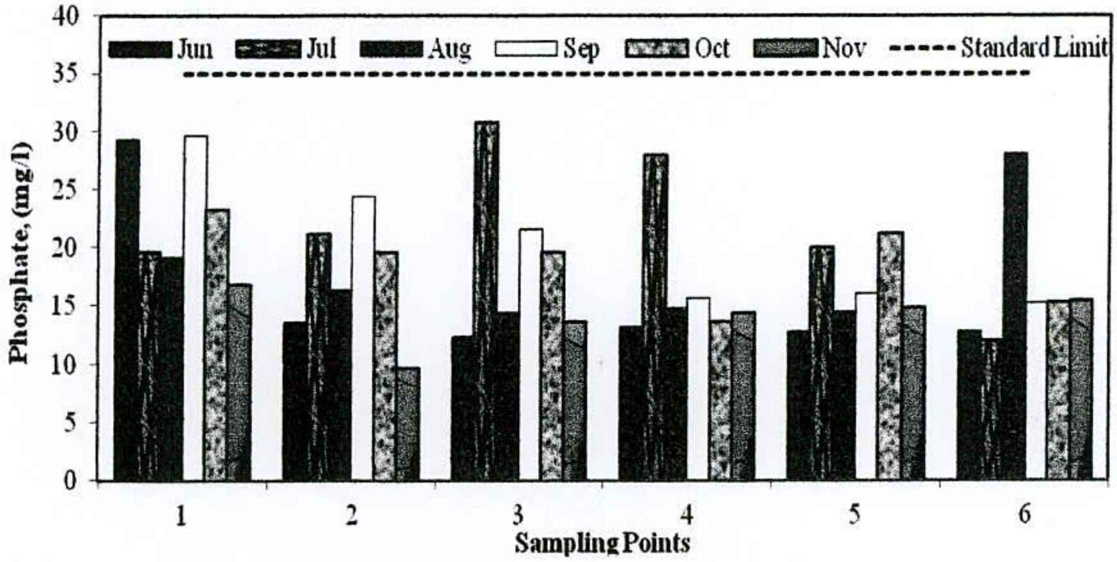

Figure 4.19: Variation of Phosphate in 2nd DEWAT plant

4.6.10 Variation of Nitrate of 2nd DEWAT plant

The laboratory test results of nitrate of the collected wastewater samples from the 2nd DEWAT plant are presented in Figures 4.20. Based on Figure 4.20 the value of nitrate at influent of settler tank of 2nd DEWAT plant was in the range of 4 mg/L to 36 mg/L, but the value of Nitrate at effluent of polishing pond was in the range of 0 mg/L to 16 mg/L. It can be seen that the average effluent concentrations were below standard value (250mg/l). Effluent concentration was strongly dependent on the influent concentration. Due to the anaerobic nature of the influent wastewater, nitrate concentration was expected to be low. After passing the wastewater through the planted gravel filter, due to nitrification of NH4 -N, the NO3-N concentration increased its mean low removal rate of nitrate.

Discharging nitrogen to surface and ground waters is undesirable for several reasons; it can lead to eutrophication, it can be toxic to fish and other aquatic life, nitrate and nitrite may reduce quality of drinking resources, and ammonia may deplete oxygen levels through nitrification [84].

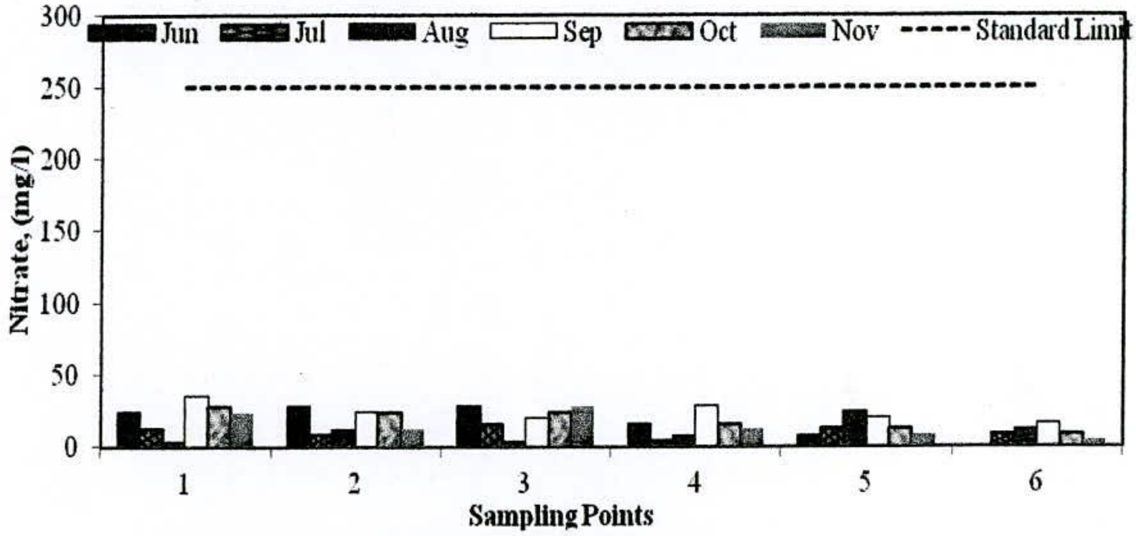

Figure 4.20: Variation of Nitrate in 2nd DEWAT plant

4.7 Comparison of 1st and 2nd DEWAT plants

Concentration based removal efficiencies of the pollutants from the 1st and 2nd DEWAT plants were compared with each other and standard values for domestic wastewater treatment.

4.7.1 Removal efficiency of the 1st and 2nd DEWAT plant

The Table 4.1 and Table 4.2 show the removal efficiency of different parts of 1st and 2nd DEWAT plants respectively. The results in the Table 4.3 and Table 4.4 show overall removal efficiency of 1st and 2nd DEWAT plants respectively. The Table 4.5 shows the comparison of removal efficiency between 1st and 2nd DEWAT plants

The average pH values were found 6.97 and 7.09 at effluent points of 1st and 2nd DEWAT plants respectively (Table 4.6). Two DEWAT plants' effluents had pH value within the standard limit (6 – 8.5) i.e. the treated wastewater is neither highly alkaline nor highly acidic. High pH reduces fish production [85] and also inhibits the growth of aquatic macrophytes [86]. Again low pH can destroy the fish population accompanied by decrease in the variety of species in food chain [87]. pH of all treated wastewater samples are also within acceptable limit of irrigation water quality.

It was observed from the result (Table 4.6) that the average temperature values were 23.65°C to 25.3°C at effluent points of 1st and 2nd DEWAT plants respectively. Effluents from both DEWAT plants had temperatures within the standard limit (30°C). Higher temperature is harmful for aquatic life. If water temperatures vary too much, metabolic activities of aquatic life can malfunction [89]. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria in a water body [88].

The average values of BOD_5 were found 30.4 mg/l and 25.7 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Effluents from two DEWAT plants had BOD value within the standard limit (40 mg/l). Excessive BOD is harmful to aquatic animals like fish and microorganisms. It also causes bad taste to the drinking water [89]. If the BOD level is too high, the water could be at risk for further contamination interfering with the treatment process and affecting the end product [90].

The average values of COD were found 1740 mg/l and 3840 mg/l at effluent points of 1st and 2nd DEWAT plants respectively (Table 4.6). Both DEWAT plants' effluents had high COD value. Higher COD concentration can cause a substantial damage to submersed plants. Like BOD, higher COD is also harmful to all aquatic life [91].

The average values of TSS were found 96 mg/l and 45 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Effluents from two DEWAT plants had TSS values within the standard limit (100 mg/l). High TSS reduces light penetration and hence decreases photosynthetic rates of green aquatic macrophytes, algae and cells which are served as food sources for many invertebrates [92].

The average values of TDS were found 1295 mg/l and 1415 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Both plants' effluents had TDS within the standard limit (2100 mg/l). TDS is important to be considered in the calculation of irrigation water quality, because many of the toxic solid materials may be imbedded in the water, which may cause harm to the plants [93]. In terms of 'Degree of restrictions on use', TDS values <450, 450-2000 and >2000 mg/l represent the irrigation water as 'none', 'slight to moderate' and 'severe', respectively [94]. According to this standard, the treated wastewaters for both plants are classified as slight to moderate. Water having high TDS values can cause osmotic stress at the root zone of plants which makes it more difficult for a plant to absorb water for growth. Thus increased TDS in irrigation water leads to lower crops production [95].

The average values of Faecal Coliform (FC) were found 1275/100ml and 11500/100ml at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Effluents from the 2nd DEWAT plant had FC higher than the 1st DEWAT plant.

The average values of DO were found 1.33 mg/l and 3.59 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Both plants' effluents were found to have DO values lower than that of standard limit (4.5-8 mg/l). The lower DO may be due to the use of anaerobic reactor in the DEWAT plants and contained more organic matter in raw wastewater. The decay of organic compounds consumes much oxygen and leads to the decrease in DO level [96]. Low concentration of DO may impact adversely on all aquatic life. As DO levels in water drop below 4 mg/l, aquatic life is put under stress [89]. Oxygen levels that remain below 1-2 mgL-1 for a few hours can result in large fish kills [97].

The average values of Phosphate were found 22.51 mg/l and 20 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Effluents from both DEWAT plants had phosphate concentration within the standard limit (35 mg L-1). Over enrichment of phosphate can lead to algae bloom, because of the excess nutrients. This causes more algae to grow, bacteria consumes the algae and causes more bacteria to grow in large amounts [89]. They use all the oxygen in the water during cellular respiration, causing many fish to die [98]. Again water with high phosphate content may lead to kidney damage and osteoporosis in human health [99].

The average values of nitrate were found 22.51 mg/l and 20 mg/l at effluent points of 1st and 2nd DEWAT plants respectively as shown in Table 4.6. Effluents from both DEWAT plants had lower nitrate values than the standard limit (250 mg/l).

The values of Oil and Grease were zero for all collected wastewater samples from 1st and 2nd DEWAT plants. Large amounts of oil and grease into the water bodies increase the BOD while also causing foul odors by trapping plants and garbage and subsequently flies and mosquitoes are attracted to this type of water causing diseases. Oil will form a layer on the surface of water and may inhibit sunlight through it and a decrease in the dissolved oxygen [100]. This will eventually affect the receiving water bodies and aquatic life within it [101].

4.7.2 1st DEWAT plant

From the Table 4.6, the results indicated that pH, BOD_5, TSS, TDS, Oil and Grease, Temperature, Phosphate and Nitrate are within standard limit. DO value also increases in the effluent of 1st DEWAT plant. Removal of COD of 1st DEWAT plant could not meet standard value. For COD, the high difference was observed in the influent and effluent. Though the value of FC value was slightly higher than standard value, treated wastewater is allowable to use as irrigation purposes or reuse or discharge to environment.

4.7.3 2nd DEWAT plant

From the Table 4.6, the results indicated that pH, BOD_5, TSS, TDS, Oil and Grease, Temperature, Phosphate and Nitrate are also within standard limit. DO value also increases up 4 mg/L in the effluent which indicates that treated wastewater is allowable to mix with natural stream. Removal of COD and FC of 1st DEWAT plant could not meet standard value. For COD, the high difference was observed in the influent and effluent. FC value was extremely higher than standard value. This high concentration could be due to difference in filter media and lower growth of microorganism.

Table 4.1: Removal efficiency of different parts in the 1st DEWAT plant

Parameters	Influent quality of septic tank	% Removal efficiency of Septic tank		% Removal efficiency of ABR		% Removal efficiency of planted gravel filter		% Removal efficiency of polishing pond	
	Range	Range	Average	Range	Average	Range	Average	Range	Average
BOD_5	128-510 mg/l	15.00-70.70	42.85	24.41-53.91	39.16	30.56-90.51	60.54	3.50-53.42	28.46
COD	960-8960 mg/l	23.21-54.95	39.08	31.71-57.99	44.85	7.14-66.67	36.91	26.87-46.15	36.51
TSS	870-1370 mg/l	63.27-89.26	76.27	34.78-72.22	53.5	8.00-68.00	38.00	12.50-77.78	45.14
TDS	1410-4580 mg/l	9.80-44.54	27.17	3.33-42.91	23.12	10.34-13.71	12.03	4.67-16.76	10.72
FC	800/100ml-2800/100 ml	10.70-28.00	19.35	38.67-54.54	46.61	18.48-40.00	29.24	22.67-54.90	38.79
Nitrate	18-46 mg/l	26.32-34.78	30.55	33.33-71.43	52.38	21.05-55	38.03	20.00-48.57	34.29
Phosphate	30-85 mg/l	9.84-60.26	35.05	3.33-57.60	30.47	18.75-39.33	29.04	12.11-63.19	37.65

Table 4.2: Removal efficiency of different parts in the 2nd DEWAT plant

Parameters	Influent quality of septic tank	% Removal efficiency of Septic tank		% Removal efficiency of ABR		% Removal efficiency of planted gravel filter		% Removal efficiency of polishing pond	
	(Range)	Range	Average	Range	Average	Range	Average	Range	Average
BOD_5	128-510 mg/l	19.8-74.02	46.91	20.61-37.55	29.08	29.6-86.42	58.01	19.03-48.3	33.665
COD	960-8960 mg/l	11.11-33.33	22.22	37.5-50	43.75	9.09-33.33	21.21	25-50	37.5
TSS	870-1370 mg/l	16.48-98.75	57.615	33.33-93.42	63.375	12.00-40	26	27.27-88	57.635
TDS	1410-4580 mg/l	2.01-32.93	17.47	3.16-5.08	4.12	1.86-24.76	13.31	1.17-35.44	18.305
FC	800/100 ml-2800/100 ml	0-6.05	3.025	1.82-47.67	24.745	11.11-36.15	23.63	1.79-54.55	28.17
Nitrate	18-46 mg/l	14.29-50	32.145	33.33-50	41.665	25-50	37.5	20-100	60
Phosphate	30-85 mg/l	14.58-53.42	34	2.94-36.07	19.505	2.7-52.38	27.54	5.00-40	22.5

Table 4.3: Overall removal efficiency of 1st DEWAT plant

Parameters	Removal efficiency, (%)					
	Feb	Mar	Apr	May	Jun	Mean
BOD_5	93.33	92.07	69.84	96.41	91.23	88.58
COD	85.76	84.62	-	66.67	71.43	77.12
TSS	97.14	98.35	74.71	96.95	94.16	92.26
TDS	72.93	38.07	15.14	33.33	-	39.87
FC	80	60	-	55.56	67.86	65.86
Nitrate	89.13	77.78	36.84	10	50	52.75
Phosphate	70.12	57.09	11.13	64.9	61.33	52.91

Table 4.4: Overall removal efficiency of 2nd DEWAT plant

Parameters	Removal efficiency, (%)						
	Jun	Jul	Aug	Sep	Oct	Nev.	Mean
BOD_5	93.99	94.13	84.57	59.9	79.61	88.03	83.37
COD	37.5	0	66.67	75	71.43	40	58.12
TSS	99.24	97.8	88.73	96.25	98.36	96.94	96.22
TDS	-	-	-	-	6.15	32.45	19.3
FC	-	28.57	20	16.67	-	5.41	17.66
Nitrate	100	33.33	-	55.56	71.43	83.33	68.73
Phosphate	56.16	38.78	-	48.65	34.48	8.33	37.28

Table 4.5: Compare removal efficiency between 1st and 2nd DEWAT plants

Parameters	Mean removal efficiency, (%)	
	1st DEWAT plant	2nd DEWAT plant
BOD_5	88.58	83.37
COD	77.12	58.12
TSS	92.26	96.22
TDS	39.87	19.3
FC	65.86	17.66
Nitrate	52.75	68.73
Phosphate	52.91	37.28

Table 4.6: Compare the 1st and 2nd DEWAT plants with recommended values

Parameters	Effluent of 1st DEWAT plant (average)	Effluent of 2nd DEWAT plant (average)	Irrigation purposes		Bangladesh Standard Limits for disposal in water bodies (ECR, 1997)
			Typical ranges	allowable ranges	
p^H	6.97	7.09	6.5 - 8.5	-	6-8.5
BOD_5, mg/l	30.4	25.7	10 - 20	<100	40
COD, mg/l	1740	3840	25 - 50	<150	-
TSS, mg/l	96	45	10- 20	<100	100
TDS, mg/l	1295	1415	10 - 20	-	2100
FC, (No./100ml)	1275	11500	<200		1000
Oil and Grease, mg/l	Nil	Nil	max 10		-
Temperature, ^0C	23.65	25.3	-		30
DO, mg/l	1.33	3.59	-		-
Phosphate, mg/l	22.51	20	-		35
Nitrate, mg/l	14	8	-		250

4.8 Operation and Maintenance

From the performance analysis it is observed that there are some constraints prevailing in the investigated DEWAT systems. The main constraint is related to the maintenance and operation of the DEWAT plants which required regular supervision and community support. The operating system of DEWAT plant is very easy that only requires regular checking of the chambers of the settling tank, anaerobic baffled reactor and anaerobic filter bed baffled reactor by opening manholes, cleaning of the planted gravel filter from unwanted materials such as rubbish or plastic and cleaning of the polishing pond. The frequency will be determined through daily observation.

Weekly monitoring of scum and solid particles in each chamber of anaerobic baffled reactors by opening the manholes should be done. Scum layers should be removed regularly when it starts to form a thick layer on the upper portion of the water surface.

Main maintenance task is back washing or flushing the filter materials which should be done whenever the filter materials become covered by bacteria that can cause clogging. This can be detected from the reduced performance of the treatment plant shown in the wastewater laboratory test. In this case, back washing should be done by emptying the chamber and then washing the filter by spraying pressurized water through the manhole. Dead bacteria will fall off and accumulate at the bottom of the chamber. The dead bacteria should be removed by using a vacuum pump (mostly utilized by sewage collectors). Spraying can be done several times until dead bacteria in the filter are removed. After years of operation, the filter material can also be replaced with a new one while the old filter material should rest for about 3-6 months. Resting period will bring back the performance of the filter and it will be ready to be used again [102].

Sludge in the settling tank and anaerobic baffled reactor should be removed according to the design period. Longer intervals of desludging will compact the sludge accumulated in the bottom and will cause low performance of DEWAT plant.

Maintaining a planted gravel filter is like maintaining a garden. Once the plants are fully matured, cutting of old leaves and removal of old/dead plants should be done. Cleaning of the filter surface from falling leaves should also be done to ensure the flow of oxygen and ultra-violet rays of the sun to enter the gravel filter [102]. Unwanted plant leaves or other materials from the planted gravel filter should be removed weekly. The harvesting of the plants should be carried out twice a year.

It is revealed that for the successful functioning of the system a community based operation, maintenance and management system need to be designed. It is realized that daily cleaning and supervision for proper operation of DEWAT plant are required. Moreover, a full time sweeper from the local community should be employed to look after the operation and maintenance of the system. It should be carefully observed that the unnecessary materials such as solid or fine particles, plastic materials etc cannot be penetrated in the DEWAT system. Furthermore, the local people, relevant stakeholders, civil servants and executives need to be trained in a strategic was based on an appropriate technical guidelines.

4.9 Possible Use of Treated Wastewater

4.9.1 Agricultural use

BOD_5, pH, and TSS effluent concentrations of both DEWAT plants could meet the water quality requirement for agricultural use. Oil and Grease of both DEWAT plants was zero which could meet the quality requirement for agricultural use. However, COD value of both DEWAT plants was higher than the guideline values. FC in the effluent of the 1^{st} DEWAT plant was sufficient for reusing wastewater for agriculture which was slight higher than 1000/100mL; however the effluent from 2^{nd} DEWAT plant had FC value highly greater than 1000/100mL. High concentration of Faecal Coliform indicated the need of further disinfection for agricultural use. So the treated water of 2^{nd} DEWAT plant needs more disinfection before it could be possibly used for watering the garden and cultivating raw vegetable and fruits which are eaten without cooking.

4.9.2 Toilet flushing

Treated water from both DEWAT plants could be used for flushing toilet due to the low concentration of Faecal Coliform. In Japan E. coli should be less then 10CFU/100 ml for reuse of wastewater for toilet flushing [103]. So, with simple disinfection technique the treated water can be reused for toilet flushing and this will minimize the consumption of fresh water.

4.9.3 Disposal in natural water bodies

BOD_5, pH, Temperature, and TSS effluent concentrations of both DEWAT plants could meet the water quality requirement for disposal in natural water bodies. Oil and Grease of both DEWAT plants was zero which could meet the quality requirement for disposal in natural water bodies. FC in the effluent of the 1st DEWAT plant was sufficient for disposal in natural water bodies which was slight higher than 1000/100mL; however the effluent from 2nd DEWAT plant had FC value highly greater than 1000/100mL. High concentration of Faecal Coliform indicated the need of further disinfection for disposal in natural water bodies. So the treated water of 2nd DEWAT plant needs more disinfection before disposal in natural water bodies. Nutrient such as Phosphate and Nitrate values were lower than the guideline values. DO in the effluent of the 1st DEWAT plant was less than 4 mg/L which indicates that treated wastewater could influence for aquatics survival; however DO value was exceed 4 mg/L in the effluent of 2nd DEWAT plant which indicates that treated wastewater could allowable to mix with natural stream.

DEWAT plant is good way to treat domestic wastewater but the reuse of wastewater needs simple tertiary treatment or disinfection depending on the use of wastewater.

4.10 Identification Technical Problems

Form the analysis of experimental data, it is summarized that the problems were raised due to choose right filter materials, clogging of filter media, limitation space above ground, and overall cost of DEWAT plant.

4.10.1 Clogging of filter media

Sand and brick khoa were used as filter material of planted filter in 1st DEWAT plant. Dust particles of brick khoa and sand mixed with treated water which passed through the filter media of planted filter. For this reason, the values of TSS, TDS, and FC of treated water were increased. The planted gravel filter of 1st DEWAT plant was fully clogged. Treated wastewater moved back toward anaerobic baffle reactor. So, total system was overflowed. Finally 1st DEWAT plant stopped to treat wastewater. For the remedy of clogging problem, Sand and brick khoa was replaced by stone/gravel in planted filter of 1st DEWAT plant. Stone/gravel was also used as filter media in planted filter of 2nd DEWAT plant which can prevent rapid accumulation of unnecessary fine particles in between the pores of the filter. But construction cost of planted filter was increased due to use of stone.

The clogging is also a problem in the anaerobic filter bed (AFB). In the 1st and 2nd DEWAT plants plastic bottle caps were used as filter material. Proper maintenance is required in this section. The filter materials become covered by bacteria that can cause clogging. Back washing or flushing filter materials should be done due to removal of dead cells. Dead bacteria accumulate at the bottom of the chamber. Sludge should be withdrawn at regular time interval due to minimizing clogging problem. Materials having high surface area to volume ratios and low void volumes should be used as filter material in the AFB. Available filter materials are Charcoal, gravel, crushed glass, plastics caps, stone etc. which resistance to shock loads and inhibitions make anaerobic filter suitable for the treatment of both dilute and high strength wastewaters.

Another problem was created by DEWAT user. They have no any knowledge about the maintenance of DEWAT plant. They use ash for dish cleaning purpose. Ash is mixed with influent of septic tank which is also responsible for clogging problem.

Therefore, it can be recommended that in the future design and construction of DEWAT system, the experiences and the performance of the existing plants might be considered for having a sustainable plant in terms of low construction cost and low maintenance.

4.10.2 Limitation space above ground and overall cost of DEWAT plant

Khulna city is very congested and unplanned city. There is the limitation of free space above ground. Land value is rapidly increased day by day. For improving sanitation condition in congested area, anaerobic treatment system is more acceptable than aerobic treatment system.

From the analysis of experimental results, the effectiveness of septic tank, anaerobic baffled reactor and anaerobic filter over the planted gravel filter considering the area required for planted filter and the associated cost. Planted gravel filter is an aerobic unit of DEWAT plant which is required large space above ground. The cost of filter material is very high and sometimes suitable filter materials are not locally available. The clogging is also a problem in the planted gravel filter.

It is observed from the result (Table 4.7) that when wastewater passed through ABR, achieved removal efficiency are 65%, 64%, 93%, 44%, 32%, 48%, and 50% for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively in the 1st DEWAT plant. Removal efficiency only planted gravel filter are 61%, 37%, 38%, 12%, 29%, 38%, and 29% concentration based removal efficiency for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively. Removal efficiency only polishing pond are 28%, 37%, 45%, 11%, 39%, 34%, and 38% for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively. Moreover, the total construction cost of 1st DEWAT plant was BDT 900000, whereas the construction cost of planted gravel filter was BDT 343112 (Table 4.9).

It is observed from the result (Table 4.8) that when wastewater passed through ABR, the 2nd DEWAT plant achieved 58%, 38%, 93%, 38%, 29%, 53%, and 37% for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively. Removal efficiency only planted gravel filter are 58%, 21%, 26%, 13%, 24%, 38%, and 28% concentration based removal efficiency for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively. Removal efficiency only polishing pond are 34%, 38%, 58%, 18%, 28%, 60%, and 23% for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate respectively. Moreover, the total construction cost of 2nd DEWAT plant was BDT 1500000, whereas the construction cost of planted gravel filter was BDT 834762 (Table 4.9).

Table 4.7: Removal efficiency of 1st DEWAT plant

Parameters	Removal efficiency Up to ABR (Average)	Removal efficiency only PGF (Average)	Removal efficiency only PP (Average)
BOD5, (%)	65.49	60.54	28.46
COD, (%)	63.7	36.91	36.51
TSS, (%)	93.24	38.00	45.14
TDS, (%)	43.65	12.03	10.72
FC, (%)	31.57	29.24	38.79
Nitrate, (%)	48.3	38.03	34.29
Phosphate, (%)	49.89	29.04	37.65

Table 4.8: Removal efficiency of 2nd DEWAT plant

Parameters	Removal efficiency Up to ABR (Average)	Removal efficiency only PGF (Average)	Removal efficiency only PP (Average)
BOD5, (%)	58.24	58.01	33.67
COD, (%)	38.08	21.21	37.50
TSS, (%)	93.38	26	57.64
TDS, (%)	38.45	13.31	18.31
FC, (%)	29.31	23.63	28.17
Nitrate, (%)	53.02	37.5	60.00
Phosphate, (%)	37.17	27.54	22.50

Table 4.9: Cost Analysis of existing DEWAT plants

Components	Cost (BDT)	
	First DEWAT Plant	Second DEWAT Plant
Septic Tank	63184	97560
ABR and AFBBR	149675	209350
PGF	343112	834762
PP	14981	21955
Others	329048	336373

Moreover, it is evident that the planted gravel filter becomes less prominent in the overall design due to the excellent treatment taking place in the baffled tank reactor and anaerobic baffled filter. From analysis of experimental result, it was also found that the maximum change was happened when wastewater passed through the anaerobic baffled reactors (ABR). For this reason, planted gravel filter can be replaced by increasing number of ABR and aeration device.

In future design and construction of DEWAT the experiences and the performance of the existing plants might be considered for having a cost effective and sustainable one.

4.11 Proposed Design of the Modified DEWAT Systems

Two alternatives are available regarding the treatment of wastewater by natural biological means. The first option is fully elimination of the planted gravel filter from DEWAT system for minimizing construction and maintenance cost. The second option is addition of biogas collector unit with the first option for the collection of biogas used as fuel and for removal pollutant from wastewater.

4.11.1 Alternative first option

From the analysis of experimental result, it is realized that most of the problems in terms of choosing right filter materials, clogging, space, maintenance and overall cost of DEWAT plant are related to the planted gravel filter bed. Moreover, it is evident that the planted gravel filter becomes less prominent in the overall design due to the excellent treatment taking place in the baffled tank reactor and anaerobic baffled filter. From analysis of experimental result, it was also found that the maximum change was happened when wastewater passed through the anaerobic baffled reactors (ABR). As the results obtained from physical, biological and chemical tests of the existing two DEWAT plants reveal that it is possible to have a modified version of DEWAT without planted gravel filter bed by increasing the number of anaerobic baffled reactor, by choosing the right filler materials and by increasing number of aeration devices in polishing pond.

Configuration of the new proposed plant without planted gravel filter

Modified version of DEWAT plant consists of four components as (i) Septic tank, (ii) Anaerobic Baffled Reactor having six compartments, (iii) Anaerobic Filter Bed Baffled Reactor having four compartments and (iv) Polishing Pond (Figure 4.21). The sizes of the compartment of each component will depend on the number of users and the span of desludging period. In the anaerobic baffled reactor the four different filler media such as crushed plastic bottle with cap, gravel/stone, Tire chips and bamboo rings may be used. To increase the oxidation process, the discharge of effluent coming from last compartment of baffled reactor into the polishing pond can be arranged in three different stages in terms of falling height through gravity system. A simple aeration device may be used in the center of polishing pond which may be also eliminated the odor problem.

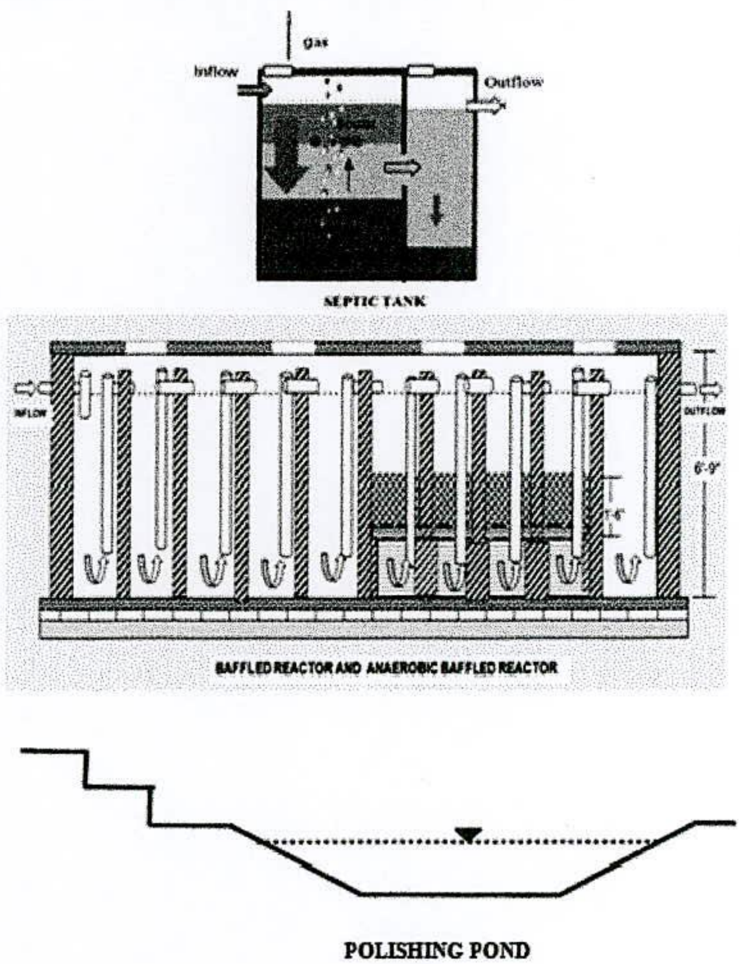

Figure 4.21: Configuration of the new proposed plant without planted gravel filter

Advantage

- Cost reduction,
- Less needed space above ground and
- With an additional benefit of having reusable treated waste water.

4.11.2 Alternative second option

In a DEWAT plant wastewater is treated by the combination of anaerobic and aerobic treatment system. Anaerobic system consists of sedimentation tank, anaerobic baffled reactor. In the absence of oxygen anaerobic bacteria decompose the organic waste to multiply and produce biogas which is a clean and renewable energy that may be substituted to natural gas for cooking, or to generate electricity. Implementation of this option may not only improve sanitation condition but also increase economic development.

Configuration of the new proposed plant without planted gravel filter

Modified version of DEWAT plant consists of four components as (i) sedimentation tank with biogas collector, (ii) Anaerobic Baffled Reactor having six compartments, (iii) Anaerobic Filter Bed Baffled Reactor having four compartments and (iv) Polishing Pond (Figure 4.22). Second option is similar of first option except the configuration of sedimentation tank. Fusing biogas collector unit with DEWAT plant, sedimentation tank will increase the value of DEWAT plant in communal level as the formed gas can be used for cooking as well as for electricity.

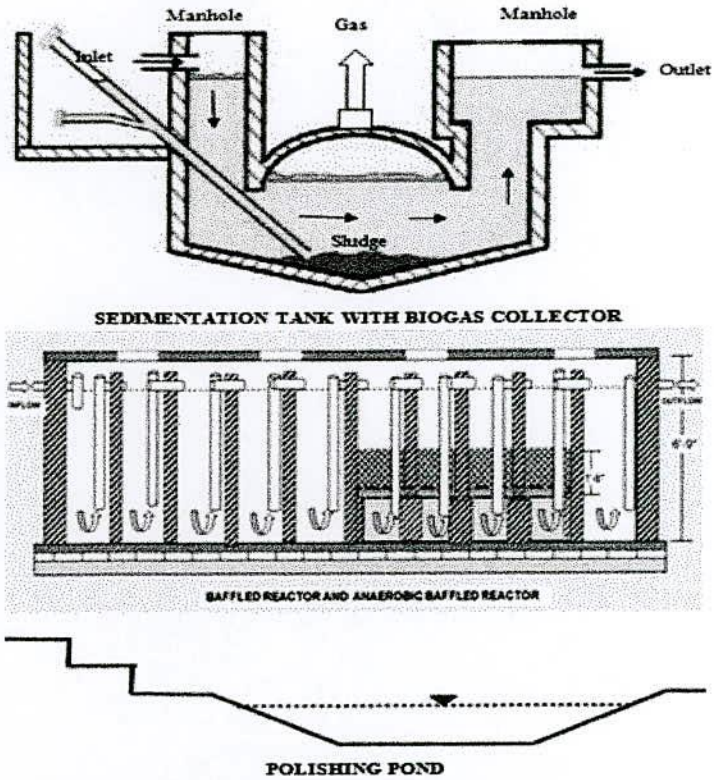

Figure 4.22: Configuration of the new proposed plant with biogas unit

Advantage

- Used biogas as fuel or generate electricity
- Less needed space above ground and
- With an additional benefit of having reusable treated waste water.

4.12 Replication

The field experience of a successful DEWAT plant considering the local socio-economic conditions, weather and climate as well as the use of local building materials will be an excellent example for the developing and low incoming countries to handle wastewater problems successfully. From this study it is realized that the successful story of the two DEWATs of Peoples' Panchtola Colony, will encourage the related stakeholders for its possible replication in other part of Khulna city as well as in the urban areas of Bangladesh. Development of technical guidelines for all types of domestic wastewater management will improve the environmental legislation of Bangladesh.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER V

Conclusions and Recommendations

5.1 Background

This research investigated the performance of Decentralized Wastewater Treatment Plants in Khulna. The study had four major objectives: (a) to study the performance of two DEWAT plants regarding its technical and socio-economic acceptance by ordinary population in Panchtola Colony in Khulna, Bangladesh; (b) to compare the performance of two DEWAT plants based on field and laboratory investigations; (c) to identify the technical problems in the operation and maintenance of two DEWAT plants; (d) to recommend the modified DEWAT plant which will reduce construction cost, require small space above ground and low maintenance and prevent the deteriorating health conditions, pollution of nearby water bodies and surrounding environment. Conclusions regarding each objective are explained in section 5.2 and recommendations are listed in section 5.3.

5.2 Conclusions

Concerning the first objective of this thesis, the performance of DEWAT plants regarding its technical and socio-economic acceptance by ordinary residents in Panchtola Colony in Khulna, Bangladesh is highly appreciated in response to colony residents who are using the DEWAT plant. Before implementation of DEWAT plants, the sanitation and wastewater management at Peoples Panchtola Colony in Khalispur, Khulna was very poor. Untreated wastewater and raw sewage were disposed to the municipal drains or beside city dweller residence and near about the premises of their residence. Blockage of drainage systems occurred for wastewater overflowed during rainy season. Almost all cannels, ponds and rivers were polluted by untreated wastewater.

All DEWAT users are satisfy for this system and aware about worrying situation which was created before implementation of DEWAT system. So, they are frankly participate management of DEWAT system. Local peoples bore 10-15% of total fund of construction of DEWAT plant. They become more conscious about clean environment. Every family pays Tk. 40 per month for dumping their daily waste to the KCC dumping area. The application of DEWAT plant is very suitable in Khulna for sustainable wastewater management.

According to economic point of view, DEWAT plants were impended as a source of water supply for irrigation purposes. It was found that treated wastewater comes from polishing can be reused for irrigation purposes or reused for the community toilet flushing. DEWAT plants can be reduced the withdrawal of fresh water from ground water. DEWAT plants not only save fresh water but also save withdrawal cost such as power cost. DEWAT plants were also profitable through reduction of medical cost and loss of income due to illness which is another positive attitude of this technology.

With reference to second objectives of this thesis, from the performance study of two DEWAT plants it can be seen that the removal rate was higher in the 1st DEWAT plant compared to the 2nd DEWAT plant. Though the two DEWAT plants at Peoples Panchtola Colony were built in different years, they have similar removal efficiencies (concentration based) except for FC. Both DEWAT plants were more efficient in removal of BOD_5, Nitrate, Phosphate, and TSS while they were less efficient in removal TDS. The DEWAT plants were designed to meet the discharge standards but the treated water coming out from the DEWAT plants could not to meet this standard as FC and COD exceeded the standard limit.

The values of Oil and Grease were zero for all collected wastewater samples from 1st and 2nd DEWAT plants. The 1st DEWAT plant achieved 89%, 77%, 92%, 40%, 66%, 53%, and 53% concentration based removal efficiency for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate, respectively. The 2nd DEWAT plant achieved 83%, 58%, 96%, 19%, 18%, 69%, and 37% removal efficiency (concentration based) for BOD_5, COD, TSS, TDS, FC, Nitrate and Phosphate, respectively. The values of DO were increasing which indicate that oxygen level was increased in treated wastewater samples from both DEWAT plants. The average effluent Temperature values were 23.65°C and 25.3°C for 1st and 2nd DEWAT plants, respectively. These values are less than standard limit (30°C). The values of pH were within 6-8.5 limits for both DEWAT plants.

Third objective was addressed to identify the technical problems in the operation and maintenance of two DEWAT plants. Although the performance of DEWAT plants was found good, the DEWAT plant had some problems. One technical issue was related with the clogging of filter media. Proper maintenance of anaerobic filter bed and planted bed filters can be effectively improved the performance of DEWATS plants.

Sand and brick khoa were used as filter material of planted filter in 1st DEWAT plant. Dust particles of brick khoa and sand mixed with treated water which passed through the filter media of planted filter. For this reason, the removal efficiency of total suspended solid (TSS) and total dissolve solid (TDS) of treated water were increased and finally the mechanism of planted filter of 1st DEWAT plant was fully clogged. Treated wastewater moved back toward anaerobic baffle reactor. So, total system was overflowed. Finally 1st DEWAT plant stopped to treat wastewater. For the remedy of clogging problem stone/gravel was also used as filter media in planted filter of 2nd DEWAT plant which can prevent rapid accumulation of unnecessary fine particles between the pores of the filter. But construction cost of planted gravel filter was increased due to use of stone.

The clogging is also a problem in the anaerobic filter bed (AFB). In the 1st and 2nd DEWAT plants plastic bottle caps were used as filter material. Proper maintenance is required in this section. The filter materials become covered by bacteria that can cause clogging. Back washing or flushing filter materials should be done due to removal of dead cells. Dead bacteria accumulate at the bottom of the chamber. Sludge should be withdrawn at regular time interval due to minimizing clogging problem. Materials having high surface area to volume ratios and low void volumes should be used as filter material in the AFB. Available filter materials are Charcoal, gravel, crushed glass, plastics caps, stone etc. which resistance to shock loads and inhibitions make anaerobic filter suitable for the treatment of both dilute and high strength wastewaters.

Another problem was created by DEWAT user. They have no any knowledge about the maintenance of DEWAT plant. They use ash for dish cleaning purpose. Ash is mixed with influent of septic tank which is also responsible for clogging problem.

One of the major problems was related with the limitation of free space above ground. Khulna city is very congested and unplanned city. For improving sanitation condition in congested area, anaerobic treatment system is more acceptable than aerobic treatment system. Planted gravel filter is an aerobic unit of DEWAT plant which is required large space above ground. The cost of filter material is very high and sometimes suitable filter materials are not locally available. The clogging is also a problem in the planted gravel filter.

Regarding the fourth objective of this thesis, the existing design of DEWAT plant was modified for sustainable development. One proposed modified design of the DEWAT plant is that planted gravel filter can be replaced by increasing number of ABR and aeration device. From analysis of experimental result, it was also found that the maximum change was happened when wastewater passed through the anaerobic baffled reactors (ABR). Moreover, it is evident that the planted gravel filter becomes less prominent in the overall design due to the excellent treatment taking place in the baffled tank reactor and anaerobic baffled filter. For this reason, planted gravel filter can be replaced by increasing number of ABR and aeration device. Modified version of DEWAT plant consists of four components as (i) Sedimentation tank, (ii) Anaerobic Baffled Reactor having six compartments, (iii) Anaerobic Filter Bed Baffled Reactor having four compartments and (iv) Polishing Pond with three steps and external aeration device

Another proposed modified design of the DEWAT plant is that ordinary settler or septic tank can be replaced by biogas settler will increase the value of DEWAT plant in communal level as the formed gas can be used for cooking as well as for electricity. Modified version of DEWAT plant consists of four components as (i) Sedimentation tank with biogas collector, (ii) Anaerobic Baffled Reactor having six compartments, (iii) Anaerobic Filter Bed Baffled Reactor having four compartments and (iv) Polishing Pond with three steps and external aeration device

Finally, it can be concluded that the modified DEWAT system should be practiced in low incoming developing countries as a mid-term solution to improve the sanitation condition

5.2 Recommendations for further studies

Further recommendation study can be:

- Detail study on Proposed Design of Modified DEWAT System with low construction and maintenance cost and low maintenance.
- Detail study on reused treated wastewater as irrigation purposes.
- Detail study on the variation of different types of local filter materials used in anaerobic filter bed and planted gravel filter.
- In order to know the variation of effluent in DEWAT plant, the long term monitoring should be carried out. The monitoring variation of effluent quality within 3 months should be performed with influent and effluent of DEWAT plant.

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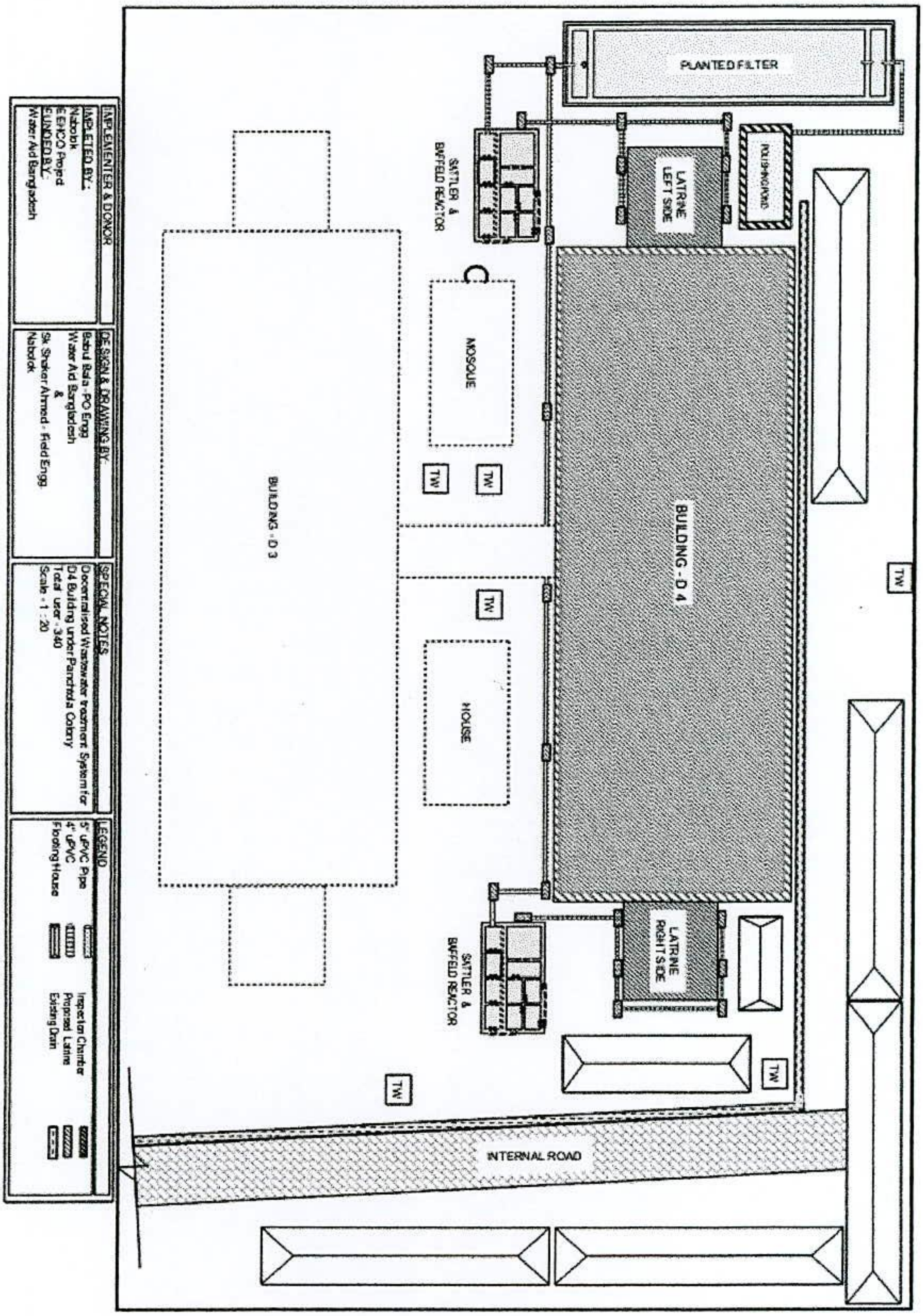
APPENDICES

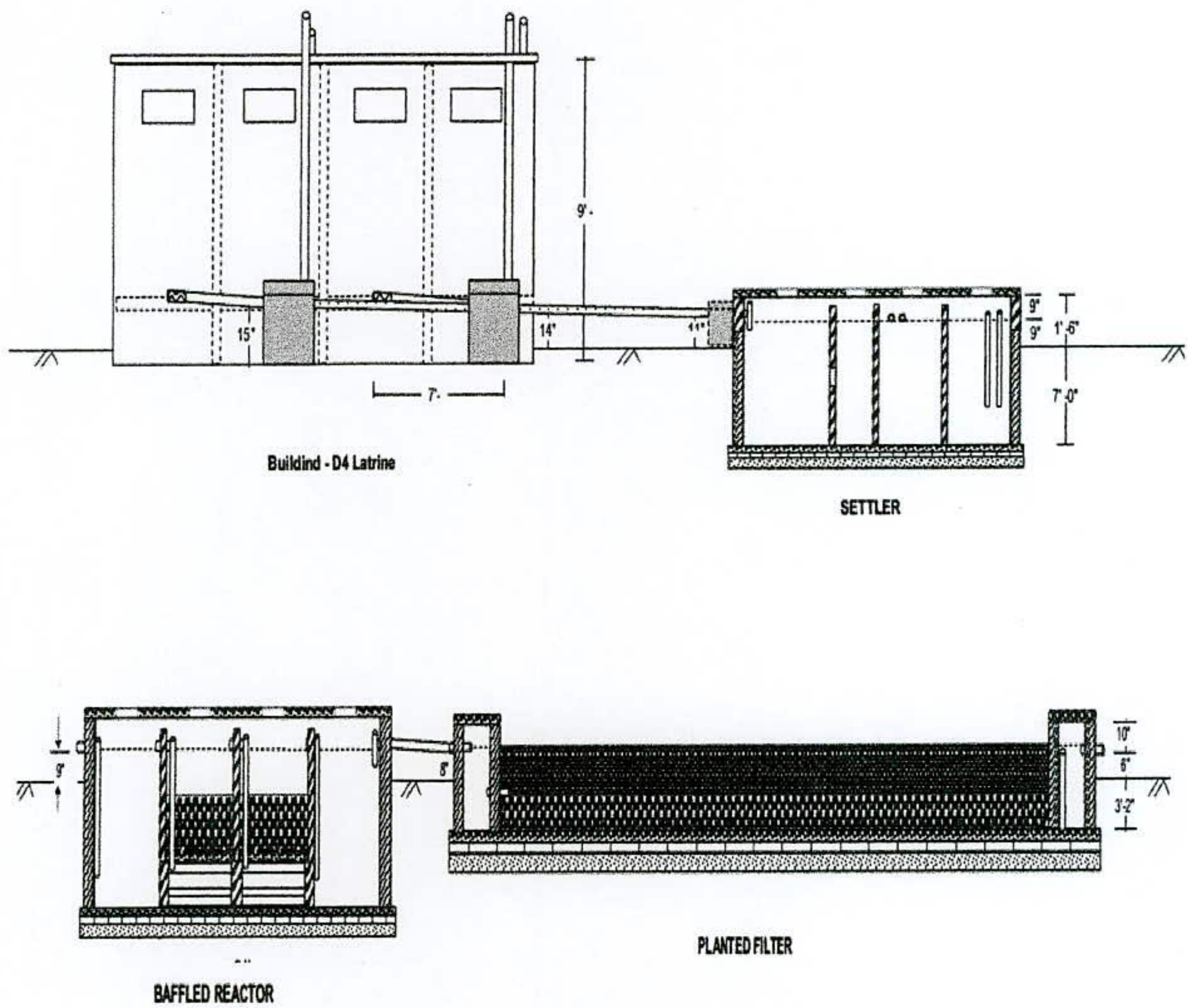
Appendix A

Area map- typical DEWAT plant



Appendix B

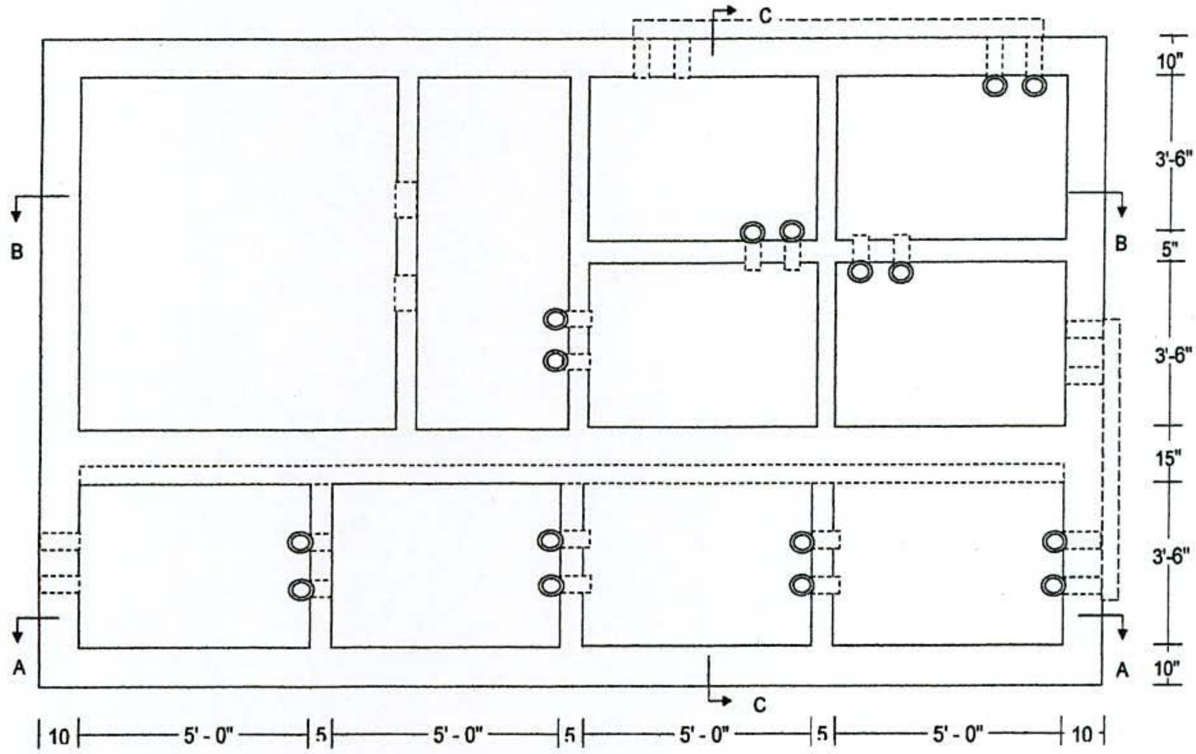
Layout – typical DEWAT plants



IMPLEMENTER & DONOR	DESIGN & DRAWING BY:	SPECIAL NOTES	LEGEND
IMPLETED BY : Nabolok EEHCO Project FUNDED BY : Water Aid Bangladesh	Babul Bala -PO Engg Water Aid Bangladesh & Sk Shaker Ahmed - Field Engg. Nabolok	DEWATS for D4 Building under Panchtola Colony Total House Holds - 170 Planted Filter Bed Slope - 3%	Old BW New BW 4" uPVC 4" Top Slab 3" Bottom Slab 3" BFS 6" SF Filter Media Inspection Chamber

Appendix C

Details drawing of typical DEWAT plants



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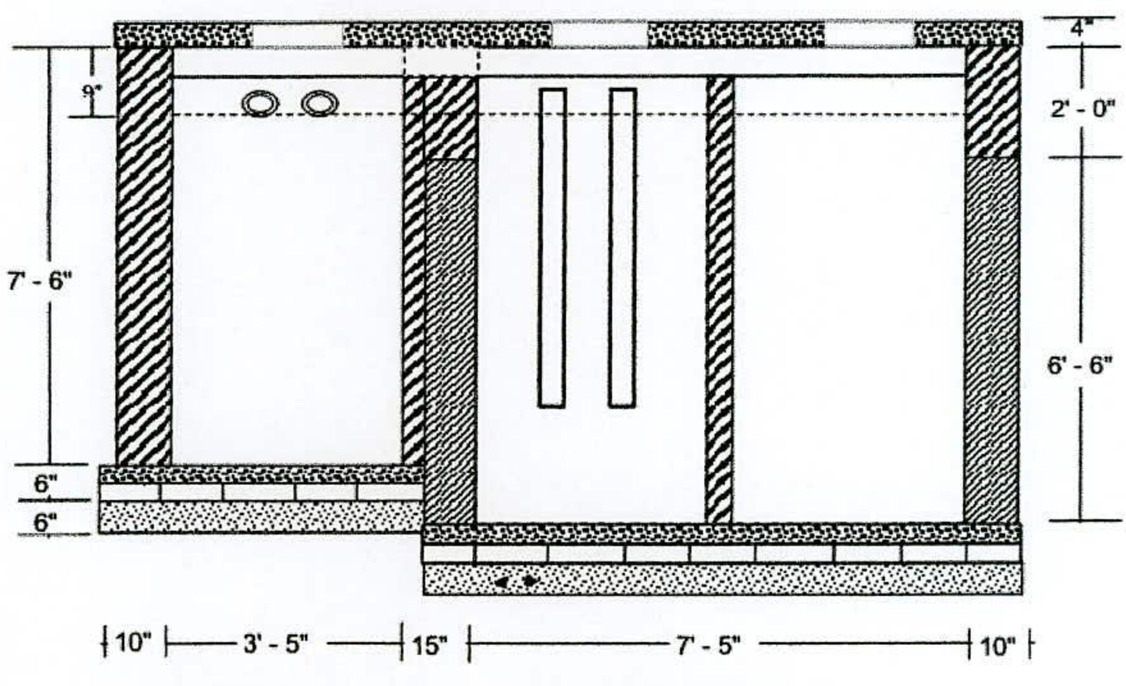

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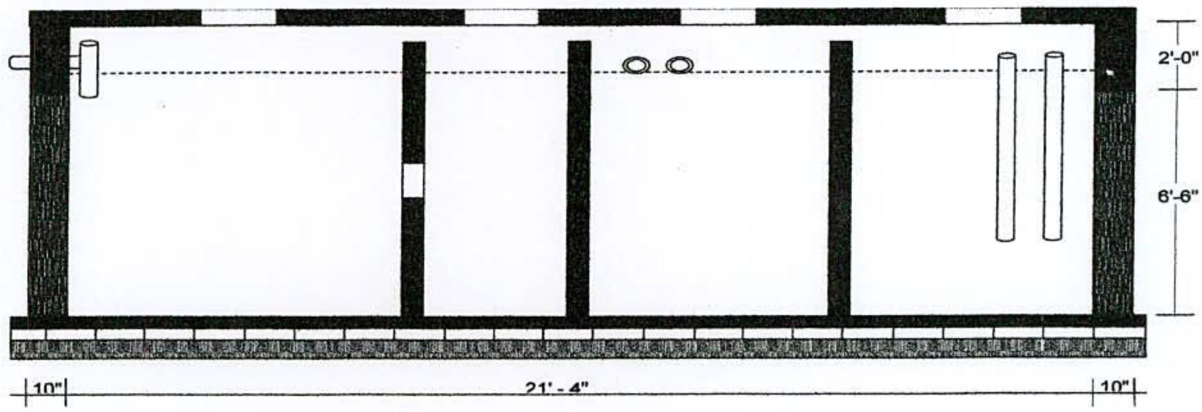

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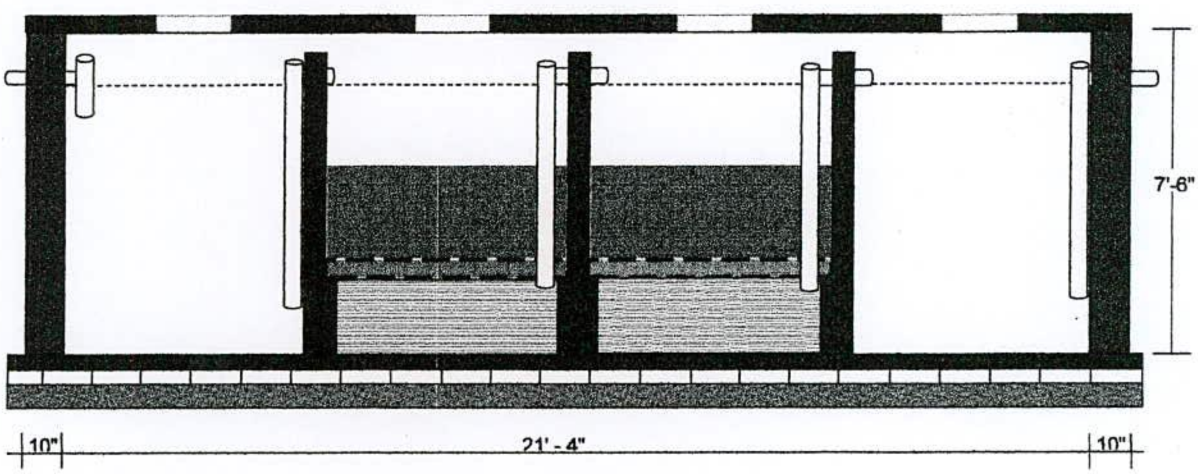
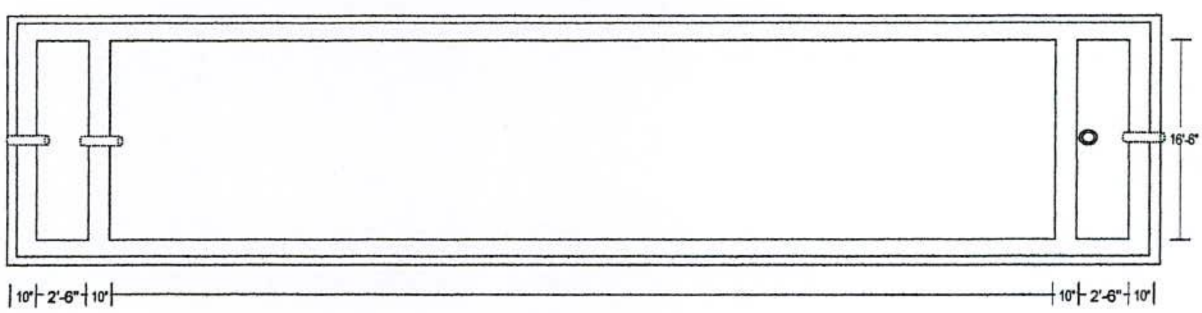
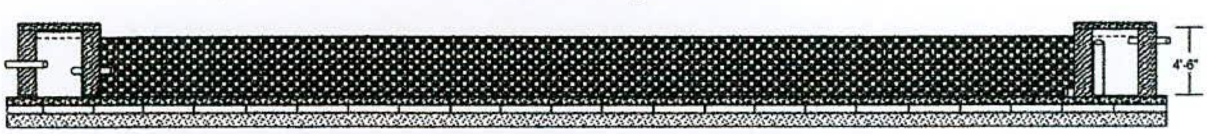
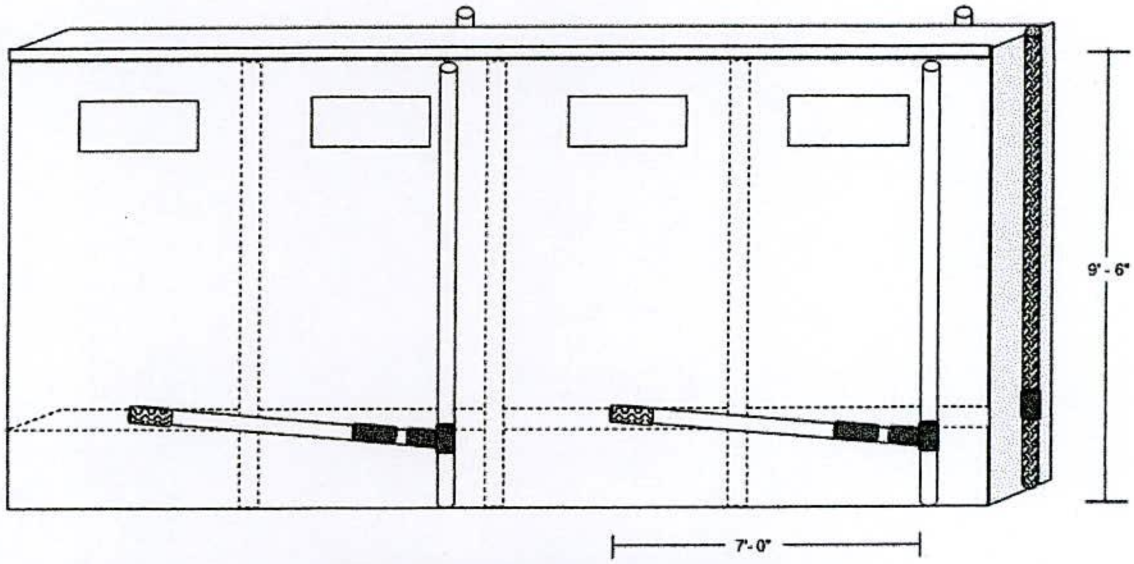


PLANTED FILTER



Section: Planted gravel filter





Plan Pipe Fittings One Floor One Side

IMPLEMENTER & DONOR	DESIGN & DRAWING BY:	SPECIAL NOTES	LEGEND
IMPLETED BY : Nabolok EEHCO Project FUNDED BY : Water Aid Bangladesh	Babul Bala -PO Engg Water Aid Bangladesh & Sk Shaker Ahmed - Field Engg. Nabolok	DEWATS for D4 Building under Panchtola Colony Total users - 340 Desludge Period - 5 Years Filter Bed Slope -3% Gravel Size - 10mm - 16 mm Scale - 1 : 80	Old BW New BW 4" uPVC 4" Top Slab 3" Bottom Slab 3" BFS 6" SF 2.5' Course Sand 1.5' Gravel

Appendix D

Nabolok - EEHCO Project
1st DEWAT plant Estimates

Settler (Septic Tank)

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	17.13	nos	365.00	6,253.92
2	Brick	720.00	nos	6.90	4,967.97
3	Sand (Kustia)	62.26	cft	19.00	1,182.95
4	Khoa	62.60	cft	60.00	3,756.12
5	MS Rod (10 mm)	200.34	kg	62.00	12,421.18
6	4" dia uPVC Pipe	50.00	ft	37.00	1,850.00
7	4" dia uPVC door " T "	4.00	nos	150.00	600.00
8	4" dia uPVC door Bend	2.00	nos	130.00	260.00
9	3" dia uPVC bend	2.00	nos	150.00	300.00
				Sub Total	**31,592.14**

2 Nos Settler = 63,184.28

Baffled Reactor

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	48.60	nos	365.00	17,738.11
2	Brick	4936.39	nos	6.90	34,061.08
3	Sand (Kustia)	245.28	cft	19.00	4,660.29
4	Sand (Local)	61.48	cft	10.00	614.81
5	Khoa	71.80	cft	60.00	4,308.17
6	MS Rod (10 mm)	95.57	kg	62.00	5,925.18
7	4" uPVC Bend	20.00	ft	120.00	2,400.00
8	4" uPVC Pipe	130.00	ft	37.00	4,810.00
9	3" uPVC Vent Pipe	10.00	ft	32.00	320.00
				Sub Total	**74,837.64**

2 Nos Baffled Reactor = 149,675.28

Planted Filter Bed

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	136.02	nos	365.00	49,648.01
2	Brick	14135.43	nos	6.90	97,534.48
3	Sand (Local)	752.02	cft	10.00	7,520.20
4	Sand (Kustia)	3728.91	cft	19.00	70,849.35
5	Khoa	372.46	cft	60.00	22,347.89
6	Gravel for Filter bed	1897.34	cft	50.00	94,866.75
7	4" uPVC Pipe	2.00	ft	38.00	76.00
8	4" dia uPVC " T "	1.00	nos	150.00	150.00
9	4" dia uPVC bend	1.00	nos	120.00	120.00
10	MS Rod (10 mm)	30.02	kg	62.00	1,861.06
				Sub Total	**343,112.67**

Polishing Pond

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement (Elephant)	6.89	nos	365.00	2,516.23
2	Brick	1495.25	nos	6.90	10,317.21
3	Sand (Kustia)	38.78	cft	19.00	736.77
4	Sand (Local)	91.13	cft	10.00	911.25
5	Khoa	0.00	cft	60.00	0.00
6	Others				500.00
				Sub Total	**14,981.46**

Pipeline Protection

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Brick	2333.06	nos	6.90	16,098.13
2	Sand	91.52	cft	19.00	1,738.94
3	Sand (Local)	187.50	cft	10.00	1,875.00
4	Cement	21.96	nos	365.00	8,016.20
5	Khoa	56.03	cft	60.00	3,361.50
6	5" uPVC Pipe	150.00	ft	80.00	12,000.00
				Sub Total	**43,089.76**

Inspection Chamber

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Earth Work	4.00	cft	10.00	40.00
2	Brick	67.83	nos	6.90	468.05
3	Sand	3.99	cft	19.00	75.82
4	Cement	0.93	nos	365.00	340.80
5	Khoa	2.38	cft	60.00	142.83
6	MS Rod (10 mm)	4.34	kg	62.00	269.08
				Sub Total	**1,336.58**

Inspection Chamber Requred 6 nos so total cost = 8,019.49

Nabolok - EEHCO Project
1st DEWAT plant for
Panchtola Colony
Estimates Cost at a glance

DEWATS Estimate

Sl	Option	Unit Price	Nos	Total Taka
1	Settler	31,592.14	2.00	63,184.00
2	Baffeld Reactor	74,837.64	2.00	149,675.00
3	Planted Filter	327,304.91	1.00	343,112.00
4	Polishing pond	14,981.46	1.00	14,981.00
5	pipeline Work	43,089.76	1.00	43,089.00
6	Inspection Chamber	1,336.58	6.00	8,019.00
7	Mason & Labour			111,971.00
8	Head Carring			5,000.00
9	Message Writing			1500
			Sub Total	**740,531.00**

Latrine Renovation

Sl	Option	Unit Price	Nos	Total Taka
1	Latrine Reno One side One floor	35,166.45	10.00	351,664.00
2	Inspection Chamber	1,284.78	12.00	15,417.00
3	Water Supply			30,800.00
4	Mason & Labour			73,400.00
5	Plumbing			10,000.00
6	Head carring			2,000.00
7	Message Writing			1,500.00
			Sub Total	**484,781.00**

Grand Total= **1,225,312.00**

Appendix E

Nabolok - EEHCO Project
2nd DEWAT plant Estimates

Settler (Septic Tank)

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	19.27	nos	480.00	9,251.69
2	Brick	1209.24	nos	8.50	10,278.58
3	Sand (Kustia)	112.47	cft	25.00	2,811.63
4	Sand (Local)	31.25	cft	25.00	781.25
5	Khoa	75.53	cft	85.00	6,420.31
6	MS Rod (10 mm)	200.38	kg	72.00	14,427.02
7	4" dia uPVC Pipe	50.00	ft	37.00	1,850.00
8	4" dia uPVC Bend	2.00	nos	150.00	300.00
9	5" dia uPVC Pipe	30.00	ft	72.00	2,160.00
10	5" dia uPVC door " T "	1.00	nos	500.00	500.00
				Sub Total	**48,780.48**

2 Nos Settler = 97,560.96

Baffled Reactor

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	34.28	nos	480.00	16,455.18
2	Brick	4514.82	nos	8.50	38,376.00
3	Sand (Kustia)	270.50	cft	25.00	6,762.57
4	Sand (Local)	61.48	cft	12.00	737.78
5	Khoa	86.62	cft	85.00	7,362.63
6	MS Rod (10 mm)	95.57	kg	72.00	6,880.85
7	4" uPVC Bend	20.00	nos	150.00	3,000.00
8	4" uPVC " T "	18.00	nos	160.00	2,880.00
9	4" uPVC Pipe	60.00	ft	37.00	2,220.00
10	1" PVC coil Pipe For anorabic Filter				20,000.00
				Sub Total	**104,675.01**

2 Nos Baffled Reactor = 209,350.01

Planted Filter Bed

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	99.26	nos	480.00	47,644.73
2	Brick	13770.54	nos	8.50	117,049.59
3	Sand (Kustia)	703.52	cft	25.00	17,587.97
4	Sand (Local)	720.00	cft	12.00	8,640.00
5	Khoa	422.08	cft	85.00	35,876.70
6	MS Rod (10 mm)	30.02	kg	72.00	2,161.23
8	Gravel for Filter bed (Khoa)	4011.08	cft	150.00	601,662.60
9	4" uPVC Pipe	70.00	ft	37.00	2,590.00
10	4" dia uPVC " T "	5.00	nos	160.00	800.00
11	4" dia uPVC bend	5.00	nos	150.00	750.00
				Sub Total	**834,762.82**

Polishing Pond

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement (Elephant)	6.38	nos	480.00	3,062.95
2	Brick	1846.49	nos	8.50	15,695.16
3	Sand (Kustia)	64.15	cft	25.00	1,603.79
4	Sand (Local)	91.13	cft	12.00	1,093.50
5	Khoa	0.00	cft	85.00	0.00
6	Others				500.00
				Sub Total	**21,955.40**

Pipeline Protection

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Cement	15.40	nos	480.00	7,393.61
2	Brick	2333.06	nos	8.50	19,831.03
3	Sand (Kustia)	115.65	cft	25.00	2,891.27
4	Sand (Local)	187.50	cft	187.50	35,156.25
5	Khoa	67.59	cft	85.00	5,744.79
6	4" uPVC Pipe	160.00	ft	37.00	5,920.00
				Sub Total	**76,936.95**

Inspection Chamber

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Earth Work	11.34	cft	4.00	45.38
2	Cement	0.80	nos	480.00	383.06
3	Brick	67.83	nos	8.50	576.58
4	Sand (Kustia)	4.95	cft	25.00	123.76
5	Sand (Local)	3.78	cft	12.00	45.38
6	Khoa	2.87	cft	85.00	244.10
7	MS Rod (10 mm)	4.34	kg	72.00	312.48
				Sub Total	**1,730.72**

Inspection Chamber Requred 6 nos so total cost = 10,384.33

Footpath

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Earth Work	187.50	cft	4.00	750.00
2	Cement	0.36	nos	480.00	173.79
3	Brick	1453.13	nos	8.50	12,351.56
4	Sand (Kustia)	43.50	cft	25.00	1,087.50
5	Sand (Local)	187.50	cft	12.00	2,250.00
6					
				Sub Total	**16,612.85**

Earth work

S.L	Description	Quantity		Unit Price	Amount in Taka
1	Sattler	0.00	cft	4.50	0.00
2	Baffeled	475.27	cft	4.50	2,138.72
3	Planted	6156.00	cft	4.50	27,702.00
4	Polishing	729.00	cft	4.50	3,280.50
				Sub Total	**33,121.22**

Nabolok - EEHCO Project
2nd DEWAT plant for
Panchtola Colony
Estimates Cost at a glance

DEWATS Estimate

Sl	Option	Unit Price	Nos	Total Taka
1	Settler	48,780.48	2.00	97,560.96
2	Baffeld Reactor	104,675.01	2.00	209,350.01
3	Planted Filter	834,762.82	1.00	834,762.82
4	Polishing pond	21,955.40	1.00	21,955.40
5	pipeline Work	76,936.95	1.00	76,936.95
6	Inspection Chamber	1,730.72	6.00	10,384.33
	Footpath	16,612.85	1.00	16,612.85
7	Earth Work			33,121.22
8	Mason & Labour			133,180.14
	Dismentalling Labour Cost			10,000.00
9	Head Carring			5,000.00
10	Message Writing			1500
			Sub Total	**1,450,364.69**

Latrine Renovation

Sl	Option	Unit Price	Nos	Total Taka
1	Latrine Reno One side One floor	42,356.65	10.00	423,566.55
2	Inspection Chamber	1,754.18	14.00	24,558.54
3	Outside Plaster with labour cost			125,428.38
4	Water Supply			35,800.00
5	Mason & Labour			103,068.77
6	Plumbing			20,000.00
7	Sanitery fixing			20,000.00
8	Painter			20,000.00
9	Dismentalling Labour Cost			15,000.00
10	Head carring			2,000.00
11	Message Writing			2,000.00
			Sub Total	**791,422.25**

Grand Total= 2,241,786.94

Appendix F

Questionnaire survey

Sample 1

Personal Information:

Name of DEWAT plants user: Munshi Abdul wyadud

Age: 65

Occupation: the president of social service development committee

No. of family member: 7

Socio-economic information:

Annual residential expense (holding tax): BDT 193

Monthly expense due to waste disposal: BDT 40

Expense due to construction cost: BDT 3500

Participation of management of DEWAT system: Frankly participate

Level of satisfaction using DEWAT plant: Fully satisfy

Loss in income due to illness: Before implementation of DEWAT plant

Medical expense: Decrease after implementation of DEWAT plants

Questionnaire survey

Sample 2

Personal Information:

Name of DEWAT plants user: Abdul Razzak Khan

Age: 35

Occupation: The secretary of social service development committee

No. of family member: 6

Socio-economic information:

Annual residential expense (holding tax): BDT 193

Monthly expense due to waste disposal: BDT 40

Expense due to construction cost: BDT 3500

Participation of management of DEWAT system: Frankly participate

Level of satisfaction using DEWAT plant: Fully satisfy

Loss in income due to illness: Before implementation of DEWAT plant

Medical expense: Decrease after implementation of DEWAT plants

Questionnaire survey

Sample 3

Personal Information:

Name of DEWAT plants user: Muhammed Hamidul

Age: 36

Occupation: Worker in jute mill

No. of family member: 3

Socio-economic information:

Monthly income: BDT 10,000

Annual residential expense (holding tax): BDT 193

Monthly expense due to waste disposal: BDT 40

Expense due to construction cost: BDT 3500

Loss in income due to illness: Before implementation of DEWAT plant

Medical expense: Decrease after implementation of DEWAT plants

Participation of management of DEWAT system: Frankly participate

Level of satisfaction using DEWAT plant: Fully satisfy

Questionnaire survey

Sample 4

Personal Information:

Name of DEWAT plants user: Muhammed Nazrul Islam

Age: 38

Occupation: Worker in jute mill

No. of family member: 5

Socio-economic information:

Monthly income: BDT 7000

Annual residential expense (holding tax): BDT 193

Monthly expense due to waste disposal: BDT 40

Expense due to construction cost: BDT 3500

Participation of management of DEWAT system: Frankly participate

Level of satisfaction using DEWAT plant: Fully satisfy

Loss in income due to illness: Before implementation of DEWAT plant

Medical expense: Decrease after implementation of DEWAT plants