Water and wastewater in Bangladesh, current status and design of a decentralized solution

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Picture on front page: Latrine with direct connection to surface water in a village in Bangladesh (with permission from Woordendaad, 2016)

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Preface

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Abstract

Wastewater treatment in developing countries is a major concern and solution has become challenging for various unfavorable conditions. Inadequate education and low economic perspective are causing difficulties in implementing advanced treatment methods. Similar to other developing countries, Bangladesh is also facing several water related problems both in the urban and rural region. Water borne diseases are the common phenomenon among the villagers as well as for urban inhabitants. Insufficiency in wastewater treatment facility is making effluent water harmful for the environment. Most of the untreated effluent is discharge to the nearest water bodies. Nowadays water scarcity is very typical in Bangladesh. Ground water depletion is increasing with time. The country requires some urgent solution to eradicate problems regarding wastewater.

High population density and economic adversity are making difficulties in implementing solution. Moreover, political issues and social restriction have a huge impact on decision making. Natural calamities such as flooding affect the country very frequently. This also makes an adverse effect on the water sector.

Decentralized wastewater treatment can make a remarkable change in the wastewater issues in Bangladesh. A recommendation of implementing decentralized wastewater system in rural Bangladesh is given in this report.

Reuse of effluent water in the agricultural fields is another perspective of decentralized system. Treated effluent could be used further in irrigation. This initiative can positively reduce pressure on groundwater as well as energy consumption.

A decentralized wastewater treatment facility for a typical village in the middle part of Bangladesh has been designed in this report. From the design, combination of an anaerobic pond with a subsurface wetland have been found efficient for that certain region. In addition, comparison between other onsite systems has been discussed. This study could be useful to choose proper technology for individual areas.

Finally, proper management and monitoring system is a vital fact. Without appropriate maintenance, the main objective of this decentralized treatment will not be acquired.

Table of abbreviations

As	Arsenic
BOD	Biochemical Oxygen Demand
CBO	Community Based Organization
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DWASA	Dhaka Water Supply and Sewage Authority
DSK	Dustho Shastho Kendro
ha	Hectare
MDG	Millennium Development Goal
TDS	Total dissolved solid
TN	Total Nitrogen
TP	Total Phosphorus
SS	Suspended Solids
VARD	Voluntary Association for Rural Development
VSST	Very Shallow Shrouded Tube well

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1 Introduction

1.1 Background

Access to safe drinking water and proper sanitation facility are the biggest need for public health concern as well as for the environment. Developing countries experience more difficulties with water and sanitation issues rather than developed countries since centuries. Typically, simple technologies are used in developing countries. Most of the community depend on point water source. Moreover, treatment is rare with pipe connected areas with seldom practiced disinfection (Mahmud *et al.,* 2007).

Bangladesh is one of those developing countries, where water and sanitation are currently challenging. Despite their low economy and high population density, Bangladesh has been developed in the accessibility of water and arsenic reduction from potable water. The last few years, there has been considerable change in awareness for sanitation and hygiene. A number of local and international organizations are trying to mitigate the water related issues. There has also been significant decrease in death due to water borne diseases.

Many initiatives have been done to install tube wells for safe water sources. But the quality of water from those tube wells have noticed to be contaminated. Around 11% of death by diarrhea have been associated with the use of untreated ground water (Knappett *et al.,* 2012). Contamination is more severe in areas with silt and clay layers. In addition, improper placement of latrines and discharge of untreated effluent in the surface water are causing more severe contamination.

Ground water depletion is another significant issue in Bangladesh. According to a report in 2011, ground water declining level is about 0.1 to 0.05 m/year in Bangladesh. Also over the last 50 years, ground water extraction has increased from 20 km^3/year to 260 km^3/year (Shamsuddoha, 2011). Water extraction for irrigation by deep tube wells are the main sector of ground water extraction.

The condition of water contamination is quite different in urban and rural areas. In urban areas water scarcity is a major concern and mainly surface water is contaminated by the illegal effluent discharge into water bodies. In rural areas relatively more people have accessibility to water sources. In the past few years' arsenic was a major issue. However, the condition has been changed by some significant approaches to mitigate this problem. In rural areas there is still lack in treatment facilities of wastewater. Village inhabitants discharge wastewater almost untreated to the nearest water bodies although there is a huge potential of this wastewater to be reused in agricultural fields. Such initiative will not only reduce ground water demand but can also serve for a better environment, if proper treatment is provided.

1.2 Aim

The objectives of this report were to analyze the current water and wastewater condition in Bangladesh and suggest an appropriate solution that limits the issues related to wastewater.

To obtain knowledge for recommendation, water and wastewater system of a developed country has been analyzed in this report. Sweden has been chosen for this propose. Available technology and management system of water and wastewater in Sweden has been discussed also in the report.

Verification of the proposed recommendation was another aim of this report. A design example has been done to verify the suggested improvement facility. A typical village in Bangladesh was considered for design purpose. The design included several facilities of decentralized wastewater management system. A comparison among the suggested decentralized technologies has also been done.

1.3 Approaches followed for the thesis

The main approach for this thesis work includes literature search and reviews. Various journals, articles and books have been used as a data source. Other related data and information are collected from the official website of different organizations. Acquired Knowledge from "Decentralized Water and Waste Water" course has influenced the recommendation.

In this report, both the rural and urban situation of the water sector in Bangladesh has been described. However, only rural sanitation has been considered for recommendation. The description has been done to visualize current condition. Some ongoing and implemented improvements in the sanitation and water sector have been described.

A case study has been presented in this report to explain the actual situation of rural Bangladesh. The case study from the official website of World Health Organization (WHO, 2016) has been used for this purpose. This case study includes sewage management of a small village in Bangladesh and its effect on drinking water source.

Swedish water and waste water technology has been presented as an example. This is done to evaluate the difference in water sector between developed and developing countries. Also, the proposed suggestion of improvement is influenced by the Swedish decentralized water technology. Decentralized wastewater systems have been suggested as solution for rural communities in Bangladesh. Decentralized systems are not the main treatment facilities in Sweden. However, these technologies appear to have potential in developing countries like Bangladesh.

A design example of according to the recommendation has been done for a typical village in Bangladesh. The design method includes empirical equations. Area requirement for various onsite treatment options has been calculated. Also nitrogen and phosphorus removal with these systems has been discussed.

A comparison among the designed onsite systems has also been done. Both primary and secondary treatment options are compared according to various parameters and situation. The comparison is based on design and data from other sources.

Finally, reuse of treated effluent in the agriculture has been suggested for sustainability. Benefits and risks associated with the reuse of effluent in irrigation has been discussed.

2 Overview of Bangladesh

Bangladesh is a small country in south Asia surrounded by India and Myanmar. The southern part touches the Bay of Bengal (Figure 1). It is one of the most densely populated countries in the world. The population is almost about 160 million with a growth rate approaching 1.6%. The area of Bangladesh is about 148,460 sq. km. Approximately. 70% land is considered for irrigation purposes and 18,290 sq. km is covered with water (Cia, 2016).

Bangladesh is situated in the tropical region. The average temperature varies from almost 18°C to 28°C and the highest precipitation is around 532 mm in July and lowest in January almost 14 mm (World bank, 2016).

Figure 1: Position of Bangladesh (Picture collected from google map)

Bangladesh came into being independent in 1971, when the two parts of Pakistan split after a bitter war. The country experienced 15 years under military rule and, although democracy was reestablished in 1990 (BBC News, 2016).

Dhaka is the capital of Bangladesh with the highest population density of about 13 million. Rapid growing urbanization in the capital is attracting people to the cities. Almost 32% people of Bangladesh live below poverty line (Cia, 2016).

Bangladesh is a land of high fertility for agricultural products. The extensive network of large and small rivers contributes a lot to the fertility. Among them, the Ganges-Padma, Brahmaputra, Jamuna, and Meghna are the major rivers. The country is serving rice, wheat, jute and different necessary products for the nation. Most of the rural inhabitants depend on agricultural based work.

The geomorphological condition makes Bangladesh more vulnerable to climate change. Two third territory of the country is less than five meters above sea level. Flooding is a recurrent and common natural calamity in Bangladesh. Nearly 30% of the country experienced annual flooding during monsoon, where 80% of total annual rainfall occur in monsoon period. Extreme events can be spread up to 70% flooding. Two biggest flood events occurs in 1988 and 1998, where 1,378 people and 1100 people died respectively in these two events (Majumder and Venton, 2013)

Despite the various adverse situations, Bangladesh has developed a lot in education. Also, Bangladesh has improved significantly in the water sector in last few years. According to Central intelligence agency US 2015, around 87% of total population have improved drinking water source. However, about 57% urban and 62% rural population have improved sanitation facility (CIA, 2016).

An "improved" drinking water source is one that protects water against contamination through its construction process. An "improved" sanitation facility is one that separates human excreta from human contact hygienically. It includes different technological options, such as flush toilet, piped sewer network, pour flush latrine, single and twin pit latrine, ventilated improved pit latrine etc. (WHO and UNICEF, 2012).

3 Drinking water in Bangladesh

3.1 Sources of drinking water

Groundwater is the major source of drinking water, both in urban and rural areas. There are plenty of rivers and canals throughout the country but surface water is not considered as a source for water supply.

The availability of water varies throughout the year. During monsoon, almost two third of the annual rainfall evaporates and 15% water percolates into the deep soil which raises the ground water table and makes it easier to collect. In dry season due to less rainfall and high evaporation the water table falls but the regular collection continues throughout the country (Rashid *et al.*, 1994).

In average groundwater is the major source of drinking water for more than 98% people of Bangladesh. The underlying sand and gravel aquifer are highly productive. Also sand and clay soil acts as a natural filter. The natural filter reduces bacterial contamination hence groundwater becomes a trusted and cheap source. In rural areas, water is collected by hand tube wells, pumps, and is almost decentralized. But in urban areas water is distributed by the piped system (Bangladesh national drinking water quality survey 2009, 2011).

3.2 Collection Technology

3.2.1 Rural water supply

In rural areas, piped system water supply not introduced and the system is decentralized. Rural water collection technologies include low-cost tube wells such as shallow hand tube wells, Tara hand pump and Very shallow shrouded tube wells (VSST). Usually, one individual household or few households share one tube well.

Shallow tube well

Shallow tube wells are quite common techniques in both rural areas and urban slums. Almost 87% of the public wells and 94% of the private wells are shallow tube wells in rural areas. They are very easy to operate and inexpensive. This pump works by creating a vacuum in the suction pipe and can draw water from 7 m below ground level. Moreover, a deep-set hand pump is an advanced technology of shallow tube well and could extract water 30 m deep below ground level (Department of Public Health Engineering Bangladesh, 2016).

Dug well

Dug wells generally are seen in hilly areas of the country such as Chittagong and Sylhet. Due to adverse hydrogeological conditions and stony soil condition tube wells are hard to construct in these areas. Dug wells are suitable for shallow depth (Department of Public Health Engineering Bangladesh, 2016).

Tara hand pump

In dry season extracting deep ground water with shallow tube wells become much harder and sometimes impossible. To overcome such situations tara hand pump was introduced. It is a force mood pump which operates below static level. The cylinder of the pump is set 18 m below ground level with a PVC hollow pump rod set vertically installed, which operates the piston (Department of Public Health Engineering Bangladesh, 2016).

Very Shallow shrouded tube well (VSST)

Usually in coastal areas where salinity is a big issue, VSST used to mitigate the salinity problem. VSST is a special type of tube well, which collect water from very shallow aquifers, formed by displacement of saline water from the continuous flow of accumulated fresh water. The freshwater lenses are usually found beneath the old ponds in coastal areas. An artificial sand packing is placed around the screen of the tube well to prevent fine sand particles from entering on the screen. This packing is called shroud. The depth could be 15 to 20 m depending on the aquifer condition (Department of Public Health Engineering Bangladesh, 2016).

3.2.2 Urban water supply

The urban water supply system is mainly centralized and managed by an organization named DWASA for the capital Dhaka city and CWASA for the port city Chittagong. Nevertheless, the water supply systems in slums of the cities are not categories as centralized. Slum dwellers collect water from municipal taps or tube wells, some also collect water from surface water bodies such as canals and rivers, which are not considered as a safe source of water.

Dhaka Water Supply and Sewerage Authority (DWASA) have the responsibility of providing water supply and managing storm water and sewage disposal in the metropolitan city of Dhaka. It covers more than 360 sq. km service area with 12.5 million people with a production of almost 2110 million liters per day. DWASA has divided the whole Dhaka city into 11 zones. Among them 10 is inside the city and one is a subzone, Narayanganj. Each zone has an individual office that works for the operation and maintenance of the particular area. According to DWASA the present water demand in Dhaka city is 2.25 million cubic meters per day, where the organization meets 2.11 million cubic meters per day supply at present. About 0.87% of water is collected from 605 deep tube wells and the rest 13% comes from surface water sources (Khan, 2012).

3.3 Quality of drinking water

According to Bangladesh national drinking water survey 2009, 22 million people are still drinking water that does not meet the standard level for arsenic of 0.05 mg/l and 5.6 million are in high risk of having water with more than 0.2 mg/L arsenic (Bangladesh national drinking water quality survey 2009, 2011).

Table 1, shows the standard values of different elements in water according to Department of public health engineering and World Health Organization. Some common elements have been selected in this table. Arsenic was a major concern in Bangladesh in recent years. BOD, COD, Nitrate, Phosphate and chloride are very important elements for drinking water. Excessive amount of these elements can cause health hazard. Drinking water should contain the following elements according to the standard stated in the table.

Table 1: Water quality parameters (UNICEF, 2011; Department of Public Health Engineering Bangladesh, 2016).

Elements	Bangladesh standard (mg/L)	WHO standard (mg/L)
Arsenic	0.05	0.01
BOD_5	0.20	-
COD	4.00	-
Aluminum	0.02	-
Hardness($CaCO_3$)	200-500	-
Iron	0.3-1.0	-
Chloride	150-600	-
Nitrate	10	50 as NO_3
Phosphate	6.0	-

The survey also stated that 98% of the tested samples meet the Bangladesh standard of 600 mg/L for chloride concentration. The condition for hardness is also in an improved state. Almost 94% of the samples meet the standard value. Fluoride concentration is very lower according to the study. Six samples (1%) exceeded the Bangladesh standard of 1.1 to 1.5 mg/L. But the condition is much different for Iron concentration in the drinking water. Throughout the country, only 60% of the tested samples met the national standard of 1 mg/L iron. The other 40% is below the standard. The amount of phosphorus in almost 93% of the sample met the standard value 1.96 mg/L that is equivalent of 6 mg/L phosphate (Bangladesh national drinking water quality survey 2009, 2011).

Good quality ground water is pumped from the deep aquifer in Dhaka city. However, the quality does not remain similar to the consumers. Along its transport through the pipe network a number of sources cause contamination of the water. Leakage in the pipe network, negative pressure due to the usage of the suction pump, service connection installation under septic tanks etc. are reasons behind water contamination in the pipe network (Khan, 2012).

3.4 Treatment of drinking water

3.4.1 Urban treatment process

In urban areas, DWASA is responsible for treating potable water for the community, in the capital city Dhaka. DWASA is currently running one large and three small water treatment plants with financial assistance from different funding organizations (Khan, 2012).

According to the department of public health and engineering of Bangladesh, most of the treatment facilities include filtration, flocculation, sedimentation and disinfection. Some also include ion exchange and filtration depending on the quality of collected water. A ground water rule is developing to specify the appropriate use of disinfection to assure public health protection.

However, to meet the fastest growing water demand and reduce ground water extraction, DWASA planned to build four large surface water treatment plants until 2021. They are "*Saidabad Phase II*", "*Saidabad Phase III*", "*Padma/Pagla*", and "*Khilkhet*". These plants have been proposed to draw water from less polluted surface water even though they are distant sources such as rivers. The four plants are expected to have a combined capacity of 1.63 million cubic meters surface water per day, whereas in 2010 the supply of ground water was 2.11 million cubic meters per day (Khan, 2012).

3.4.2 Rural treatment process

Easy availability and no content of pathogenic microorganisms makes ground water so popular that most of the rural population are now dependent on low-cost tube wells. Studies stated that Bangladesh achieved a remarkable success providing 97% of the rural population with bacteriologically safe tube well water. In some regions where tube well water is not trust worthy, People usually boil water for purification.

Arsenic contamination is one of the major challenges in the shallow aquifers and many parts of the country have made shallow tube well water unsafe for drinking. Different strategies have been developed to mitigate the arsenic problem. Those are classified as chemical and non-chemical treatment. Pond sand filters, dug and ring well, chulli water purifiers (CWP) are some nonchemical solution for arsenic contamination. Chulli water purifier is a special type of clay oven with metal coil. Water is passing through the coil and gets purified from arsenic by heat (Johnston, 2009). Chemical options include different types of filters such as SIDKO, SONO, READ F, and AIKAN (Department of Public Health Engineering Bangladesh, 2016).

3.5 Current issues on drinking water

Various issues are currently affecting the drinking water sector in Bangladesh. Some of them are described below.

Arsenic

Arsenic in water is one of the major health concerns in Bangladesh. According to Bangladesh national drinking water quality survey of 2009, almost 20% shallow tube wells contain arsenic in the water. In 271 out of 463 upazilas (sub units of districts) arsenic was identified from the Survey of DPHE-UNICEF & DPHE-BGS. The Survey also stated that, 198 safe upazilas identified 12 more upazilas having the arsenic problem (Department of Public Health Engineering Bangladesh, 2016). Estimation stated that approximately 57 million people in Bangladesh drink water, which exceeds WHO guideline of as level 10 µg/L (Robinson *et al.*, 2011). Especially shallow tube wells of less than 150 m deep contains more arsenic concentration than the deep tube wells. Different local and international organizations are still working to mitigate the arsenic problem in Bangladesh.

Ground water depletion

Excessive extraction of ground water from shallow aquifers causes lowering of the ground water table. In dry season water scarcity becomes so high that in some places it is rare to have water from deep tube wells. According to DWASA, the aquifers of Dhaka city are about to exceed its withdrawal limit. Ground water depletion is occurring at an alarming rate. The ground water level has been decreasing by two to three centimeters each year in most places. Estimation from a study says groundwater depletion in the Bengal basin is almost -0.34 to -1.14 cm/year. In the Ganges and Brahmaputra basin the depletion rate is -1.1 and -1.5 cm/year (Taylor *et al.,* 2012). Intensive groundwater extraction in agricultural purpose and low permeable surface in urban areas are contributing to ground water depletion. About 79% irrigation area is covered by groundwater (Ullah & Kabir, 2012).

Demand exceeding supply

The fast growing population creates a huge amount of water demand. Water use in agriculture has increased by 2.73 times during 1991 to 2001.According to a projection, in 2018 water the supply will be 23,490 mega cubic meter and the demand will be 24,270 mega cubic meter (Ahmed & Roy, 2007).

Water Pollution

Water pollution is one of the major problems in Bangladesh. However, the collected water from ground water sources is not contaminated. It gets worse during its way to the consumer. Surface water is already being polluted and is not considered as a direct source for potable water. A number of people around the country suffer from water-borne diseases every year.

4 Existing sanitation condition in Bangladesh

Sanitation is one of the biggest issues in Bangladesh and has become a major sector of concern. Sanitation facilities are worse in rural areas than in urban areas. Some urban slums still do not have improved or shared latrines. In 2009, 65% of the urban slum had shared latrines. However, it has been improved during past years, in 2006 only 17% had the facility of shared latrine. In rural context, situation has changed a lot since last few years. Access to improved sanitation facility increased in 2006 to 2009 at 57%. However, 20% of the poorest household still defecate openly (Zheng *et al.*, 2013).

Since 2000 significant activities are going on to improve the sanitation condition in Bangladesh. Though in 2009, 55% of the total population had improved sanitation facility. It is far from meeting the millennium development goal target of 70% in 2015 (Zheng *et al.*, 2013).

4.1 Urban context

Dhaka City Corporation has the responsibility for waste management in Dhaka and municipalities of other cities are responsible for their waste management system. DWASA is responsible for sewage treatment in the capital city Dhaka. There is one large sewage treatment plant, which covers 30% of all households in Dhaka. Other households have their own septic tank. Different NGOs are also playing a vital role financially and by providing hardware support, advocacy networking, institution building, training information, research, evaluation and monitoring (Jahan & Rahman, 1997).

Single and twin pit latrines are the most common types of improved sanitation facilities in urban areas. They are also available in rural areas. Homemade latrine (HML) consisting of an unlined pit covered with a platform and a hole are also seen in urban slums (Rashid *et al.*, 1994).

DWASA has divided the whole Dhaka city into 6 different zones to maintain the entire sewer system. In each zone there is several sewer lift station and all the connection is continued till it reaches the treatment plant. Only 30% of the city is covered by this system. So there is a huge community who is still not considered to have adequate sewer system.

Different initiatives have already been taken to improve the situation. DWASA has introduced a small-bore sewerage system in the Mirpur area with financial aids from ADB. Other initiatives includes rehabilitation of the Pagla sewer treatment plant financed by JICA in 1990s and the Urban Development Project of IDA involving the construction of latrines in the slum areas (Haq, 2006).

4.1.1 Pagla WWTP

At present Dhaka has one sewage treatment plant Pagla sewerage treatment (PST) plant in Saidabad. The capacity of the plant is 120 000 m^3/day. The plant has 49 000 domestic sewer connections, 778 km of sewer line of different diameter, 20 sewer lift stations, 1 central pump station and 3 truck interceptor sewers. As the topography of Dhaka is mostly flat gravity system is used. In this system pipes are installed about 1 m from ground level carried to a depth of 6 m with a slope of about 0.66% accumulating the effluent in a sump. The effluent is lifted by pumps from the sump and discharged to an intake at 1 m depth from the ground surface and this process continues till the effluent reaches the treatment plant. The treated effluent is discharged to the nearby river Buriganga. The treatment plant was designed for a wastewater with a BOD concentration of 200 mg/L and SS of 200 mg/L. The treatment plant has also been designed for an effluent quality of 50 mg/L and 60 mg/L of BOD and SS respectively to release into the environment (Haq, 2006).

The treatment is generally based on a low cost option consisting of grit chamber, primary sedimentation tanks, facultative lagoons, a chlorination system and a sludge lagoon. The designed BOD and suspended solid removal rate is about 70% and 75% (Amin *et al.*, 1998).

4.1.2 Sludge disposal

Different types of pit emptying process include manual or mechanical emptying. In Dhaka mechanical emptying is more common than the other cities of the countries. Almost 30% of the households in Dhaka prefer a mechanical emptying process rather than the manual one because of community pressure. Other household in Dhaka and other cities still uses a manual emptying process. In addition, a mechanical emptying service is more available in Dhaka than the other cities. Different NGO's that have WASH programs provide this facility. Pits in Dhaka cities are emptied more frequently than in the other cities. Almost 90% of the households empty their pit once a year (Opel *et al.*, 2012).

Especially in Dhaka most of the sludge is dumped in the open drain or water bodies. This practice is less common in the other cities. However, in many areas sludge is not disposed in the designed sites. Putting sludge in open places are contaminating water, causing health hazard to human life, and making negative impact to the environment (Opel *et al.*, 2012).

4.1.3 Urban Issues

Poor sanitation condition

Existing sewerage and sanitation capacity of Dhaka is not adequate. Present sewerage system only covers about 30% of the total population of Dhaka (or 25% of the DWASA service area). An estimation states that, 30% of the population uses approximately 50 000 septic tanks and another 15% have access to bucket and pit latrines. The remaining population does not have appropriate sewerage disposal system. Most of the sewerage collection and transportation system is in a poor condition because of lack of a proper repair and maintenance. Sewage overflow into storm drains during the rainy season occurs due to this condition. It also creates unsanitary conditions that are aggravated by the lack of a well-functioning drainage system (Haq, 2006).

Urban sanitation is limited to on-site options (e.g. septic tanks and pour-flush pits) or conventional waterborne sewerage (only in parts of Dhaka city) and excludes a range of intermediate technology options which could be cost effectively used based on user preferences and willingness to pay (Jahan & Rahman, 1997).

Illegal connection

A high number of septic tanks have been connected illegally to the central sewage network. This is increasing the influent load in to the treatment plant and thus decreasing the efficiency of the plant.

From a study based on optimization of the treatment process at Pagla WWTP, the average flow rate was found to be higher than the designed value. The value found is 163,000 m^3/day in wet season and 122,250 m^3/day in dry period. This could be due to illegal connection to the sewage network. Unexpected BOD_5 and COD values were found in the range of 500 mg/L to 2500 mg/L. Higher concentration of suspended solid and fecal coliform were also found in this study (Amin *et al*., 1998).

Lack in operational system of plants

The quality of the final effluent of Pagla wastewater plant has exceeded the allowable limits of Bangladesh Environmental Quality Standard. From the study based on optimization of the treatment process at Pagla WWTP, BOD_5 values and COD values were found maximum 455 and 475 mg/L respectively. These values are even worse in winter 720 and 830 mg/L respectively. Suspended solid and fecal coliform have also exceeded the limit of Bangladesh Environmental Quality Standards. The values were found 180 mg/L SS. The dissolved oxygen content was found 0.42 to 1.2 mg/L in the dry season, which is very low. Also the sludge bed contains heavy metal including lead, chromium, copper and zinc. High amount of BOD, COD, SS, low level of DO in the outlet and heavy metal in the sludge bed indicates presence of industrial waste and other pollutants in the inflow sewage. Also Characteristics of effluent indicates the poor performance of the plant (Amin *et al*., 1998).

In Faridpur there is only one faecal sludge treatment plant. This plant was constructed in 2009 but still has not been tested and commissioned. Already many elements of the plants are damaged. The size of the plant is 24.5 m^3 and capacity is 15.31 m^3 in six months treatment time. With the annual treatment capacity of 30.62 m^3 this plant can serve 0.45% of the total sludge of the city annually (Opel *et al*., 2012).

Unplanned industrialization

Unplanned industrialization and untreated effluent discharge has been considered as a major pollution source. From the beginning of the independence of Bangladesh, industries have grown tremendously in an unplanned way especially in residential areas. About 250 tanneries in the Hazaribagh area in the Dhaka city are causing serious environmental pollution and health hazard. which is making the area unsuitable for habitation. The Buriganga, the Shitalakhya, the Karnafuli and the Rupsha rivers are already been polluted by the effluent of different industries around these rivers (Hossan, 2014).

4.2 Rural context

The department of public health and engineering has the functional responsibility for the rural area. Some private sectors and NGO's are also working for a better sanitation and health issues in rural areas of Bangladesh (Haq, 2006).

Rural sanitation activities started in the public sector from 1954 with assistance from the world health organization (WHO). After that latrine slabs were distributed free. Latrines were subsidized by UNICEF. During 1990s use of hygienic latrines in rural areas increased dramatically to 33% (Rashid *et al*., 1994).

Home made single pit and water seal latrines are widespread in rural areas. The pit used for latrines usually has five concrete rings with ferrocement or reinforced concrete slab. The water seal latrines are mostly made of ferrocement. In case of twin pit latrines, a new pit is to be dug as well as the super structure has to relocate (Rashid *et al*., 1994).

Pour flash latrines are common both in rural and urban areas. In pour flash latrine a latrine pan with a shallow U-bend water seal is used. Water is needed to flash the excreta in to the pit or sewerage system. This type of latrine causes less odour and it is easy to clean (Harvey, 2007)

4.2.1 Rural Issues

Water borne diseases

Unhygienic condition and water pollution makes the situation so bad that water borne diseases are now quite usual in Bangladesh. About 41000 children of under five year die each year in diarrhea (Wateraid, 2016). The number of diarrheal cases and deaths in 2009 was double than that of the previous year (Ullah & Kabir, 2012). Beside diarrhea, other diseases like cholera and typhoid are associated with water and are making harmful health disaster to the people.

Annual flooding

Flooding is a common annual disaster in Bangladesh. On an average 20% to 30% of the country's area is flooded by monsoon each year. At least eight extreme flood events occurred during the last half century, and affected 50% of the land area (Ullah & Kabir, 2012). Flooding has vulnerable impacts on human health. Drinking water sources, water supply systems as well as sewerage system are adversely affected by flooding. Especially in post flood period, the risk of diarrhea is considerably higher. Also there is a potential risk of cholera for unsanitary toilet users (Hashizume *et al*., 2008).

Poor maintenance

Pour-flush pit latrines appear to be the only low cost sanitary option available to the rural population. Homemade pit latrines are the cheapest option but may not be appropriate for all soil types and many believe that this method is not fully sanitary. Also improper maintenance of water seal latrines leads to water seals clogging which users are unable to clear. This often leads to users breaking the water seal.

Direct discharge in surface water

Rural sanitation suffers from poor understanding of the health benefits of sanitary latrines. Latrines are used for reasons like convenience and privacy rather than health reasons. Even though villagers have pit latrines, they discharge fecal waste in a wrong way. Many households in rural areas discharges waste from pits directly in the nearby water bodies. Figure 2, is a real picture from a typical village in Bangladesh. In figure 2, a latrine is seen with a direct discharge pipe in the surface water.

Figure2: Latrine with direct connection to surface water in a village in Bangladesh (With permission from Woordendaad, 2016)

Seepage from pit

Pit location near tube wells in rural areas causes contamination of drinking water. Most of the villagers are not aware of the pit seepage below the ground to the nearby water sources. In addition, sometimes pits are within the minimum distance between water sources and through seepage water gets easily contaminated.

4.2.2 A case study on rural Bangladesh

In a small village "Kanpura" in Bangladesh near the northeast border with India, a case study was carried out by "WHO" to evaluate the present water quality and sanitation facilities. The village has a population of 525 persons with 88 households. Among them 18 households still defecate openly. There are 60 latrines but 50% of them are considered as non-hygienic (WHO, 2016).

The main source of potable water is ground water and 46 shallow tube wells are found in this region. However, peoples have water to drink but it is not safe enough to drink directly from tube wells. Still families are suffering from cholera, diarrhea and other water borne diseases.

The worst finding is that 12 out of 60 latrines in this village are not within the safe distance 30 feet from potable water sources. The distance measured is 6.1 m between latrine and tube well. It is one of the major reason behind ground water contamination. Seepage from the pits is mixed with ground water and thus the tube well water becomes polluted. In addition, platforms under tube wells are missing in some places and drains are not maintained properly. which is also contributing to ground water pollution (WHO, 2016). Figure 3 is a representative figure showing the process how the source of groundwater is polluted with seepage from latrines.

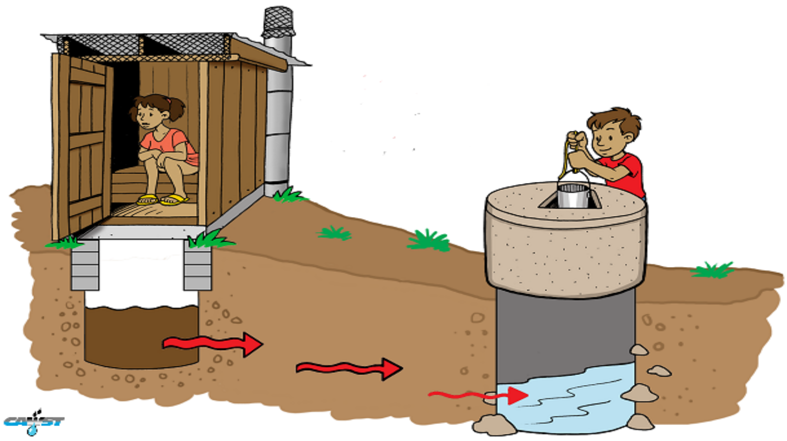

Figure3: Seepage from pits to ground water sources (Picture used with permission from CAWST,2016)

The situation has now changed by an awareness activity. A community based organization (CBO) was made with 11 members from the village and this organization worked under supervision of a Bangladeshi NGO named VARD. During their work, most of the latrines were moved to a safe distance from water sources. Other different awareness programs was also done by the CBO (WHO, 2016).

There are several villages like "Kanpura" in Bangladesh, where sanitation facilities are available but improper position of toilets near potable water sources and lack of sludge discharge facilities makes the ground water polluted. This case study is an example of the actual situation of rural areas in Bangladesh. Though there remain a number of other issues related to wastewater in Bangladesh. However, this case study is presented to understand the necessity for proper wastewater management. In addition, only implementation of infrastructure in not sufficient, appropriate management and knowledge is essential.

5 Implementation of legislation

Bangladesh government has many legislations and rules to protect their water and environment. Different governmental organizations as well as NGOs work for implementing regulations. The Department of Environment (DoE) is a government organization, it works on that basis. This organization has created mobile court in order to implement action against ECA violator under the Environment Conservation (Amendment) Act-2010. “Polluters pay principal” is mentioned in the Environment Conservation Act, 1995 (Hossan, 2014).

The environmental conservation rule 1997 states some standard for surface water (Government of Bangladesh, 1997). Table 2 represents guidelines for different parameters in surface water. Surface water used by different activity should maintain concentration of various parameters according to the table below.

Table 2: Standard for surface water (Government of Bangladesh, 1997)

Classification	pH	BOD(mg/L)	DO(mg/L)	Total coliform (number/1000)
1.Water usable for recreational activity	6.5-8.5	3 or less	5 or above	200 or less
2.Water usable by cooling industries	6.5-8.5	10 or less	5 or above	5000 or less
3. Water usable for fisheries	6.5-8.5	6 or less	5 or more	-
4. Water usable for irrigation	6.5-8.5	10 or less	5 or more	1000 or less

The industrial policy, 1986 recommends to the sanctioning agencies that project involving pollution and health hazards should contain adequate affluent treatment and disposal with pollution control devices. The policy also says existing industries should act appropriately to control pollution with in the specified period set by the government (Hossan, 2014).

The National Environment Management Action Plan (NEMAP), 1995 includes identification of major environmental issues and action to minimize environmental degradation. improving natural environment by conserving biodiversity. It developed with in the period of 1995 to 2005 (Hossan, 2014).

Different international organization also helps financially by providing fund for implementing environmental regulations in Bangladesh. They are DANIDA, SIDA, USAID, CIDA etc. (Hossan, 2014).

6 Present strategies for solving water issues

The Bangladesh government as well as a number of organizations and institutions are currently working to find appropriate solutions for the water related problems in Bangladesh. Among them arsenic is one the major concern.

6.1 Color scale for identifying aquifer with arsenic

Recently one international research team from KTH Royal Institute of Technology has created an easy-to-use method for identifying aquifers with safe levels of arsenic. The main finding from the research was that the color of sediment obtained through test borings correlates to the concentration of arsenic found in the water. They made a color scale with five color based on the local drillers' color perception and Munsell's color system (Sida, 2014). By which the driller can compare sediment color and determine presence of arsenic in the water. The (SASMIT) sustainable arsenic mitigation project also created 300 new wells that supply drinking water to 24000 people using this color scale (Sida, 2014).

6.2 Reuse of grey water

Reuse of grey water could be an attractive solution to minimize water scarcity. Recently some research was going on to initiate and analyze the possibility. About 75% of the total wastewater is grey water (Khatun & Amin, 2011). If this amount of wastewater could be treated and reused, a huge amount of wastewater load could be reduced from the treatment plant. In addition, this initiative could reduce the quantity of nutrients and other toxic contaminants entering in the waterways. However, the implementation of a separate plumbing system for collecting grey water for treatment and reuse could be difficult. In addition, acceptance and cost are important issues (Khatun & Amin, 2011).

6.3 Decentralized fecal sludge management

In 2005, a project started by GHK international, an international organisation to establish a decentralized fecal sludge management in Bangladesh. Two NGO's PRISM and Water aid were involved in this project. PRISM initiative was to promote integrated wastewater treatment and aquaculture. The use of wastewater stabilization ponds in Khulna was one initiative by PRISM, which were used for treatment of wastewater and production of duckweed and finally used to feed fish (Parkinson, 2005).

6.4 Support to slum dwellers

Another initiative by Water Aid is to provide support to slum communities for improve access to water supply and sanitation facilities. With the support from Water Aid and DSK, an NGO in Dhaka piloted a latrine-emptying machine called Vacutug. This was developed and adopted to be a cost-effective alternative to traditional practices (Parkinson, 2005).

7 Swedish technology on water and wastewater

Sweden is a country in Scandinavia and has a population of about 9.6 million (World Bank 2014). The area of Sweden is 450000 sq. kilometer. Stockholm is the capital of the country. The climate is quite cold. Average temperature of July is almost 18°C and winter temperature is below freezing in January and February. Average precipitation of the country is almost 600 mm in the south and 1500 mm in northwest mountains (Svenskt Vatten, 2000).

The country has an advanced and developed water system as well as plenty of water. The Swedish water sector is entirely public. There are some municipally owned companies as well. About 99% of the total financing comes from tariffs (Palme *et al.,* 2008).

7.1 Drinking water in Sweden

Drinking water is considered as food in Sweden. Therefore, water is treated as production of food. The water quality is so reliable that people can even drink directly supplied tap water.

Almost 100 000 lakes cover 9% of the total area. About 50% of the total drinking water comes from surface water sources, mainly the lakes. There are almost 200 large treatment plants and 2000 water works in Sweden. A number of small plants use ground water as a source of drinking water, which makes up 25% of the total produced water. Remaining 25% water is collected as artificial ground water. Average water consumption per person per day is almost about 330 liters (Palme *et al.,* 2008).

7.1.1 Treatment of drinking water

Figure 4 shows typical treatment process for a surface water source. Typical treatment includes screening of coarse materials, flocculation and sedimentation. Rapid and slow sand filters are used for further treatment. Generally, disinfection is done by chlorination. However, ozone treatment and UV radiation is also used in Sweden.

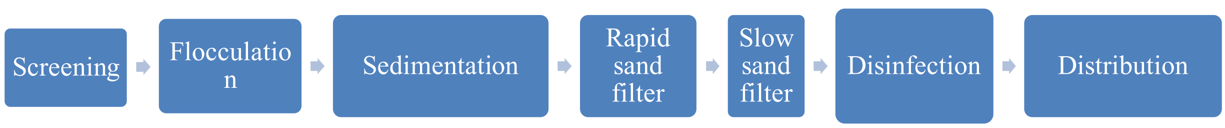

Figure 4: Typical treatment process of drinking water in Sweden (Svenskt Vatten, 2000).

7.2 Wastewater in Sweden

Sweden started supplying good quality water in urban areas in the mid of 19th century after huge outbreaks of cholera in Stockholm and Gothenburg (Svenskt Vatten, 2000). Sewage treatment started from 1930. During that year, a popular swimming contest had to be discontinued for health risk in Stockholm. From then the necessity of sewage treatment was noted. In 1950, biological treatment was introduced to supplement mechanical treatment. Later in 1970 chemical treatment to precipitate phosphorous was introduced. Sweden has mostly separate system. However, before 1950 combined system was popular. After 1950 combined system has been renewed by separate system. Still, about 20 to 25% of old urban connection has combined system (Svenskt Vatten, 2000).

7.2.1 Wastewater treatment

Sweden has 2000 sewage treatment plants, which serves almost 7.7 million people. Some plants have biological, chemical treatment and nitrogen removal system. Those plants cover

36% of the total population. About 58% of the total population is served by plants without nitrogen removal system. Some of the other plants have only biological or only chemical treatment facility (Svenskt Vatten, 2000).

Typical centralized treatment process for wastewater consists of mechanical, biological and chemical treatment. Most of the plant uses activated sludge process. Pre-treatment is done mechanically. Organic matter and nitrogen are removed in the biological treatment and chemical precipitation is used to precipitate phosphorous (Svenskt Vatten, 2000).

7.2.2 Effluent quality

Sweden has far-reaching effluent demand for treated wastewater. Typical limit values are organic matter (BOD_7) 10 to 15 mg/L, phosphorus 0.2-0.5 mg/L and nitrogen 10-20 mg/L (Svenskt Vatten, 2000).

7.2.3 Sludge disposal

At the end of the treatment process 230 000 tons of sludge is produced annually. This expressed as dry solid. However, this sludge contains a high amount of phosphorous to be used as fertilizer. But Sweden has an ambition to use 30% of the sludge to use as fertilizer in the agricultural sector (Svenskt Vatten, 2000). A previously common option for sludge disposal at landfill was prohibited in 2005. According to Swedish Environmental objectives phosphorous has to be recycled before disposal to reduce health impact (Palme *et al.,* 2008).

7.3 Decentralized system in Sweden

In Sweden almost one million households far away from urban areas are not connected to centralized system. Different onsite technologies are used for treating wastewater and drinking water production and distribution. These on site systems are mainly used for population ranging up to 500 inhabitants. This range could be increased in some particular places (Norström, 2005).

Mainly source separation systems and natural systems are two divisions of these on site systems. Source separation includes separation of urine, black water and grey water. End pipe solutions include different technologies such as small treatment plants based on biofilm process or sequencing batch reactor (SBR), artificial filters and natural system etc. (Norström, 2005).

7.3.1 Source separation

The concept of source separation has been developed in the last 10 to 15 years. This system can be combined either with municipal centralized treatment or in decentralized treatment. The main purposes of a separation system are recovery of resources, reuse nutrients, emission reduction to the environment and more efficient handling of flow. It is estimated that, Urine separation could reduce N and P concentration in the treatment plant by 55% and 33% respectively (Mels *et al.*, 2007).

In Sweden, ten projects with urine separation have been implemented. Among them 'Understenshöjden' in Stockholm consists of 44 rental house with source separating sanitation system. The urine is collected one a year and it is then stored for six months to remove pathogens. Then this urine is used as a fertilizer for cereal crops. Previously grey and brown water is locally treated but to fulfill effluent standard it is currently discharged in to the municipal sewer system (Mels *et al.*, 2007).

7.3.2 Natural systems

Natural systems are those that depend on natural components. Sometimes these need external energy sources. These are also known as “Green” system. Different natural system includes wetlands, anaerobic, aerobic and facultative ponds. Sub surface wetland is common in Sweden for onsite treatment (Norström, 2005).

Small plants based on biofilm processes are more flexible than the activated sludge process concerning large variation in hydraulic load and organic load. SBR system has also shown good performance in small sites. Several small plants use chemical precipitation as a pretreatment for infiltration and sand filter. Sand filters and infiltration units are most common on site treatment process in Sweden (Norström, 2005).

7.4 Reason for presenting Swedish water technology

The system used in Sweden has great efficiency. The above description is some of the advancement of their water technology. From this study a huge difference in water sector between a developed and developing country can be noticed. Countries like Bangladesh is very much lacking behind in the water sector compare to Sweden. However low population density, good economic condition and available area may contribute a lot for the developed countries like Sweden.

Bangladesh has a lot of difficulties in its way to development. Moreover, the geographical conditions and climate in Bangladesh is not similar to Sweden. Bangladesh is a tropical country and Sweden lies in the northern latitude. Average temperature in Sweden is about 10°C lower than Bangladesh. However, from the above study an inspiration can be gained. Technologies used in Sweden could be someway efficient enough in Bangladesh.

In Sweden most of the population is served by centralized advanced wastewater treatment. Decentralized wastewater treatment has been used by remote regions where piped connection is hard to reach. However, this decentralized wastewater treatment can make remarkable change in the field of wastewater management in rural areas of Bangladesh. Population density is quite low in rural Bangladesh and Swedish decentralized solution could be used for the current issues.

8 Decentralized wastewater solution

8.1 Concept of decentralization

A decentralized approach for wastewater treatment is mainly a combination of some onsite systems, where treatment is mainly done next to the source of wastewater. Decentralized wastewater treatment does not mean one specific plant for the whole population of a defined area but it rather defines more than one or an assortment of technologies (Libralato *et al.,* 2012).

This system is mainly designed for a low to moderate population and small-scale treatment (Massoud *et al.*, 2009). Decentralized wastewater systems are appropriate especially for semi urban and rural communities, where population density is comparatively low and scattered. Decentralization is considered as an ecologically sustainable and environmental friendly form of treatment. It involves both conventional and innovative technologies. Sometimes existing on site system can be used effectively as a functional unit rather than replacing it (Pipeline, 2000).

8.2 Necessity of decentralized treatment in Bangladesh

Wastewater treatment is quite different in urban and rural areas in Bangladesh. As per information above in urban context, there is at least presence of a wastewater treatment plant in Dhaka, though its efficiency is not enough. However, in rural areas pit latrines are common and usually changing of pit location is usual practice. Most of the villages lack proper wastewater disposal facilities.

Bangladesh government and different NGOs are trying hard to increase sanitation facility in rural areas. In a study by UNICEF in 2008, open defecation was noticed in around 10%. Almost 52% to 56% households in the studied rural area had pit latrine and 43% have proper wastewater disposal system (Health impact Study, 2008). Even though improvement has been made in the usage of latrines in rural areas, there is still risk for water borne diseases like diarrhea. Improper location of pit near to tube wells and lack of proper disposal facility of effluent are the major reasons behind this.

Therefore, it is noticeable that increased accessibility to proper sanitation is not enough for a healthy environment. A proper treatment and discharge of wastewater is also significant. Decentralized wastewater treatment could be beneficial to reduce contamination in an environmental friendly way. Reuse of nutrients and water in agriculture could be another approach especially in rural poor communities in Bangladesh.

In Bangladesh centralized agencies struggle to move ahead with the urban development, also many communities suffer from environmental health related problems due to the poor collection and treatment of fecal sludge and domestic wastewater (Perkinson, 2005). So it would not be wise to initiate another centralized plan for the rural area where human resources are not sufficient for a centralized plant.

Small villages in Bangladesh lack proper funding to establish a centralized treatment plant. Decentralized onsite treatment could make a revolution and can be implemented with low cost funding, even some available facilities can be used as an alternative. In most of the villages, septic tanks are available and these could act as a pretreatment. So cost for an additional pre treatment facility could be reduced. Abandoned pond in villages could be used as stabilization ponds. Such things will make decentralized wastewater treatment facility easier to implement in small villages of Bangladesh.

8.3 Technological option

Decentralized wastewater treatment is mainly onsite and a combination of different technological units. Depending on geological characteristics and water table, suitable technological option could be chosen.

8.3.1 Primary treatment

A primary treatment is needed to remove settleable solids from the effluent. Septic tank is a common technology, which could act as a primary settler. A conventional septic tank functions as an aerobic bioreactor to promote partial digestion of organic matters. To reduce clogging septic tank could be modified with an additional effluent filter (Massoud *et al.*, 2009).

8.3.2 Secondary treatment

A septic tank or similar primary treatments are not enough to remove nitrogen, phosphorous and pathogenic organisms from the effluent. Further treatment and proper disposal facility is necessary to protect public health and environment.

Different secondary treatment options are available such as wetland, sand filter, facultative lagoon, wastewater pond etc. The most suitable option should be chosen according to available land, funding and soil characteristics.

Wetland

Wetland is land partially or fully flooded with water with vegetative plants on it. Wetlands are flooded for a certain period of the year or all over the year depending on the situation. It could be natural or manmade. Manmade wetlands are known as constructed wetland (Kadlec & Wallace, 2009).

Constructed wetland is one of the popular technologies for secondary treatment in onsite-decentralized system. This system has been using for wastewater treatment purpose since 1980 (Lizama *et al.*, 2011). Constructed wetlands have a potential of transforming pollutants in to harmless byproducts and nutrients using biological treatment. Constructed wetlands also provide greater level of nitrogen removal. It is one the least expensive treatment technologies (Kadlec & Wallace, 2009).

Basic types of constructed wetlands are free water surface wetland (FWS), horizontal subsurface flow (HSSF) and vertical flow wetland (VF). Each of the categories are varies with layout, plants and flow pattern. Sometimes depending on wastewater characteristics, different types of wetlands can be combined to achieve higher degree of treatment, this is known as hybrid constructed wetland (Kadlec & Wallace, 2009).

Figure 5 represents a typical combination of wastewater treatment system with wetland following by a septic tank.

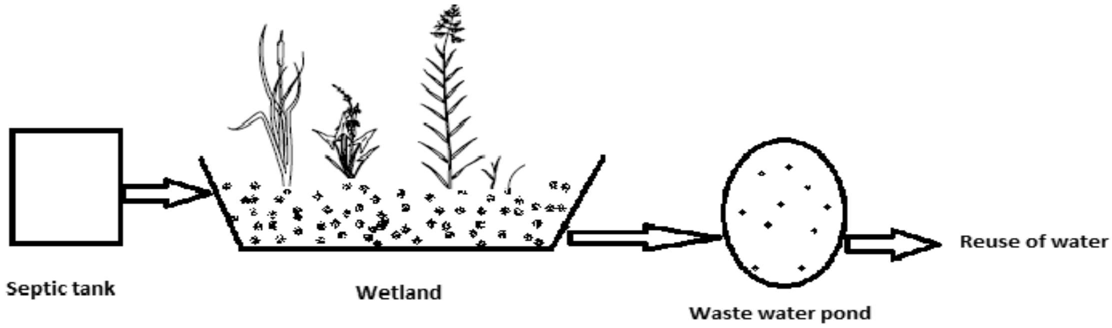

Figure 5: Wastewater treatment with a primary treatment wetland and a wastewater pond.

FWS wetlands have open water areas, floating vegetation. Wastewater is treated through the process of sedimentation, filtration, oxidation, reduction, adsorption. This type of wetland is suitable mostly for all climate conditions. This wetland has the ability to work under varying water levels. A risk with human and wildlife exposure to pathogenic organisms could occur due to open flow of water (Kadlec & Wallace, 2009).

HSSF wetlands consist of gravel or soil beds with vegetation. The wastewater is intended to stay under the surface media and flow around the roots of the plants. They generally consist of inlet piping, a clay or synthetic liner, filter media, emergent vegetation, berms, and outlet piping with water level control. As water flows beneath the surface, risk associated with human and wildlife exposure to pathogenic organism is decreased. Also, it causes less habitat for mosquitoes. HSSF are usually efficient for smaller flow rates and is more expensive than FWS wetland (Kadlec & Wallace, 2009).

In VF wetland water is distributed vertically through the surface of a sand or gravel bed with planted vegetation. This type of wetland provides higher level of oxygen transfer. Thus it results in oxidation of ammonia in greater level. Very concentrated wastewater can be treated with VF wetlands (Kadlec & Wallace, 2009).

The addition of a subsurface treatment wetland after the septic tank can compensate for substandard infiltration conditions and provide a greater level of nitrogen control. Some studies have been carried out to investigate the removal of metal in wetlands and few experimental studies have designed to investigate arsenic removal potentiality of wetland (Lizama *et al.*, 2011).

Stabilization pond

Stabilization ponds are also known as oxidation ponds. An oxidation pond is a shallow pond, which is designed to treat sewage by the influence of air and sunlight with natural processes. Interaction between bacteria and algae include the main processes in this system. The constituent of sewage is digested and oxidized by bacteria and become harmless and odor free. Algae utilize the carbon dioxide and through photosynthesis produce oxygen needed for the bacteria to sustain in the treatment process (Hussain & Al-Hashimi, 2013).

A series of ponds could act as a whole treatment process including primary, secondary and tertiary treatment. Normally primary treatment is done in an anaerobic pond. The depth of these types of pond varies from 2 to 5 m and could receive wastewater with high BOD load (greater than 100 g BOD/ per day). Normally anaerobic ponds do not contain algae and the BOD is removed by sedimentation and subsequent anaerobic digestion of sludge. Facultative ponds normally have three zone, a surface zone with bacteria and algae, an anaerobic bottom zone and an intermediate zone with partially aerobic and anaerobic condition. Facultative ponds are usually 1.5 to 2 m deep and followed by an aerobic pond. They are normally considered for a secondary treatment. Treatment process includes anaerobic digestion of settleable and flocculated organic matters in the bottom and aerobic decomposition of suspended matters. Sometimes for greater level of treatment, an aerobic pond is used as a tertiary process. Aerobic maturation ponds are usually shallow in depth (Hussain & Al-Hashimi, 2013).

Figure 6 shows a series of stabilization ponds for wastewater treatment, where an anaerobic pond is considered as primary treatment and a facultative pond for secondary treatment. An aerobic pond can serve as a discharge pond.

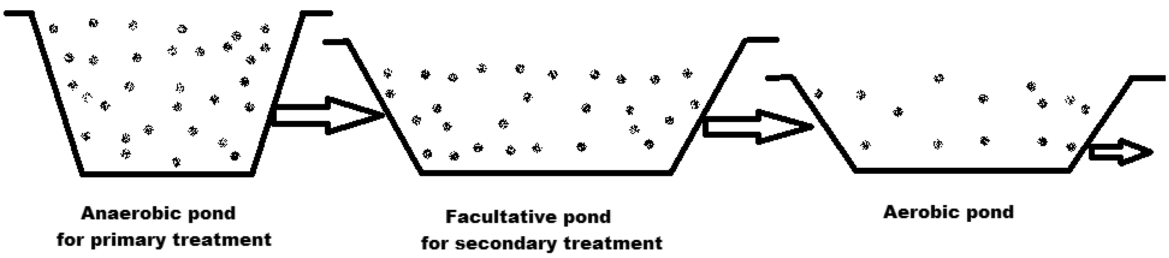

Figure 6: Stabilization pond system for domestic wastewater treatment

Stabilization ponds are mostly used in rural areas with availability of lands. Relatively low population density is efficient for the process. Main advantages of this treatment process are easy operation, energy requirement is relatively low and sludge thickening is good. Proper designed and maintained stabilization pond system could decompose waterborne organic waste effectively. It could also be efficient in reducing problems associated with disposal of wastewater (Hussain & Al-Hashimi, 2013).

Sand filter

Sand filter is another onsite treatment approach for treating wastewater by removing particles and impurities. This type of filter media normally consists of a sand and gravel bed. Water is uniformly distributed from the top and allow to flow through the filter media. Normally it is used as a secondary treatment process. After filtration process, water is collected from under drain of the filter and by a soil absorption system water is then disposed. The bed of the sand filters is lined with water resistant material to protect leakage of effluent in the underground. The depth of media varies from 61 to 107 cm. Sand particles should all be about same size. Otherwise, the smaller particle can occupy the space between larger particles and thus make the system clog. Physical, chemical and biological processes occur in sand filter. Water is treated by filtration, chemical sorption and assimilation. Contaminants stick in the sand surface and through assimilation process aerobic microbes grows on the nutrients. Aerobic condition should be available to keep the biological process go on (Lesikar, 2008).

Partially and fully buried sand filters are available and used based on purpose and land condition. In areas with high water table, sand filter is built above ground. To prevent from heavy rain and freezing some kind of cover is used but the system must be aerated. Intermittent and recirculating sand filters are common types of sand filter. Intermittent filters normally have fiter beds of about 61 cm deep and the surface of the bed is intermittently dosed with effluent (EPA, 1999). In recirculating filters, recirculation of water from pretreatment such as septic tank to the sand filter occurs several times (Lesikar, 2008). Compared to other onsite technologies sand filters are relatively expensive and skilled maintenance required. Clogging is another problem that could reduce the efficiency of the treatment process.

8.4 Advantages of decentralized wastewater treatment

There are a number of conveniences of decentralized wastewater treatment system. Both economically and environmentally, this is an appropriate option for small villages with relatively low population density.

8.4.1 Low cost

Firstly, it requires less implementation cost for collection of wastewater. Traditional collection for centralized plant needs huge amount of pipe connections and costs around 60% of the total budget. Decentralized onsite systems make the collection component as minimal as possible and focus on necessary treatment and disposal. A conventional centralized plant includes advanced treatment processes and treats a large amount of water. So constructing a centralized plant in small villages of developing countries could result in burden of debt (Massoud *et al.*, 2009).

8.4.2 Water reuse

Decentralized wastewater treatment increases the possibility for reuse of water depending on the community type, technical options and local settings. Effective operation and proper maintenance promotes increased use of treated wastewater. If the treated effluent quality fulfills the local requirements, reuse of water in agriculture can be beneficial (Massoud *et al.*, 2009).

8.4.3 Could implement for a particular place

Another significant feature of decentralized system is, overcoming of various geological problems. These types of onsite facilities can be made according to ground water tables, soil and bed rock condition. Decentralization allows flexible management. For a particular site with geological difficult condition, the system can be adjusted to meet treatment goals (Massoud *et al.*, 2009).

8.4.4 Easy maintenance and operation

Compared to centralized treatment, decentralized systems requires less skilled labor to operate and maintenance. Therefore, this onsite system can be an appropriate option for village habitants, where skilled workers are lacking (Libralato *et al.*, 2012).

8.5 Disadvantages of decentralized wastewater treatment

8.5.1 Acceptability

Design of a treatment system not only depends on geological and environmental conditions, but also acceptance by the users is important. Sometimes a well-designed system could work less effectively if the public do not use it properly.

People in rural areas in Bangladesh are mostly not well educated to understand the concept and advantages of decentralized wastewater treatment system. Huge space requirements for the onsite system could be an issue. In addition, people could react negatively to change their present system. Poor villagers could prioritize to use the land for agricultural purpose rather than for treatment purposes. Cost is one of the main issues. People may not agree to invest more in treatment, where they already have existing septic tanks. In developing countries like Bangladesh, it is hard to introduce a change in the present system, which has been there for years.

8.5.2 Flooding

Bangladesh is a flood prone country and the country faces a number of flood phenomenon frequently. About 30% of the country is flooded each year with annual flooding during the monsoon. In 1988 and 1998 two biggest disasters occurred. About 89970 km^2 and 100,250 km^2 area was flooded respectively in these two events (Majumder &Venton, 2013). In a country like Bangladesh with frequent flooding events, it is hard to establish a proper on site treatment system. The performance of treatment could be less effective in time of flooding. Design of wetland or stabilization pond must be according to the flood level.

8.5.3 Habitants of mosquitos

Onsite systems are open and attractive for animals and other habitats. Mosquitos are one of the dangerous insects very often found to spread in water. Different types of diseases like Dengue and Malaria are very common mosquito borne diseases in Bangladesh. Therefore, onsite system like wetland and sand filters could become a habitat for the mosquitos.

8.6 Suitability of decentralization in Bangladesh

A most appropriate technology is the one which is economically affordable, environmentally sustainable and socially acceptable (Massoud *et al.*, 2009). To be economically affordable, investment and operational cost should meet the financial ability of the community. For decentralized treatment cost would be much lower than the conventional centralized system. A huge cost would be saved from the reduced sewage connection. Especially in rural areas with availability of land and present septic tank facility in houses, decentralization will be a cheaper option for treating wastewater. Decentralization is cost effective in implementation also; it requires less technical equipment than centralized one. In a developing country like Bangladesh, where economy is a big issue, it would not be wise to invest more money in a centralized plant.

An environmentally sustainable technology should include environmental protection, nutrient recycling and water reuse. Decentralization fulfills above parameters and these are the main key issues for decentralized treatment. In Bangladesh water pollution is a major concern. Water is polluting because of improper disposal facility of sewage and waste, thus making the public health to a dangerous condition. In such condition decentralized waste water treatment could reduce the amount of water pollution by a systematic disposal of effluent.

Social acceptance of decentralization is also an important parameter to evaluate its efficiency. Although it could some times be hard to make people understand the benefits of proposed system, there is the possibility to make them aware by different awareness programs. Community based education could be beneficial to make rural uneducated people understand the consequence of water pollution.

9 Design of a wastewater treatment process in a typical village in Bangladesh

To evaluate the recommended decentralized treatment option in rural areas of Bangladesh, a typical village in the middle part of the country has been selected as a case to make a design of the proposed treatment process, which is decentralized wastewater treatment.

9.1 Area selected for design

The village named “Bami” is situated in Lauhati union, Delduar upozila, Tangail district and Dhaka division. The area is mostly flat and the climate is tropical. Average temperature for this area is about 25.5°C and the total annual precipitation is about 1872 mm. Highest rainfall occurs in July and lowest in December (Climate data, 2016). In 1988 a number of flood damages were recorded (Banglapedia, 2016).

According to Population Census 2011, the total population of this village is 970 with 201 households (Population Census Bangladesh, 2011). Agriculture is the main occupation in this area. Tube wells are the main sources of drinking water. Almost 93% of the population use tube wells for potable water collection. Also ponds and other surface water sources are available for collecting water. In this area almost 36% of the households use sanitary latrines and 58% has non sanitary latrines. Almost 6% has no latrines at all (Banglapedia, 2016). So it indicates that, this area has a deficiency in sanitation. No information of wastewater treatment facility was found for this area.

Figure 7: Location of the selected area (Collected from Google map)

In the data source used, 30 km^2 area was given for the total area of the upozila including 15 other villages (Banglapedia, 2015). To make the calculation simple, it has been assumed that all the villages are similar in size. Then the area of the selected village has been found about 2 km^2.

The condition presented is a typical condition for most of the villages in Bangladesh. There is a significant improvement potential in latrine use and reduction of open defecation but still people are in risk without any proper waste water management. Only use of latrines cannot be a single solution, also appropriate wastewater treatment is needed to complete the process and make a healthy environment.

9.2 Estimation of water flow and BOD_5

Before designing the process, some basic parameters have been collected from various sources. Among them average water consumption in rural areas of Bangladesh was found to be 83.17 liter /person/ day (Amin *et al.,* 2011). It is a bit lower than the urban water consumption. This could be due to less water availability or poor economic condition.

Average daily water consumption Q = 83.17 liter /person/day = 0.083 m^3 /person/day (Appendix 1) will result in an average daily waste water flow Q_D = 68.43 m^3/day, where, wastewater flow is assumed to be 85% of daily water consumption.

Table 3 includes BOD, TN, N as NH_4^+ and TP in the daily wastewater flow. It also includes required amount of BOD, N and P in the effluent for water usable in irrigation. Average BOD_5 in the influent is calculated in Appendix. The required BOD value in the effluent is found from Table 2. The required value for N and P in the effluent are found from a report named water quality for agriculture (Ayers and Westcot, 1994). Average amount of TN, N and TP in the influent is estimated as typical content in municipal wastewater with minor industrial contribution (Henze, 2008). Calculations are found in Appendix 1.

Table 3: Concentration of various parameters in influent and effluent

Parameter	Average concentration in the influent (mg/L)	Required concentration in the effluent (mg/L)
BOD_5	566	10
Total nitrogen (TN) as NO_3^+	30	0 to 10
N as NH_4^+	20	0 to 5
Total Phosphorous as PO_4^{3-}	6	0 to 2

BOD in the influent is calculated from an empirical equation (Appendix 1), for influent BOD, C_0 =1000 B/Q_D, BOD contribution per day (B) is assumed to 40 g/capita/day for medium sized communities (Kayombo *et al.,* 2005).

9.3 Pretreatment facility

A primary treatment is needed to make the whole treatment process more efficient and to reduce the organic load in the secondary treatment. A septic tank is one of a common type of primary treatment. Also anaerobic ponds can also act as a primary treatment tools. Septic tank can be installed in each household or one anaerobic pond can be used for the whole community.

9.3.1 Design of septic tank

An Indian standard code will be used for the design of the septic tank in Bami village.

Table 4 represents recommended size of septic tanks according to the number of users (Bureau of Indian standards, 1993).

Table 4: Recommended septic tank sizes for Indian style residential purpose (Bureau of Indian standards, 1993).

Number of users	**Length**	**Width**
5	1.5	0.75
10	2.0	0.90
15	2.0	0.90
20	2.3	1.10

If 5 persons in each house is assumed for the selected village, then from Table 4 the size of a septic tank can be found to be of 1.5 m long and 0.75 m wide. The depth is assumed 1.3 m including 1 m depth from the outlet pipe to the bottom of the tank and 0.3 m distance from roof to liquid. So 1.13 m^2 septic tank could be recommended for each household in this village.

V (volume of septic tank) = (1.5*0.75*1.3) = 1.46 m^3 (approximately)

This septic tank can store 1460 L liquid and each of the houses will need septic tank of approximately 1.46 m^3.

Several requirements are stated for installing a septic tank. It should be 60 m away from any community well, 9 m away from any buried water storage tank and 15 m from any source of potable water or natural water body (Yukon, 2014).

A septic tank can remove BOD, TSS, oil and grease. Typically a septic tank can remove 30 to 50% BOD and 60 to 80% TSS (Eliasson, 2004).

9.3.2 Design of anaerobic pond

Design of an anaerobic pond below has been done using ´Waste stabilization pond and Constructed Wetland Design Manual´ (Kayombo *et al.,* 2005)

Volume of anaerobic pond $V_A = C_O Q_D \, / \, \lambda v$ (1)

Where λ_v is the volumetric loading of BOD to the pond, which is assumed to be 350 ($g/m^3/day$) for a temperature greater than 25°C (Kayombo *et al.,* 2005), and Q_D, is in (m^3 /day).

From equation (1), $V_A = 110\ m^3$ (Appendix 2)

Depth of anaerobic pond is considered to be 3 m and the area would then be almost 37 m^2.

Hydraulic retention time $t_{AN} \ = \ V_A \, / \, Q_D$ (2)

= 110/68 = 1.6 days (approx.)

The minimum value of retention time is recommended to be one day. With the designed anaerobic pond almost 70% BOD removal is possible in the temperature above 25 °C (Kayombo *et al.,* 2005).

9.4 Secondary treatment

Only a primary treatment is not enough to make the effluent in quality of an accepted level. With the above design of septic tank and anaerobic pond 30 to 70% of BOD removal is expected. For secondary treatment different option can be chosen, such as wetland, facultative pond or sand filters. Depending on the geography, landscape and weather condition various option can be adopted.

9.4.1 Design of Facultative pond

Area of facultative pond $A_F = \ 10 \ C_O Q_D / \lambda_s$ (3)

Equation (3) is collected from (Kayombo *et al.,* 2005).

Where, surface loading λ_s (kg/ha.day) = 20T-120 = (20). (28) – 120 = 440 kg/ha.day

In Bangladesh, average temperature is assumed to be more than 25°C. Here in the calculation 28°C have been used. In this design a primary treatment has already been suggested. In primary treatment, for septic tank almost 30% BOD is removed. So in further secondary treatment design a reduced BOD in the secondary influent is assumed.

From equation (3), $A_F = 612\ m^2$ (appendix 3)

Retention time $T_F \ = \ A_F \, D \, / \, Q_M$ (4)

$Q_M = \frac{Q_I + Q_E}{2}$ (5)

$Q_E = \ Q_M - \ 0.001 \ A_F \ e$ (6)

Equation 4,5 and 6 have been collected from Kayombo *et al.* (2005). Where, D is the depth of the pond (1.5 m usually) and Q_M is mean flow, Q_I is influent flow, Q_E is effluent flow and (e) is evaporation rate.

Evaporation rate for Bangladesh is found from a historical data study and the values vary with temperature during the year. An average monthly evaporation value of 120 mm for 28°C is considered in this calculation (Rajib, Rahman & Mcbean, 2010). From this a daily evaporation rate can be calculated.

Average daily evaporation rate (e) = 120 /30 = 4 mm/day

From equation (6) and (5), $Q_E = 66m^3/$ day, $Q_M = 67m^3/$day

Then, Putting values of Q_M and Q_E in equation 4, T_F = 14 days (Appendix 3)

Again, if an anaerobic pond is considered as primary treatment, from the above equation the area for facultative pond becomes 260 m^2 and the retention time found 6 days. This variation is because of the high BOD removal in the anaerobic pond, with almost 70% BOD removal in an anaerobic pond.

9.4.2 Design of wetland

Area of reed bed of wetland $A = KQ_D (\ln C_O - C_t)$ (7)

K is a rate constant, the value found for BOD removal K_{20} = 180 m /year = 0.5 m/day for subsurface wetland, which is calculated from Kayombo *et al.*(2005).

$$K_T = K_{20}\, \theta^{(T-20)} \quad (8)$$

From equation 8, the K value is calculated for 28°C. K_{28} = 1.08 m/day

Using values of K in Equation 7, A = 272 m^2 (Appendix 4)

This area for subsurface wetland is calculated with 30% BOD reduction from septic tank. The value varies if an anaerobic pond is used as pretreatment. Then the area needed will be 209 m^2. The depth of the wetland designed above is considered to be 0.6 m. Equation 7 and 8 have been collected from Sim (2003).

9.4.3 Design of sand filter

Using a guideline from Washington State Department of Health (2012) an intermitted sand filter is designed below.

The surface area of the filter bed, $A_S = Q_D/$ Loading rate (9)

The maximum loading rate is 2 to 5 gal/day/square feet recommended in the EPA design manual.he depth of media is between 46 to 91 cm (EPA, 1999). Design loading rate is considered 4 gal/day/square feet.

Using all the values in Equation 9, A_S = 420 m^2 (Appendix 5)

420 m^2 sand filter is found to be suitable for loading rate 4 gal/day/square feet.

9.4.4 Nitrogen and Phosphorus removal

Decentralized wastewater technologies have great potential in nutrient removal. Though nutrients are useful for irrigation purpose, sometimes it has adverse effect as well. Such as excessive amount of nitrogen may cause negative effects on crops (Ayers and Westcot, 1994).

A facultative pond is very efficient in nitrogen and phosphorous removal. From a typical facultative pond almost 60 to 70% N (Middlebrooks *et al.*,1999) and 50 to 70% P could be removed (Mbwele, 2006). Though the removal efficiency depends on plants type and temperature. At higher temperature phosphorous removal efficiency is higher than at lower temperature (Mbwele, 2006). In the design above, if 70% N and P is assumed to be removed by the facultative pond, then the N and P values in effluent become 9 mg/L and 1.8 mg/L. This meets the required values in Table 3, and the effluent water could be easily used in agricultural purpose without any concern.

In a constructed wetland nitrogen is removed through microbial interactions with nitrogen, sedimentation, chemical adsorption, and plant uptake. Average nitrogen removal capacity in a wetland is about 40 to 50% and phosphorous removal capacity 50 to 60% (Lee, Fletcher and Sun, 2009).

If 50% N and 60% P removal is considered in the subsurface wetland, Then TN as NO_3 will be 15 mg/l, N as NH_4^+ will be 10 mg/L and TP will be 2.4 mg/L (Lee, Fletcher and Sun, 2009). The value is a bit higher than the guideline limits in Table 3 for both N and P. However, some nitrogen and phosphorous could also be removed in the primary treatment process. In this case an anaerobic pond could be efficient rather than septic tank.

A study regarding recirculating sand filter in Michigan, USA has shown an average nitrogen removal 53% to 73% from effluent with recirculating sand filter. However, with a denitrification system the efficiency reaches higher (Graham and Shaw, 1998). Moreover, phosphorus removal capacity of a typical sand filter is relatively low. About 40% TP can be removed from effluent using sand filter. But addition of chemicals can improve the efficiency (Van *et al.*, 1999).

Considering 65% N and 40% P removal in sand filter, expected N and P in the effluent can be found 10.5 mg/L, TN as NO_3, 7 mg/L N as NH_4^+ and 3.6 mg/L TP.

9.5 Comparison between options

Different options for decentralized treatment have been found in the above design. Various available onsite systems perform in different way. Based on the design above a comparison among the selected options has been made. This comparison could be beneficial to choose appropriate technology for a specific area. As all areas do not have similar problems, different technology could be beneficial different regions.

Table 5, below shows expected performance of the primary treatment options suggested in the design. Some parameters are collected from various sources and others are from design (Eliasson, 2004) and (Kayombo *et al.,* 2005).

Table 5: Comparison among primary treatment facilities in primary treatment.

Options	Septic tank	Anaerobic pond	Source
BOD removal	30 to 50%	Almost 70%	Eliasson, 2004; Kayombo *et al.,* 2005
Area required	High compared to total (each house required 1.13m^2, total 226m^2) (Calculated).	Less area required, according to design 37 m^2 (Calculated).	Calculated
Problems with flooding	Reduced if it is buried under ground.	Could associate problem and treatment efficiency could be reduced.	Masood *et al.,*2009
Maintenance	Require maintenance in each house and costly.	Not in each house but a community maintenance and less costly.	Masood *et al.,*2009
Secondary treatment	Require high level of secondary treatment (Calculated).	Comparatively smaller secondary treatment needed (Calculated).	Calculated

Although anaerobic pond seems to be efficient for BOD removal and little area is required, it would not be wise enough to build an anaerobic pond in a high flood prone area. During flood the whole pond could be flooded and seepage could occur and treatment efficiency could be reduced. Also treatment efficiency in anaerobic pond could be affected by unexpected rain water in monsoon.

Moreover, user acceptability is an important factor of choosing technology. It depends on how local inhabitants accept the proposal and their willingness to use that system.

In table 6, secondary treatment options selected in the design above have compared. The comparison has been done according to the performance of the technologies in various concern. This comparison is based on the design in section 9 in this report and other references (Lee, Fletcher and Sun, 2009; Graham and Shaw, 1998; Van et al.,1999; Middlebrooks et al.,1999; Mbwele, 2009; Masood *et al.,*2009).

Table 6: Comparison among secondary treatment facilities

Options	**Facultative pond**	**Subsurface wetland**	**Sand filter**	**Source**
Area required	260 m^2 (Anaerobic pond)	209m^2 (Anaerobic pond)	420 m^2	Calculated
Risk with flooding	Efficiency could be reduced	Could be affected	If buried then could be efficient	Masood *et al.,*2009
Habitants of mosquitos	Possible	Possible	Less possibility	Masood *et al.,*2009
Cost	Lower than others	Comparatively high	High	Masood *et al.,*2009
Nitrogen removal	60 to 70%	40 to 50%	53 to 73%	Middlebrooks et al.,1999; Mbwele, 2009; Lee, Fletcher and Sun, 2009
Phosphorous removal	50 to 70%	50 to 60%	40%	Graham and Shaw, 1998; Van et al.,1999

Similar to primary treatment facilities, secondary treatment facilities also show variation in different conditions. Area requirement is less for subsurface wetland with an anaerobic pond as a primary treatment option.

Table 6 shows also a significant comparison on nutrient removal efficiency of these three technologies. For both nitrogen and phosphorus removal facultative pond is relatively more efficient than other the two technologies. However, this estimation is based on the literature studied in the report. In the design above (9.4), nutrient concentration in the effluent in subsurface wetland have been found to be quite higher than the guideline limit. To reach the guideline limit of 10 mg/L TN and 2 mg/L TP in the effluent using subsurface wetland, some additional measure should be taken.

There could be a change in performance of the technologies in different areas. In addition, other possible issues can be significant for a specific region. Such as, in coastal areas salinity should be of concern.

Again, in rural Bangladesh cost efficiency is an important factor for implementing new system. Though all these three system are low cost technology, but some more cost assessment should be beneficial to compare the expenses.

9.6 Design summary

The above design shows an overview of the total decentralized system for a typical village. The area of the village is about 2 km^2 (assumed). Primary treatment facilities show to occupy a small area of about 37 m^2 for the anaerobic pond. For secondary treatment, the area of a wetland found was almost half of the facultative pond. To implement a facultative pond of 612 m^2 in this small area will not be suitable.

In the above design several systems are discussed with an example size of treatment facility. Also a comparison between options has been done to evaluate suitable options according to the situation.

Further in this report reuse of effluent from the treatment process will be discussed. Which is another objective of this report. To make the effluent reusable, required BOD value has been calculated according to the requirements given by the government in Table 3.

As nutrient concentration is important for reusing the effluent water in irrigation, nitrogen and phosphorus removal has been discussed. With a facultative pond the effluent fulfills requirement given in Table 2. But for the other two systems N and P concentration was higher than requirement.

9.6.1 Design limitations

In the above design, some assumptions have been done for various parameters for calculation. In some cases, assumptions may not be similar to reality. Also temperature has been considered as 28° C, which may be a bit lower than real situation. This is considered to make the calculation simple.

Chosen area is considered as a typical village, but there are areas with different topography than the designed one. So this design may not be appropriate for hilly or coastal regions in the southern and northwest part of Bangladesh.

Nitrogen and phosphorus removal for the designed system has been calculated with a rough estimation. The efficiency could be different in practical case.

This design is an example and a model of the recommended solution. When implementing this solution in reality, some changes according to necessity could be done. Such as for places with a high ground water table, depth of anaerobic pond or septic tank could be adjusted.

In addition, any specific value of the area of this village has not been found. Therefore, an estimation and assumption have been done.

9.7 Reuse of water in agriculture

Bangladesh is an agricultural based country and the majority of the population especially in rural areas depends on agriculture. Bangladesh is the world's 4^{th} largest rice producing nation. A huge amount of water is required for harvesting and other agricultural purposes. Most of the farmers use deep groundwater for irrigation. Estimated water use in irrigation is almost about 24 km^3, among which 18 km^3 are from ground water extraction (Shamsuddoha *et al.,* 2011).

From this report, it is already known that ground water depletion is one of the major issues in Bangladesh. So reuse of treated wastewater in the agricultural fields will be an effective initiative to reduce groundwater extraction.

The area selected above for design is mainly an agricultural based area. Rice, paddy, wheat and soya are major cultivated crops in this region (Banglapedia, 2015). From design, an average waste water flow has found 68.43 m^3/day, was found for this area. With proper treatment this water can be reused in irrigation. Though there will be some loss during the treatment and collection process. 20% water loss can be assumed. Then we can get almost 1642 m^3 of treated water per month. This water can be stored in another separate storage pond and delivered for irrigation. The size of the storage pond will be depending on the time for storage. For example, if water will be stored for 1 days,

Volume of storage pond V = ((68.43 m^3/day) (1 day)) -20% water loss = 50.74 m^3 = 51 m^3

Area of the storage pond will be 33 m^2 with a depth of 1.5 m.

9.7.1 Benefits and risk with water reuse in agriculture

Reuse of treated wastewater in agriculture has many positive effects for the environment. It will reduce groundwater depletion and huge amounts of energy can be saved through reduced pumping. Organic and inorganic nutrients such as nitrogen and phosphate in wastewater have the potential to be used as fertilizer. Increased metabolic activity in soil microorganism has also been noticed with sewage effluent in irrigation (Toze, 2006).

Although treated wastewater contains a definite amount of nutrients, it has to be within the standard limit allowable for irrigation. In this report from Table 3, a guideline consisting the required value of different parameters for water to be used in agriculture after treatment can be found.

A number of risks can be associated with the reuse of wastewater in agriculture. The presence of virus, bacteria, heavy metals and salinity can affect the quality of agricultural products. Sometimes many diseases can be caused by the presence of harmful compounds in water. So a treatment is needed before reusing this wastewater for irrigation. Decentralized wastewater treatment mentioned above will reduce the associated risk with reusing this wastewater. However, in this design pathogenic organisms have been the main concern to be removed. To be used widely presence of other harmful compounds should be observed (Toze, 2006).

10 Discussion

The study showed that wastewater in urban areas of Bangladesh is of more concern by the government than rural areas. The presence of wastewater treatment plant has only seen in urban areas. Information regarding rural wastewater treatment was not found in the sources used in this report. Only household treatment processes are somewhere found. Whereas implementation of a suitable treatment facility and reuse of treated effluent water in agriculture can certainly make influence both on the economy and sustainable environment.

The short discussion of Swedish water technology in Chapter 7 gives information about wastewater management system in developed country. The recommendation of decentralized system in Bangladesh was influenced by Swedish decentralized wastewater technology. This system is not the major treatment facility in Sweden. Only distant areas, those are hard to connect with the centralized system use the decentralized system. However, the benefits and potential of this system seems to be much suitable for rural areas in Bangladesh.

Decentralized wastewater treatment in rural Bangladesh can serve as a significant measure to mitigate the water issues. This small scale solution will not only make the wastewater harmless, also it could change the social view on water treatment as this could act as an alternative to larger treatment plants. This method is likely to be adjusted according to the geographical condition. For example, in a flood prone area a subsurface wetland can serve better than a facultative pond.

In the design example in Chapter 9, a decentralized treatment has been designed for a small community of 970 inhabitants in a flat and agriculture based village in the middle part of Bangladesh. It has been designed with different alternative options. Among them, combination of subsurface wetland followed by anaerobic pond is suggested to be suitable according to area requirement. The comparison study stated in Chapter 9.5 could be very useful to select suitable options according to the issues in a particular region. Such as area requirement should not be taken as the main concern for implementing solutions in a high flood prone region. Safety and sustainability should be the main concern in the areas with high risk of natural disaster.

Nutrient removal with the facultative pond was expected to be more efficient than the other two methods. Though N and P removal rate is higher in the constructed wetland, but it does not meet the requirements given in Table 3. Also nutrient removal efficiency is relatively low in sand filter. In the designed area a constructed wetland is suggested to be efficient according to area requirement, but nutrient concentration is not acceptable with this system. To reduce nutrient concentration a maturation pond after the wetland can be introduced. Biological activity in the pond will reduce the nutrient concentration in the effluent.

To make the recommendation more sustainable and ecological, reuse of wastewater in the agriculture has been suggested. Reuse of effluent water in agriculture is the potential of the decentralized wastewater treatment. A huge amount of water can be saved by this system which was about to misused. It is an ecological solution to reduce groundwater depletion. However, several risk factor can be associated with this as well. Water quality should be checked before using it in irrigation. If any harmful compound remains in the water, they could affect negatively and abolish the purpose of the solution.

11 Conclusion

The present study of water and sanitation of Bangladesh indicates that the current situation is not in a sustainable condition. Also there are places where treatment is rarely found. For an improved and sustainable environment urgent s is needed to meet the millennium development goal (MDG). However, due to economical instability centralized solutions seem hard to implement. Small scale solution could play an active role for developing countries like Bangladesh. As small scale solutions are comparatively economical and less skill required than centralized system.

The proposed decentralized wastewater treatment in Bangladesh is expected to be efficient and appropriate for the wastewater sector. However, there remain a lot of other factors those are related to the effectiveness of this proposal. The success can only be seen after installation and proper operation. The area selected for design in chapter 9, has a record of damage in previous years flooding. Therefore, in case of unfavorable climate conditions or natural calamity, treatment could fail. So, one specific solution is not enough to serve the whole country. The strategy should be adjusted according to the requirement of a particular area.

In a country where wastewater treatment is rare, this initiative for implementing decentralized treatment plants in rural areas can certainly be a suitable beginning toward sustainability. First step for development can be done by this proposal, even though there remains risk and dependency on climate.

This report basically represents a technology transfer process. An insignificant technology in one country could be significant in another. Such thought is used for recommendation purpose.

Finally, social acceptance is an important factor of implementing this solution. The benefits and outcomes from this system with reuse of water in agriculture is very much depended on user behavior. In addition, appropriate installation and proper maintenance of the system could make a better and sustainable solution.

12 Future work

A suitable solution for the urban issues could be found in future. Problems with illegal connection in the centralized network could be controlled by government participation. Also government should play an active role in implementing of laws and regulations.

To solve water scarcity problem reuse of waste water could be suggested widely in the urban areas as well. Especially reuse of industrial wastewater might reduce contamination of surface water.

To motivate the user about the benefits of decentralized wastewater treatment, some social awareness program and training can be arranged for the villagers. This could help them to understand decentralization properly.

In the design of decentralized wastewater treatment in Chapter 9, mainly BOD was focused. In further analysis nitrogen and phosphorous concentration in the effluent should be checked. Also the presence of other harmful materials like heavy metals in the effluent can be checked. If any other kind of harmful material is present in the final effluent.

A pilot project can be implemented to verify the design. If this system works properly, it can be applied to other regions as well.

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Appendix

Appendix 1

Calculation of water flow and BOD

Average daily water consumption Q = 83.17 liter/ person/day = 0.083 m^3/person/day

Waste water flow is assumed to be 85% of total water consumption.

Q_D (Average daily waste water flow) = (0.85) Q = (0.85) (83.17 liter/ person/day)

= 70.7 liter/ person/day =68 m^3/day (approx.) (for 970 person)

BOD_5 of the influent C_0 =1000 B/Q_D = 566 mg/L

Where B is BOD contribution per day and which is assumed 40 g/capita/day for medium sized communities

Appendix 2

Calculation for anaerobic pond volume

Volume of anaerobic pond $V_A = C_O Q_D \, / \, \lambda\mathrm{v}$ (1)

Where λ_v is the volumetric loading of BOD to the pond, which is assumed to be 350 (gram/m^3/day) for a temperature greater than 25^{o}C (Kayombo *et al.,* 2005), and Q_D, is in (m^3 /day).

V_A = (566) (68)/350 = 109.804 m^3 =110 m^3 (approx.)

Appendix 3

Calculation for facultative pond

Area of facultative pond $A_F = \ 10 \ C_O Q_D / \lambda_s$ (3)

Equation (3) is collected from (Kayombo *et al.,* 2005).

Where, surface loading λ_s (kg/ha.day) = 20T-120 = (20). (28) – 120 = 440 kg/ha.day

As 30% BOD removal is considered in primary treatment, BOD in the influent will be 0.7 C_0 .

A_F = (10) (0.7) (566) (68)/ 440 = 612 m^2 (approx.)

Retention time $T_F = A_F$ D / Q_M (4)

Equation 4,5 and 6 have been collected from Kayombo *et al.* (2005). Where, D is the depth of the pond (1.5 m usually) and Q_M is mean flow, Q_I is influent flow, Q_E is effluent flow and (e) is evaporation rate.

$$Q_M = \frac{Q_I + Q_E}{2} \quad (5)$$

$$Q_E = Q_M - 0.001\, A_F\, \mathrm{e} \quad (6)$$

From equation (6) and (5),

Q_E = 68- (0.001) (612) (4) = 65.97 m^3/day = 66 m^3/day

Q_M = 67.20m^3/ day = 67m^3/day

Then, Putting values of Q_M and Q_E in equation 4,

T_F = (612) (1.5)/ 67.20 = days = 14 days (approx.)

Appendix 4

Calculation for wetland

Area of reed bed of wetland A $= KQ_D$ (ln $C_O - C_t$) (7)

K is a rate constant, the value found for BOD removal K_{20} = 180 m /year = 0.5 m/day for sub-surface wetland and θ is constant and the value is 1.1 which is calculated from Kayombo *et al.* (2005).

$$K_T = K_{20}\, \theta^{(T-20)} \quad (8)$$

K_{28} = (0.5) $(1.1)^{28-20}$ = 1.08 m/day (for 28°C)

Using values of K in equation 7,

A = (1.08) (68) (ln ((0.7) (566)) -ln 10) = 272 m^2 (approx.)

Appendix 5

Calculation for sand filter

The surface area of filter bed $A_S = Q_D /$ Loading rate (9)

The maximum loading rate is 2 to 5 gal/day/square feet recommended in the EPA design manual.he depth of media is between 46 to 91 cm (EPA, 1999). Design loading rate is considered 4 gal/day/square feet.

A_S = 68579(L/day) /163 (L /day/m^2) = 420 m^2 (approx.)

Popular scientific summary

This report includes a description of the present condition of water and wastewater in Bangladesh, limitations in the water sector and a recommendation of decentralized wastewater treatment.

In developing countries, water and wastewater are challenging for centuries. Economic adversity and high population density are the great barriers for taking solutions. In recent year's significant development has been done for drinking water but wastewater treatment still remains rare. Bangladesh is such a developing country, which is facing the similar water and wastewater related issues. To overcome the issues decentralized wastewater treatment for rural areas of Bangladesh has been suggested in this report. Decentralized wastewater treatment is a small scale onsite system and often a low cost solution. According to the recommendation a design example for a small village has also been done.

Bangladesh is a country in south Asia with 160 million populations and 148,460km^2 area. This small country has a number of issues related to water both in urban and rural areas. Among them, water pollution, water scarcity and groundwater depletion are major problems. Agriculture is one of the major occupations for the inhabitants and a major sector of ground water extraction. Though a number of rivers and canals are available in this country, ground water is considered as the main source of water. Government as well as international organizations have worked a lot for arsenic mitigation, safe access to water and increase sanitation facility. However, a number of people still suffer by water borne diseases every year. Only having toilets is not enough, the wastewater and sewage has to be managed in a good manner. There is only one wastewater treatment plant in the capital city Dhaka and almost no treatment plant in any villages. Also, centralized plants in Bangladesh is struggling to move ahead and has low efficiency and poor management. A case study in this report represents actual situation a typical village in Bangladesh. Due to inaccurate pit location the main purpose of sanitation was affected, even though there was enough sanitation facility in that village.

A decentralized wastewater treatment has been suggested as an alternate solution to centralized treatment for the rural areas in Bangladesh. In the design example in this report different decentralized options including septic tank, anaerobic pond, wetland, facultative pond and sand filter have been designed as alternatives. Comparison between the options has also been done to choose the appropriate system for a specific region. A wetland of 209 m^2 with an anaerobic pond of 37 m^2 as a primary treatment have been found to be suitable for that region. To make the solution more environment friendly and sustainable reuse of treated wastewater in the agricultural field has been recommended. This initiative can reduce groundwater depletion by reducing huge groundwater extraction for irrigation. The decentralized wastewater treatment can make a revolutionary change in water sector of Bangladesh. It can be implemented and maintained with low cost and less skilled worker. This can be a beginning towards sustainability.