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Performance evaluation of water and wastewater treatment plant in Kathmandu Valley

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Abstract

In this work, assessments of technology of the water and wastewater treatment plants including constructed wetlands in Kathmandu valley are presented. There are nine water treatment plants among which two are not in operation; seven constructed wetlands among which two are under maintenance and one is not in operation. In addition, one conventional wastewater treatment plant is studied in order to highlight the associated benefits and identify challenges of water and wastewater treatment in Kathmandu valley.

A constructed wetland uses less energy to treat wastewater than a conventional wastewater treatment plant. Thus, wetland systems have benefit in a country where energy scarcity occurs. However the technical and managerial problems and lack of awareness decrease the success of the wetland systems, but technical as well as managerial problems exist also in water treatment plants even Kathmandu Upatyaka Khanepani Limited (KUKL) has responsibility over it.

Analysis of chemical parameters that indicate the characteristics of wastewater from constructed wetlands is done by collecting one sample for each parameter. Similarly, assessment of technical and operation and maintenance for water and wastewater treatment plants including constructed wetlands are obtained by field observation and conducting questionnaire survey. Interviews with care operator are made for all studied treatment locations and reviews from user committees, non- user committees and farmers are made only for constructed wetlands.

A comparative analysis between conventional wastewater treatment plants and constructed wetland is also presented. Compared to conventional wastewater treatment systems, constructed wetland systems uses less energy and are less costly as well as easier to maintain due to simple construction and efficient functioning. More attention has given to water treatment plants though it does not show good performance in operation when compared to wastewater treatment plants.

The results showed that there is a need of development in water and wastewater management with systematic operation and maintenance. An effective study of the most fruitful type of plants and their monitoring after establishment is essential. Treatment efficiency of water and wastewater treatment plants has not shown very high performance. It is necessary to address issues, including economical, technical, social and personal to improve the systems.

Table of Contents

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Nomenclature

ABR= Anaerobic baffled Reactor

ADB = Asian Development Bank

AEC = Aquatic Ecology Centre

BF= Biological Filtration

BOD= Biological Oxygen Demand

BOD_5 = Biochemical Oxygen Demand 5-day test

BSP = Bio- gas Sector Partnership

CBS= Central Bureau System

CF= Chlorine Feeding

COD = Chemical Oxygen Demand

CS= Coagulation- Sedimentation

CWs= Constructed wetlands

DEWATS= Decentralized wastewater treatment systems

DH = Dhulikhel Hospital

ECOSAN = Ecological Sanitation

ENPHO = Environment and Public Health Organization

EPA= Environmental Protection Act

FWS= Free water surface

GI = Galvanised Iron

HFRBS= Horizontal Flow Reed Bed System

HRT = Hydraulic Retention Time

IOE = Institute of Engineering

KU = Kathmandu University

KUKL= Kathmandu Upatyaka Khanepani Limited

LPG = Liquefied Petroleum Gas

MGD = Million Gallons per Day

MLD= Million Liters per Day

MLSS = Mixed Liquor Suspended Solids

NPK = Nitrogen Phosphorous Potassium

NTU= Nephelometric Turbidity Units

O&M = Operation and maintenance

RBTS = Reed Bed Treatment System

RSF= Rapid Sand Filter

SDB = Sludge Drying Bed

SSF= Subsurface Flow

TN= Total Nitrogen

TP= Total Phosphorous

TSS= Total Suspended Solids

TU = Tribhuvan University

UN-HABITAT= United Nations Human Settlements Programme

USEPA= United States Environmental Protection Act

UV= Ultra violet

VFRBS= Vertical Flow Reed Bed System

VOCs = Volatile Organic Chemicals

WHO= World Health Organisation

WTP = Water Treatment Plant

WWTP= Waste Water Treatment Plant

n.d. = no date

List of Figures

List of Tables

1. Introduction

Nepal, a small landlocked and mountainous country, is situated in the southern transitional terrain of the Central Himalayas in Asia. It is one of the most densely populated countries in the world with a total population of 28,901,790 in 2007 and each year growing by the rate of 2.5% (CBS 2007). Human activities like industrialization, urbanization as well as rapid population growth (Sherbinin *et al*. 2007) gives increasing to water demand and distribution challenges along with increased wastewater production. Thus the process of sustainability and sustainable sanitation is coming in front to adjust the economic, social and environmental conditions (Ellingsen 2010).

The continuous population growth, urbanization, agricultural intensification and rapid industrialization has caused global water quality crisis. These factors are putting pressure on water resources and increasing the unregulated or illegal discharge of contaminated water within the natural water bodies (Corcoran *et al*. 2010). There are many causes driving this crisis, but it is clear that freshwater ecosystems across the globe are in danger. According to Corcoran *et al*. (2010), it is now clear that future water demands cannot be met unless wastewater management is efficient. Without better infrastructure and wastewater management, Corcoran *et al*. (2010) concluded that many millions of people will continue to die each year and there will be further losses in biodiversity and ecosystem resilience. A healthier future needs urgent global action for smart, sustained investment to improve wastewater management.

According to Regmi (2013), "Rainfall, glaciers, rivers and groundwater have been serving as the major sources of water for people in the country of Nepal". Among these sources, the rivers are the most important source of water in terms of volume and potential for social, economic and environmental needs and whereas rainfall and groundwater are the other mostly used sources for water utilization (Regmi 2013).

There is a need of proper water treatment before distributing to the social network. Due to this reason, there is an expansion of the construction of water treatment plants in Nepal. A treatment plant has applies different types of treatment methods to treat water in order to get hygienically safe drinking water. It is important that the water which is supplied to the public must be free from all types of impurities as well as any kind of bacteria and other contaminants which can cause serious health problems. Therefore, treatment of water is necessary according to the types of impurities contained in water. It is proved by the presence of water treatment facilities in different parts of the world.

Proper management of wastewater is necessary since it is finally discharged into natural water bodies and there is an excessive dependent on surface water (Regmi 2013). Production of wastewater in any area is from domestic, commercial and industrial routes and directly discharged into water bodies (Regmi 2013). Wastewater is produced from domestic sources while washing, cleaning, bathing and using it for sanitary purposes (Jha & Bajracharya 2014). Not only this, these water bodies also receive high quantity of storm water directly from the roads in the urban areas and the runoff from the agricultural lands (Gurung & Oh 2012).

Lack of sanitation has deteriorated the quality of the local streams and rivers. Proper wastewater treatment is absent from almost all urban cities in Nepal including Kathmandu where there is a lack of adequate wastewater collection and treatment, solid waste collection and disposal, proper water treatment and proper drinking water supply. Domestic, agricultural runoff and industrial discharge without proper treatment are drained to natural water bodies and leads to the adverse effects on the human health as well to the environmental systems, which later affects the economic conditions. Therefore the sustainability approaches is absolutely necessary to control the situations especially in the densely populated urban cities.

Different approaches to sustainable sanitation can be implemented in developing countries which consider economics, culture, environment, resources etc. Decentralized wastewater treatment systems (DEWATS), Ecological sanitation, community based sanitation are possible approaches to sustainable sanitation (Ellingsen 2010). Kivaisi (2001) stated that constructed wetlands are among the recently proven efficient technologies for wastewater treatment. These are very cost effective, can be locally managed and advantageous to the developing countries like Nepal (Corcoran *et al*. 2010). However, these systems have not found widespread use, due to lack of expertise and awareness among the people (Kivaisi 2001; UN-HABITAT 2008).

In this study, the focus is on performance evaluation and technological assessments of constructed wetlands, conventional wastewater treatment and water treatment plants.

2. Research objectives

The objectives of the study are listed as follows:

- Technological assessment of constructed wetland systems, conventional wastewater and water treatment plants.
- Performance analysis of different constructed wetlands in terms of total nitrogen and phosphorous removal
- Awareness regarding knowledge and the involvement of people to the respective systems (Social aspects)
- Comparative studies of constructed wetland and conventional wastewater treatment regarding their operation and maintenance.

3. Literature review

3.1. Water treatment plants

3.1.1. History and introduction of Water treatment

Water treatment is the process of enhancing the quality of water in accordance with meets the water quality criteria to be suitable for the intended use. Water treatment plants are those services that treat ground or surface water and produce potable water for public consumption (Bhusal n.d.). The drinking water supply needs proper and continuous monitoring till water reaches to the client households as user requirements in terms of colour, pH, taste, odour which is the main goal of water treatments.

According to WHO (2013), mentioned in Bhusal (n.d.), "lots of cases have occurred in the world due to unsafe drinking water for example: 1.6 million people die each year due to diarrhea, 160 million people are infected with Schistosomiasis, around 1.5 million cases of clinical hepatitis each year and intestinal helminthes (Ascariasis" Trichuriasis and hookworm infection) are spreading over the developing countries due to inadequate safe drinking water and inadequate sanitation".

In the history, trend of water treatment practice is found as that ancient Greek and Sanskrit (India) writings have recommended water treatment methods such as filtering through charcoal, boiling, straining and exposing to the sunlight (EPA 2000). In that period, turbidity was the main driving force in the water treatments and have not concerned much about microorganisms" or chemical contaminants. But with a pace of time new techniques are developed and then water disinfection with chlorine and filtration become effective treatment technique (EPA 2000).

Water supply and wastewater management in Kathmandu valley has become a major problem regarding sufficient drinking water and poor distribution system. Due to overgrowth of population, there is acute shortage of drinking water with increasing to demand (Bhusal n.d.).

There is also mismanagement of distribution system and network problems along with poor treatment performance of treatment plants due to poor functional and maintenance state and unavailability of spare parts in all treatment plant (KUKL 2008). This leads proper access to drinking water for customer and government could not fulfill water supply demand. KUKL (2008), stated that," to overcome and minimize the water demand of Kathmandu valley a public company was registered under government of Nepal".

KUKL is a public corporation registered in accordance with Nepalese Government Ordinance No. 2063 who has responsibility for collecting, processing and distributing drinking water to the people of Kathmandu Valley (KUKL 2008). The Water Treatment Plant in Kathmandu Valley is currently managed by Kathmandu Upatyaka [valley] Khanepani [drinking water] Limited (KUKL 2008). The major objective of KUKL is operation and management of the water supply and sanitation system of the valley by providing quantitative, qualitative and reliable service to the consumer with minimum cost which consumer can afford (KUKL 2008).

The existing water treatment plants in Kathmandu valley are: Balaju treatment plant, Bansbari, Bhaktapur Jagati, Dhobi Khola, Kalanki, Lokanthali, Kalimati, Lagan Tole, Mahankal chaur, Manohara, Sinamangal, Tahachal treatment plant etc. According to Belbase (2011), twenty seven treatment plants exist in Nepal, among which the large ones Baude, Mahankal Chaur, Bansabari and Tahakhel are operated in satisfactory or good condition. The remaining 22 small scale water treatment plants are operated in deficient functional condition and /or out of service and only 13 treatments plants have any disinfection plants (6 dosing pumps and dripping) (Belbase 2011; KUKL 2008).

A typical water treatment plant uses a process of coagulation, sedimentation, filtration and chlorination to treat drinking water. The Water treatment Plant (WTP) has adopted conventional purification processes and it is operated on a gravitational flow system.

3.1.2. Treatment processes

The treatment processes are raw water storage, aeration, coagulation-flocculation, sedimentation, filtration, and disinfection by chlorine.

a) Collection from source and storage (Intake):

Water is pumped from different sources as surface water and ground water and directed into pipes or holding tanks. Screening is the first step of purification of surface water treatment which removes large fragments such as sticks, leaves, trash and other large particles which may create problem in later purification steps (Wiki n.d.). Most deep groundwater does not need screening before other purification processes.

Storage means to improve quality of water through sedimentation of silt and other suspended matter by the action of gravity (Wiki n.d.). Colour and turbidity are subjected to reduce for considerable percentage and bacteria also disappear to as much as 90 to 95 % (Belbase 2011).

b) Aeration of raw water:

Water is mixed with air to increase dissolved oxygen through aeration which removes dissolved gases such as carbon dioxide and oxidizes dissolved metals such as iron, hydrogen sulfide, manganese and volatile organic chemicals (VOCs) (Rabah 2012). Higher oxygen level in water helps formation of coagulation mass, further it also enhances taste and remove odour (Belbase 2011). In general, aeration is done with the treatment of groundwater supplies in conjunction with lime softening and for the removal of some VOCs (USACE 1985).

Different types of aerator are found such as gravity, fountain, diffused and mechanical whose objective is “to maximize the area of contact between the water and the air” (TAS n.d.). Cascade aerator is one example of gravity aerator found at WTP in Nepal.

c) Coagulation and flocculation:

Coagulation is the process used to remove very high suspended materials that don’t settle during storage. Coagulation starts when positively charged coagulant particles attracting negatively charged colloidal suspended particle and form flocs which increase in size throughout the settlement thereby processes called flocculation (WHO n.d.). Flocculation process helps uniform distribution of the coagulant and colloidal particles in the water which leads to floc formation and thereby causes the settlement of all colloidal impurities in water including bacteria (WHO n.d.). During flocculation, the stirring should be gentle and can be achieved through baffled mixing, mechanical mixing and air agitation (WHO 1996). Bhusal (n.d.) listed types of flocculators where in baffled mixing water is made to pass through a channel interrupted by incomplete partitions called baffled and rotating paddles are employed for stirring in case of mechanical paddling". While in the air agitation" compressed air is diffused through water for thorough mixing (Bhusal n.d.).

Aluminum and ferric based coagulants and polymers are used to facilitate the bonding between particles and precipitating agents like lime, soda ash is also added to reduce raw water hardness (USACE 1985).

d) Sedimentation and settling:

After flocculation basin, water entered into the sedimentation basin also called clarifier or settling basin which allows floc to settle to the bottom. The amount of floc that settles out of the water is dependent on the time and depth of the basin. Normally detention time for settling basin is 2 to 4 hours (WHO 1996). During storage, about 90% of suspended solids settle down within 24 hours and water become clear and clean and certain heavier chemicals also settle down during storage (Belbase 2011).

e) Filtration:

Filtration is the process of passing water through any kind of porous material to remove particulate and other impurities such as floc as the final step in water treatment process. The sand gravity filter consists of rectangular tank which contains (Belbase 2011):

i. A top layer (1m thick) of fine sand.

ii. Middle layer (0.3m-0.5m thick) of coarse sand.

iii. A bottom layer (0.3m-0.5m thick) of gravel.

Two common types of filter used in water purification are biological or slow sand filter which uses bacteria to treat the water and other, physical or rapid sand filter that have fairly high flow rates and require relatively little space to operate (WHO 2006).

Pressure filters are modern filters which are used to remove iron and manganese especially better for ground water (EPA 1995). Groundwater is first aerated to oxidize the iron or manganese, and then pumped through the filter. The WTP in Nepal has used pressure filters when ground water is source. A pressure sand filter is contained under pressure in a steel tank, which may be vertical or horizontal varying on the space available (EPA 1995; MRWA n.d.).

Roughing filters is other example of filters which can also found in WTP of Nepal. It can be applied as pre-filters prior to other processes such as slow sand filters and coarse gravel or crushed stones as the filter medium that can treat water of high turbidity (>50 NTU) (WHO 2006). WHO (2006) also stated “the advantage of roughing filtration is that as the water passes through the filter in which particles are removed by both filtration and gravity settling method”.

f) Disinfection:

Chlorination, chloramination, the use of chlorine dioxide, ozonation, UV radiation and advanced oxidation processes are the disinfection methods (WHO 2006). But Chlorine is the commonest disinfectant agent used for the disinfection of filtered water because it is cheap, efficient, reliable and harmless in acceptable level (Pain & Spuhler n.d.). Bleaching powder is mixed for oxidation of iron & disinfection.

The filtered water is finally disinfected by chlorination that kills or inactivation of microorganisms still present in water and also effective against the bacteria commonly associated with waterborne diseases (EPA 2000) and control of algae and other plant life since it is a powerful germicide and algaecide (Belbase 2011). Chlorine removes tastes and odor oxidizes iron and manganese, improves coagulation, and removes color (Belbase 2011; WHO 2006).

g) Storage and distribution:

All treated water is stored in a reservoir and then distributed to the different places or different households through pipelines. The water is sampled and tested for the treatment plant. Sampling is analysed to make sure the processes are working and the water is safe for consumption.

3.2. Constructed wetlands

3.2.1. History and introduction of CWs

In early 1950s, for the first time wetland vegetation was used to removes various pollutants from wastewater. During 1967-1969, the first full-scale free water surface FWS treatment system was built in the Netherlands. Later on in 1980s, soil was replaced with washed gravel. Since then, a more thorough understanding and research has developed the specific strengths and weakness for CWs as treatment systems. Thus constructed wetland is getting much popularity than conventional wetland and this has increased worldwide acceptance (Vymazal 2005). With the increasing need of nitrogen removal from wastewater, vertical flow CWs, which is responsible for nitrification, are mostly used in 1990s. After few years it has been noticed that nitrification and denitrification are equally important to remove total nitrogen, hence hybrid system has been introduced to effectively remove pollutants from wastewater (Gil 2014). Constructed wetlands are used for all kinds of wastewater since 1990s (Vymazal 2005) and its application not only used in developed but also in developing countries.

According to Pillai & Vijayan (2013), "constructed wetlands function as Ecological Sanitation systems to achieve water reuses, nutrient reuse and biomass production as well as engineered ecosystem with plants and rhizosphere microorganisms living in a physical arrangement to remove pollutants from waste water". Constructed wetlands alternative to the conventional wastewater treatment plant can be used as part of decentralized wastewater treatment systems and are a vigorous and "low tech" technology with low operating facilities (Pillai & Vijayan 2013). Since the mid-1990s, constructed wetlands have been increasingly used as a low green energy technique in the wastewater treatment, due to the rise in cost of fossil fuels and increasing concern about climate change (Lee *et al*. 2009). They are gaining importance of the context of sustainability for the treatment of wastewater and can play an important role in ecological sanitation concepts (Hoffmann *et al*. 2011).

According to UN-HABITAT (2008), a constructed wetland is a shallow basin filled with filter material (substrate), mainly sand or gravel, and planted with vegetation tolerant of saturated conditions. Wastewater is introduced into the basin and flows over the surface or through the substrate, and then discharged out of the basin which controls depth of the wastewater in the wetland (UN-HABITAT 2008).

3.2.2. Types of CW

A "constructed wetland" is defined as a wetland mainly built for the purpose of pollution control and waste management, at a location other than existing natural wetlands (Reed 1993). There are two basic types of constructed wetlands according to the flow pattern:

- The free water surface wetland
- The subsurface flow wetland

Both free water surface and subsurface flow utilize emergent aquatic vegetation. FWS contains appropriate emergent aquatic plant at relatively shallow depth, flow horizontally over the bed of the media. In this case, the surface of the wastewater is exposed to the atmosphere as it flows through the bed (Shrestha 1999). On the other hand, SSF wetland basically consists of the same components as the FWS system, but the wastewater is confined to the substratum. The subsurface zone is generally anoxic, but plant can transfer excess oxygen to the root system thus creating aerobic micro sites adjacent to the root and rhizomes.

According to direction of flow, SSF can be further divided into two beds:

1. Horizontal Flow Bed
2. Vertical Flow Bed
3. Hybrid system

Horizontal Flow Reed Bed System (HFRBS)

It is called horizontal- flow because the wastewater flows slowly through the bed in horizontal path. During the flow wastewater will come into contact with a network of aerobic, anoxic and anaerobic zones (Cooper *et al*. 1996, cited in UN-HABITAT 2008). Horizontal flow constructed wetlands are efficient to remove organics compound and suspended solids but less efficient to remove nutrients (Vymazal 2005).

Vertical Flow Reed Bed System (VFRBS)

In vertical flow reed bed, wastewater flows through vertically and they are fed intermittently and the liquid is dosed onto the bed in a large batch thus flooding the surface, which then gradually drains completely as it allows air to refill the bed (UN-HABITAT 2008). Each dose of liquid traps the air and subsequent dose creates aeration into the bed which leads to good oxygen transfer and hence the ability to nitrify (Shrestha 1999).

Hybrid System

There has been a limitation on both Horizontal flow (HF) wetland as well as vetical wetland system (Vymazal 2010). It has been well known that horizontal flow bed helps to remove BOD_5 and TSS from wastewater treatment and is better for denitrification too but not suitable for nitrification whereas Vertical flow (VF) wetland has greater oxygen transfer capacity and considerably require less area than HF (Shrestha 1999). But VF wetlands also have some drawback like less efficient in solids removal and clogged problem if the selection of media is not done correct (UN-HABITAT 2008). Due to these reasons, there has been a growing interest in combined wetlands whixh we generally refer as hybrid system (combination of both). In these systems, the advantages and disadvantages of the HF and VF are combined to get better results.This can be done with horizontal followed with vertical or vice versa.

3.2.3. Advantages and limitations of CW

The major advantages of constructed wetland systems are (Shrestha 1999; Davis 1995, Patel & Dharaiya 2013):

- Wetlands can be less expensive to construct than other treatment options
- Utilization of natural processes
- Good nutrient removal, good up to very good with respect to pathogens
- Simple construction (can be constructed with local materials) and as well as operation and maintenance
- Cost effectiveness (low construction and operation costs)
- Aesthetic appearance

Limitation concerned to the constructed wetland (Shrestha 1999; Davis 1995, Patel & Dharaiya 2013):

- Large area requirement
- Wetland treatment may be cost-effective relative to other possibilities if land is accessible and cost is affordable
- Design criteria have still to be developed for different types of wastewater and climates
- Proper compilation of the filter media needs a lot of experience

3.2.4. Pollutant removal processes in CW

Treatment process mechanism

To design and develop a wetland for effective wastewater treatment, it is necessary to understand the processes that occur in wetlands and primary processes include (Davis 1995):

• Uptake, breakdown and conversion of nutrients and pollutants by microorganisms and plants.

• Filtration and chemical precipitation is done through contact with substrate and litter.

• Filtration and chemical precipitation through contact with substrate and litter.

• Settling of suspended particulate matter.

• Chemical transformation of pollutants (i.e. ammonification of nitrogen).

• Absorption and ion exchange on the surfaces of plants, sediment, and litter.

• Predation and natural die-off of pathogens.

Pollutant removal mechanism

Charicteristics of wastewater, amount of oxygen supplied to microbes and wetland system determines the pollutant removal mechanism in wetlands. Among this all, the most important removal processes are the physical methods of sedimentation through reduced velocities, and filtration by hydrophytic vegetation. These methods accounts for the high reduction rates for suspended solids and the particulate fraction of organic matter (particulate BOD) as well as sediment-attached nutrients and metals too. Oils and greases are effectively removed from impoundment, photo-degradation and microbial action. Similarly, pathogens show good elimination rates in constructed wetlands through sedimentation and filtration, natural die-off and UV degradation processes.

1. Organic matter removal mechanism: Organic matter is removed in CW by biological process, which is mainly depended on activity of microorganism. Soluble organic matter is mostly degraded aerobically by bacteria in the water column, plant-attached algal and bacterial relations and bacteria at the sediment surface (Gil 2014; Poh 2003).

*2. Solids removal***:** Settable solids are removed through gravity sedimentation as wetland systems generally have long hydraulic retention times. Non-settling colloidal solids are removed through the mechanisms include: straining (if sand media is used); sedimentation and biodegradation (as a result of bacterial development); and adsorption of other solids (plants, soil, sand and gravel media etc.) (USEPA 2000).

3. Nitrogen removal: Nitrogen removal processes in constructed wetlands consists of volatilization, sedimentation, ammonification, nitrification, denitrification and plant uptake matrix adsorption (Lee *et al*.2009). The removal of nitrogen depends on the form of nitrogen present (nitrite, nitrate, ammonia or organic nitrogen). Ammonia is removed largely from microbial nitrification (aerobic) where ammonia is converted into nitrite and further into nitrate and nitrates are then converted to nitrogen gas (N_2) and nitrous oxide (N_2O) by denitrifying bacteria in anoxic and anaerobic zones denitrification (anaerobic) condition (Rani *et al*. 2011). Plants remove ammonia nitrate into nitrite which are then incorporated into the cell mass. Nitrate is removed largely from denitrification and plant uptake (Lee *et al*. 2009). Lee *et al*. (2009)

stated that denitrification is the primary removal processes in constructed wetlands which contribute 60-70% of the nitrogen reduction and remaining 20-30% were absorbed by plants (Hendrawan *et al*. 2013).

In HFBs, nitrification is limited due to low oxygen availability close to the surface or around the roots and denitrification is efficient even at very low carbon to nitrogen ratios (Hoffmann *et al*. 2011; Ellingsen 2010).

In VFBs, oxygen supplies is high since it is intermittently loaded which allows air to enter the bed and therefore ammonia can be oxidised by autotrophic bacteria to nitrate and the process is called nitrification (Hoffmann *et al*. 2011; Ellingsen 2010).

Nitrogen removal through plant harvesting plays an important role in tropical and subtropical regions where the plants grow rapidly and harvesting takes place many, particularly lightly loaded systems (Garcia *et al*. 2010). Plant uptake is effective only when plants are harvested (Vymazal 2010).

4. Phosphorous removal: Phosphorus is available as orthophosphate and organic phosphorus in wastewater. The major responsible phosphorus removal is adsorption, precipitation and plant uptake. Sundaravadivel & Vigneswaran (2001) stated two processes of phosphorous removal. First, uptake by plants and microbial organisms in substrate media and sediments, are the short-term processes and other is absorption and accretion into the sediments is a long-term removal process. Removal of phosphorous occurs through plant absorption and subsequent burial in the litter compartment which is the main pool for phosphorous (Sundaravadivel & Vigneswaran 2001). Adsorption and precipitation reaction are the major removal pathways when the hydraulic retention time is longer and finer – textured soils are being used, since this allows greater opportunity for phosphorous sorption and soil reaction to occur (Rani *et al*. 2011).

Phosphorus is a limiting factor of vegetative productivity since it is an important nutrient required for plant growth (Ellingsen 2010). The removal, of P in HFB is found to be a function of the bed area, hydraulic loading and influent concentrations. However, the media is also an important factor of phosphorus removal which depends on sorption capacity and efficiency decrease if the system operates for longer period (Rani *et al*. 2011). Gravel is preferred to soil in horizontal CWs however it has low sorption capacity and does not clog easily and can be reused;

consequently sorption is expected to be of little significance as a removal mechanism for P (Ellingsen 2010).

Sundaravadivel & Vigneswaran (2001) also described harvesting plants and/or dredge the substrate media is important to effective removal of phosphorous. Otherwise, it also will be return back to the system due to decomposition.

5. Trace elements: Removal of these elements principally heavy metals occurs mainly through sorption. The processes of metal removal of the wetland system also cover sedimentation, filtration, adsorption, complexation, plant uptake and microbial mediated reaction.

6. Microorganisms: Microorganisms are removed by die-off, filtration, sedimentation, entrapment, predation, radiation, desiccation, chlorination (when disinfection is applied) and adsorption.

3.2.5. Vegetation (*Phragmites karka*)

Vegetation and its litter are necessary for the performance of constructed wetlands and help to give aesthetically appearance. The vegetation to be planted in constructed wetlands should fulfill the following criteria (UN-HABITAT 2008):

- Application of locally dominating macrophyte species.
- Deep root penetration, strong rhizomes and massive fibrous root
- Considerable biomass or stems densities can achieve maximum translocation of water and assimilation of nutrients.
- Maximum surface area is required for bacterial populations.
- Transport of oxygen into root zone facilitates oxidation of reduced toxic metals and supports the large rhizosphere.

Phragmites karka is widely used as vegetation in constructed wetlands which is one of the most productive, widespread and variable wetland species in the world and also a predominant species in wetland systems due to its climatic tolerance and rapid growth.

3.2.6. Operation and maintenance in CW

Every constructed wetland should have a proper maintenance and operation plan so that the system can perform well. According to constructed wetland manual, operation and maintenance can be divided into three stages, start-up, routine and longterm (UN-HABITAT 2008). Along with this, thorough checkups must be done twice a year for the effective operation of the wetland. The most important things to be considered during operation and maintenance of wetland can be summarized as below:

- Water levels adjustment
- Maintenance of flow uniformity (inlet and outlet structures):
- Management of vegetation and odour control:
- Maintenance of walls

Management of wetlands is important to perform well. Wetland management should focus on the most important factors of better performance in the treatment process (Davis 1995):

- providing sufficient time in contact of the water with the microbial community and with the litter and sediment
- assuring that water flows reach all sections of the wetland
- Maintaining a healthy environment for microbes and maintaining a vigorous growth of vegetation.

Kadlec & Knight (1996) (cited in Rousseau 2005), mentioned that monitoring and regulation of flows, water levels, water quality and biological factors are the only regular activities required to achieve successful performance in CWs (Rousseau 2005).

3.2.7. Decentralized Wastewater Treatment Systems:

Decentralized Wastewater Treatment Systems (DEWATS) is a sustainable treatment of wastewater that mainly emphasis on locally adjusted solutions which help to maintain low costs.

According BORDA (2011) (cited in Ellingsen 2010), constructing treatment system with low maintenance requirements, no energy inputs and locally available materials, costs can be minimized and also useful for the community members to operate and maintain without skilled technical assistance.

Depending upon the size, location and a number of determining factors, the configuration of DEWATS can vary. In Nepal, the mostly accepted components for primary treatment are anaerobic processes (Anaerobic Baffle Reactors; ABRs) and combine ABRs with bio digesters. Davies (2013) summarized “An ABR consists of series of baffles, under which the wastewater is directed to flow through the layers of settled sludge” and trapped solids at the bottom of the reactor are consumed through the anaerobic digestion process. Bio digesters uses microbial degradation treatment processes for the collection of biogas (Davies 2013).

3.3. Conventional wastewater treatment plants

3.3.1. History and introduction of Wastewater treatment

The treatment of wastewater is most important mainly because of its characteristic bad odour. On the other hand wastewater also contains human waste which is very harmful to the environmental if discharged carelessly. The untreated wastewater is directly discharged into a natural water body constitute a great hazard for the environment and a health risk for human and animal life. It is essential to collect and perform a proper treatment. In centralized system, there is collection of both storms, domestic as well as industrial sources.

During the late 19th and the early 20th century, centralized wastewater treatment systems are growing concern in the United Kingdom and the United States. Collection and treatment before discharge of wastewater, physical, biological and chemical processes are need to address for the removal of pollutants. According to Britannica (2012) (cited in Kvernberg 2012), more concern is shown on wastewater disposal. More advanced treatment techniques are developed for the treatment of wastewater including tertiary treatment steps for removal of nutrients which leads to eutrophication. Treatment processes are designed accordingly to the need pollutants to be removed from wastewater.

The characteristics of wastewater depend on the source of its generation. Production of wastewater in Nepal in the cities like Kathmandu is mainly from domestic, commercial and industrial routes and directly discharged into water bodies (Regmi 2013).

Almost all municipalities in Nepal do not have proper wastewater treatment plants, except three municipalities in Kathmandu valley. Five sewage treatment plants of design capacity of 35 MLD (Figure 16): Dhobighat sewage treatment plant (15.4 MLD), Kodku (1.1 MLD), Sallaghari (1 MLD), Hanumante (0.05 MLD) and Guheshwori (17.4 MLD) are present in Nepal now (Poh 2003). These plants are practically non-operational except for Guheshwori and even those non-operational plants are rehabilitated, the total treatment capacity is not sufficient for the cities (Poh 2003). Those are also not so effective due to lack of skilled manpower, functioning cost and other social and political barriers (Bista & Khatiwada n.d.).

3.3.2. Wastewater treatment processes

The following section reviews the functions of different treatment steps and important design parameters of a conventional attached growth biological wastewater treatment plant.

a) Primary treatment: It involves screens or grit chambers for primary sedimentation. Its main objective is to remove a large fraction (50-70 %) of the total suspended solids available in the wastewater. Around 25-40 % of the total BOD is removed in the process since suspended solids contributes to the content of BOD in the wastewater, (Metcalf & Eddy 2004). Removal of suspended solids also lowers the operational problems in the next treatment processes.

b) Secondary treatment: Kvernberg (2012) stated microorganisms oxidize dissolved and particulate biodegradable matter into simple end products, which can be removed from the wastewater stream as sludge through biological wastewater treatment. Such processes can also remove suspended and non-settleable colloidal solids through biological flocs or biofilm. The main objective of secondary biological treatment is to remove readily biodegradable BOD that has escaped the primary treatment, in combination with further removal of suspended solids (Kvernberg 2012). Biological treatment can be achieved either in the presence of oxygen (aerobic processes) or in the absence of oxygen (anaerobic processes). Two main types of biological treatment are common in wastewater treatment, one is attached growth biological treatment, also known as biofilter process, and the other is suspended growth biological treatment, also known as activated sludge process.

An activated sludge process is a biological wastewater treatment process which increase speeds for waste decomposition by recirculating sludge. NSFC (2003) stated activated sludge is added to wastewater and then the mixture is aerated and agitated. Settable activated sludge through sedimentation after a certain amount of time, it is either disposed to sludge drying beds or reused, means returned to the aeration tank. An oxidation ditch is the type of biological aeration process, consisting of a ring or oval shaped channel equipped with mechanical aeration devices, such as disc aerators. According to NSFC (2003), "Oxidation ditches operate in aeration mode with long solids retention times (SRTs) and solids are maintained in suspension as the mixed liquor circulates around the ditch".

Secondary clarifier: It is a secondary sedimentation tank where solids are settled and removed from the wastewater stream as sludge.

c) Tertiary treatment: Tertiary treatment is the advanced treatment process which removes the nutrients such as phosphorus and nitrogen. Beside these, all suspended and organic matter from waste water, which comes after secondary treatment, are also removed to produce high quality of water.

4. Methodology

This study was conducted by field observation of constructed wetlands and water treatment plants including wastewater treatment plant in Kathmandu valley. For the survey and investigation, relevant data was collected from different sources including organizations, research papers, internet and literatures. Data collected was processed, reviewed and edited.

The research sites are located inside and outside Kathmandu Valley. The findings of this research were obtained through the following methods: site observation, sampling, validating questionnaires and user interviews.

Observation of inlet and outlet arrangement, distribution systems and their function as well as operation and maintenance for each site were studied in order to assess the technical performance.

Sampling for the chemical parameters is performed by collecting one sample for each parameter at inlet and outlet points of the constructed wetlands. Analysis is made in laboratory at Institute of Engineering (IOE), Pulchowk Campus in Kathmandu.

Validating of questionnaires is conducted through the MSc. first year students from IOE. After validation, primary data were collected through research questions to individual respondent, to the community, farmer and caretaker/operator of the constructed wetlands in order to assess the knowledge of constructed wetland systems and the positive and negative impacts of using treated water in the farming. In case of conventional wastewater and water treatment systems, care operator is interviewed.

4.1. Water treatment plants

4.1.1. Mahankalchaur treatment plant

Background

Mahankalchaur treatment plant is the largest water treatment plants within Kathmandu valley and is also one of the collectors of raw water, processor and distributor branch office of KUKL which is located in Mahankal chaur, Kathmandu. The plant supplies water that draws from Sundarijal source and from different ground water source and process in the Mahanlakchaur office and distributes to the city around the office (Belbase 2011).

In treatment plant, there are two reservoirs tanks for the storage of treated water having capacity of 22 lakh liters (2 nos.) and 45 lakh liters (1 nos.) according to the chemist or care operator of the plant Mr. Basant Kumar Pal. A storage reservoir is built to collect water from filters and store it until it is distributed. The stored water is then distributed to the different places of Kathmandu valley up to Basnatapur, Kalimati and Maharajgunj area (Belbase 2011). It usually holds from 1 to 3 days or more of the average daily demand to meet fluctuations and one day's storage reservoir is better from sanitary point of view (Belbase 2011).

Technical components

The main components of MCWTP (Mahankalchaur water treatment plant) (Figure 1):

- Bio filter unit with caustic soda feeding unit
- Flocculation and sedimentation unit, Poly Aluminum Chloride (PAC) feeding unit and slaked lime feeding unit
- Rapid sand filter
- Clear water reservoir with pump
- Sodium hypochloride generator and bleaching powder feeding unit
- Sludge and drainage
- Water quality meter and water quality test unit: After the treatment, physical, chemical and pathological testing of water is done in laboratory.

Figure 1: Pictorial representation of Mahankalchaur Treatment Plant

Operation and maintenance

The WTP is operated and maintained by the "KUKL". A care taker and also chemist Mr. Basant Kumar Pal is assigned to the operation and maintenance of the plant.

The following operation and maintenance are performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,
- Regular monitoring of the treatment units for ongoing treatment and observe the turbidity of raw water for dosing the disinfectants agents
- Dosing of chemical agents used for treatment
- Cleaning of settling tank, reservoir and disposing sludge

- Chemical analysis of water in lab before distribution

4.1.2. Bansbari treatment plant

Background

The Bansbari Water Treatment Plant was constructed in 1975, and 41 years have elapsed since its construction. A well has been constructed in the treatment plant having intake capacity of approx. 500m^3/day. The water contains underground silt and the well can be used only as an auxiliary water source. The source of this plant is Mahadev River and two conveyance pipes are used to intake raw water from river which comes under the gravity flow system.

The oldest water treatment plant has one reservoir of capacity 25 lakh liters according to the care operator and civil engineer from Bhaktapur Khanepani Ltd.

Technical components

The water is flocculated in the flocculation basin, settled in the horizontal-flow sedimentation basin and then put into slow sand filtration (Figure 3). After that, chlorination is added in the treatment/distribution reservoir prior to distribution. Figure 2 shows the water treatment process.

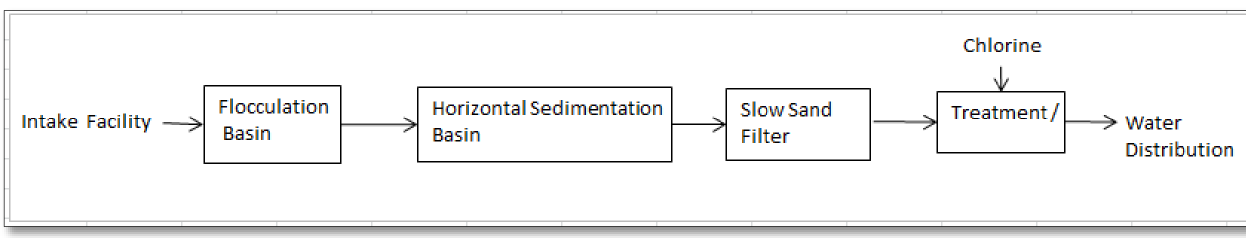

Figure 2: Disinfection Process at the Bansbari Water Treatment Plant (Hazama and Ando, 2015)

Figure 3: Pictorial representation of Bhaktapur Bansbari Treatment Plant

Operation and maintenance

The WTP is operated and maintained by the "KUKL" under Bhaktapur branch office. A care taker and also chemist Mr. Kedar Kafle along with other one is assigned for the operation and maintenance plant.

The following operation and maintenance are performed to ensure proper running of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,

- Regular monitoring of the treatment units for ongoing treatment and observe the turbidity of raw water for dosing the disinfectants agents
- Dosing of chemical agents used for treatment
- Cleaning of settling tank, reservoir and disposing sludge

4.1.3. Lokanthali treatment plant

Background

Lokanthali treatment plant is a small scale water treatment plant for drinking water production having distribution reservoir capacity of 3 lakh liters (2 nos. reservoirs of each 1.5 lakh liters). The source of the plant is ground water which has been pumped through the use of submersible pump.

Technical components

The components that are used for the treatment of groundwater and up to distribution are as shown in Figure 4 and Figure 5 . Raw water from tube well is passed through Aerator. Aeration is done by cascade constructed above sedimentation tank. Water from aerator is passed to sedimentation tank through mixing channel where bleaching powder is mixed. Detention time of sedimentation tank is 60 minute. Water from sedimentation tank is pumped to pressure filter in order to remove iron and turbidity. The filter media of filter consists of multi-media sand and gravel where the effective size of filter sand is 0.6 and depth is 0.7 m (KUKL n.d.). Filtered water is passed to clear water reservoir with disinfection done by bleaching powder. Water is distributed to system by Booster pump. Two pumps are installed each capacity of 60 cu.m per hour (KUKL n.d.).

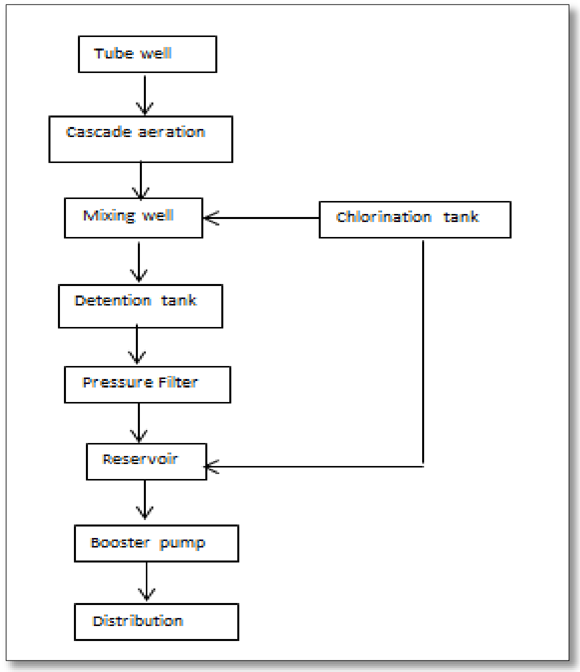

Figure 4: Flow diagram of Lokanthali Treatment plant (KUKL n.d.)

Figure 5: Pictorial representation of Lokanthali Treatment plant

Operation and maintenance

Care operator, Muktinath Adhikari along with two others is assigned by KUKL for regular operation and maintenance of the plant on the shift basis.

The following operation and maintenance are performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,
- Regular monitoring of the treatment units for ongoing treatment and dosing of the disinfectants and chemical agents
- Maintenance of machinary part done by Sundarighat mechanical electrical Shakha.
- Cleaning of settling tank and disposing sludge

4.1.4. Bhaktapur Jagati treatment plant

Background

Bhaktapur Jagati treatment plant is a small scale water treatment plant for drinking water production having distribution reservoir capacity of 1 lakh. The source of the plant is ground water which has been pumped through the use of submersible pump same as in Lokanthali treatment plant.

Technical components

Technical components are similar to the Lokanthali treatment plant (Refer Figure 7). Instead of pressure filter, gravity filter is used for filtration (Figure 6).

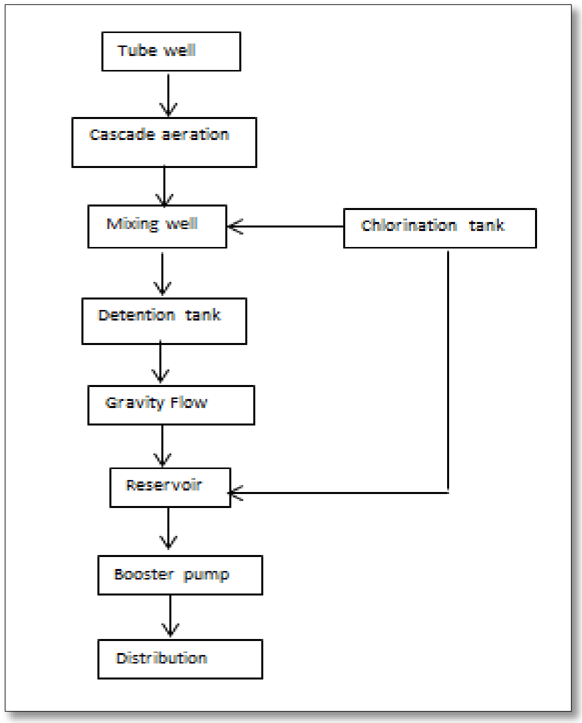

Figure 6: Flow diagram of Bhaktapur Jagati Treatment plant (Hazama and Ando 2015)

Figure 7: Pictorial representation of Bhaktapur Jagati Treatment Plant

Operation and maintenance

Care operator, Pancha Kumar Mahaju along with other four are assigned by "KUKL" under Bhaktapur Branch Office for regular operation and maintenance of the plant on the shift basis.

The following operation and maintenance are performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,
- Regular monitoring of the treatment units for ongoing treatment and dosing of the disinfectants and chemical agents
- Maintenance of machinery part.
- Cleaning of settling tank and disposing sludge
- Cleaning of reservoir done twice a year and cleaning of filter tank is also performed

4.1.5. Balaju treatment plant

Background

Balaju treatment plant in Kathmandu valley is one of the collectors of raw water and purified before distribution for production of drinking water, under responsibility of KUKL. The plant purify water from the Alle, Baude, Bhandare, Panchmane and Chhahare sources at Balaju treatment plant and collected in the reservoir of Balaju.

In treatment plant there are one reservoirs tanks for the storage of treated water having capacity about 51 lakh liters according to the care operator of the plant Mr. Ravi Karki. A storage reservoir is built to collect water from filtration units and store it until it is distributed. The stored water is then distributed to the locals of ward-13, 15 and 16 of Kathmandu Municipality according to the care operator.

Technical components

The technical components of balaju treatment plant are Coagulation, Sedimentation, Rapid Sand Filter, Chlorine Feeding for disinfection (Figure 8).

Figure 8: Pictorial representation of Balaju Treatment Plant

Operation and maintenance

A care operator, Ravi Karki is assigned by "KUKL" for regular operation and maintenance of the plant.

The following operation and maintenance are performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,
- Regular monitoring of the treatment units for ongoing treatment and dosing of the disinfectants and chemical agents
- Monitor on damage of treatment units and maintenance of machinary part.

- Cleaning of settling tank, reservoir and disposing sludge

4.1.6. Dhulikhel treatment plant

Background

Dhulikhel treatment plant is located at Dhulikhel Municipality which follows gravity flow system. It is established under German and Nepal Co-operation with moto " Safe drinking water for Healthy Life". The source of plant are Panauti and Roshi River that are draws to treat and purify for the production of drinking water for Dhulikhel area. The plant have a reservoir capacity of 5 lakh liters for distribution.

Technical components

The main components of treatment plant consists of following unit (Figure 9)

- Intake
- Horizontal Roughing Filter unit
- Slow sand filter unit
- Reservoir and Chlorination unit

Figure 9: Pictorial representation of Dhulikhel Treatment Plant

Operation and maintenance

Care operators, Ashok Shrestha along with another one are assigned by Dhulikhel Khanepani and Cleaning Consumer limited for regular operation and maintenance of the plant.

The following operation and maintenance are performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe,
- Regular monitoring of the treatment units for ongoing treatment and dosing of the disinfectants and chemical agents
- Monitoring if any damage on the treatment units and maintain them
- Cleaning of slow sand filter, gravels on roughing filter and reservoir and disposing sludge

4.2. Constructed wetlands

4.2.1. Srikhandapur constructed wetland

Background

The Srikhandapur wastewater treatment plant was constructed in 2008, which is located 32 km from Kathmandu in Dhulikhel municipality to treat the sewage generated from ward 8 and 9 and designed to serve 200 households (ENPHO 2010a). Its objective is to improve environmental and hygienic condition through DEWATS for treatment prior to discharge into the river and to produce biogas as a sustainable alternative energy source for cooking. In addition to show the application of DEWATS and biogas together at a community scale.

The treatment plant was built by Srikhandapur Wastewater Treatment Plant Users Committee and Dhulikhel municipality with design and supervision support from ENPHO/ BSP- Nepal and technical/financial assistance from UN-HABITAT.

Technical Components

The technical components of Srikhandapur constructed wetlands are (ENPHO 2010a) shown in Figure 10 are listed as

- Flow diversion from main sewer
- Grit chamber and bar screen
- Two parallel biogas units
- Outlet discharge to all 6 wetlands
- Six parallel horizontal flow wetlands
- Sludge drying beds

Figure 10: Pictorial representation of Srikhandapur Constructed Wetlands

Operation and maintenance

The WWTP is operated and maintained by the User Committee named "Srikhandapur Sewage Treatment Users Committee". A care taker is assigned for the operation and maintenance of the constructed wetland as well as user committee president is also an active in O&M.

The following operation and maintenance are performed to ensure proper functioning of the wetland:

- Regular maintenance works at the wetland comprised of daily activities of opening/closing the biogas valve,
- Removal of unwanted vegetation from the beds, cleaning of the inlet/outlet systems as well as cleaning the filter screen, grit chamber and digester chamber is performed and harvesting of the vegetation is done annually.
- The bed material is clogged and is reused by washing the gravel which had done last year around January, 2015 (mentioned by President, Purna Bahadur Kamarcharya interviewed on 24.02.2016)
- The operation and maintenance costs including the caretaker salary are covered by the biogas consumer (5 households), which are required to pay NRs 500 per month according to the president of Srikhandapur wetlands and household connected to WWTP are required to pay NRs 200 per year mentioned by Davies *et al*. (2015).

4.2.2. Kathmandu University constructed wetland

Background

In 2001, a subsurface flow full scale constructed wetland using local reeds (*Phragmites karka*) was introduced in Kathmandu University located 28-Km north-east of Kathmandu. The constructed wetland units comprised of a horizontal flow bed (HFB) and followed by a vertical flow bed (VFB) which is widely adopted combination in Nepal. Its objective is to treat the wastewater before it gets discharged to the natural water bodies.

The system was designed by ENPHO under the leadership of Dr. Roshan R. Shrestha.

Technical Components

The system comprises the components are (Figure 11):

- Manhole collected wastewater from girls hostel and staff quarter
- 3 chambered Sedimentation tank
- Horizontal flow bed
- Two vertical flow beds
- Outlet

Figure 11: Pictorial representation of constructed wetlands at Kathmanu University

The intermittent interflow system is maintained to feed the water for horizontal and vertical bed. It discharges about 1m^3water each time. The system run without electric energy as the wastewater is feed hydro-mechanically into the beds (Poh 2003).

Figure 12: Flushing buckets and intermittent loading system

Management for Intermittent loading system

The intermittent loading system is maintained by hydromechanics (without any external energy) and the system is unique and probably used for the first time in RBTS in Nepal. According to UN-HABITAT (2008), feeding of water into the beds is maintained by water level through a special bucket (Figure 12) that floats on wastewater. When the water level reaches certain height, a stopper stops the bucket to move up. Water level rises and fills the bucket and then the bucket gets heavier and sinks. Wastewater flows from the settlement tank to the beds. When there is no more water to flow or when the tank is empty the water in the bucket also siphons out (UN-HABITAT 2008). After wastewater gets siphoned out from the bucket, bucket floats on wastewater when it fills again. It is believed that the system is one of best possible intermittent systems, which is suitable for Nepal.

Operation and maintenance

The constructed wetland is operated and maintained by Department of Environmental Science and Engineering. No care operator is assigned and if maintenance is required then helped by CED (Civil Engineering Department) who engaged in maintenance of the system including worker needed for harvesting and removal of unwanted plant. Ratna Shrestha from CED was choosing to done with questionnaire (02.03.2016). The following operation and maintenance are performed to ensure proper functioning of the wetland:

- Monitoring of feeding tank in order to check the operation of the siphon and intermittent feeding tank to the beds.
- Removal of unwanted vegetation in the bed and annual harvesting of the vegetation.
- Desludging of the settling tank is done once a year
- Changing of the substrate in the bed when it is clogged and washed the gravel which needs to be.

4.2.3. Dhulikhel constructed wetland

Background

Dhulikhel Hospital constructed wetland system, constructed in 1997, was the first constructed wetlands for wastewater treatment in Nepal located in Dhulikhel Municipality, Kavrepalanchowk District. The constructed wetland is a two-staged subsurface flow system, which consists of a horizontal flow bed followed by vertical flow bed (Poh 2003). According ENPHO (2010b), in 2008 the treatment system upgraded and expanded due to the hospital expansion to meet current and future flows. Its objective is to treat all the wastewater generated in the hospital to reduce the environmental impacts and ensure that the people living around the hospital have access to clean treated water for irrigation (Tuladhar *et al*. 2008).

The treatment plant was built by Dhulikhel hospital with technical support from BOKU Austria designed and supervision support from Environment and Public Health Organisation (ENPHO).

Technical Components

The components of constructed wetlands at Dhulikhel hospital are shown in Figure 13**.**

- Diversion tank to spilt flow between systems
- Two parallel Settlers (1 ABR large, 1 settler small)
- Two parallel horizontal low constructed wetlands
- Two parallel vertical flow constructed wetlands
- Sludge drying bed

Figure 13: Pictorial representation of wetlands located at Dhulikhel Hospital

Operation and maintenance

A care taker is assigned for the operation and maintenance of the constructed wetland and regular maintenance responsibility is taken by Dhulikhel Hospital Engineering department. The operation and maintenance work are done by performing following responsibilities:

- Same as other constructed wetlands, Dhulikhel Hospital constructed wetlands for regular maintenance works involves removal of unwanted vegetation from the beds along with cleaning of the inlet/outlet systems.
- Removal of unwanted vegetation is carried out along with the general cleaning works and also vegetation is harvested once a year.
- The sludge from the settling tank is desludged in 1 month ago due to the increase in wastewater flow to the wetland reported by Ram Gopal Ranjitkar, a caretaker (25.02.2016).
- The substrate used in the bed has been cleaned at surface done in a year but usually it depends on clogging of the bed.

4.2.4. Constructed wetlands at IOE, Pulchowk

Background

CW of IOE is constructed in 2012, located at Pulchowk Engineering Campus. It is horizontal bed subsurface flow constructed wetland which treats domestic wastewater of neighboring houses and IOE cafeteria. Design and supervision of this project is done by Krishna Ram Yendyo, Iswar Man Amatya (TU) and Lee, Kijung (KOV).

Technical Components

The treatment plant comprises of the following units (Figure 14):

- Inlet
- Settling tank
- Horizontal flow bed
- Outlet

Figure 14: Pictorial representation of Constructed Wetlands at IOE, Pulchowk

Operation and maintenance

The following operation and maintenance are performed to ensure proper operation of the wetland:

- Regular assessment (weekly done) of system to ensure proper operation
- Regular removal of unwanted vegetation in the bed.
- Annual harvesting of the vegetation and trimming of the plant is done every 3 months reported by care operator, Ram Hari Shrestha (15.03.2016)
- Cleaning of inlet and out systems

4.2.5. Sunga Constructed wetland

Background

The wastewater treatment plant was constructed in 2005 by ENPHO, with support from ADB, UNHABITAT and WaterAid Nepal introduced a community-based wastewater treatment plant at Sunga, located within the Madhayapur Thimi Municipality (Tuladhar *et al*. 2008). The system is a platform of larger scale application of DEWATS for community benefit and community managed wastewater treatment systems. It has provided a platform for many students, researchers and professionals who visit the plant.

Technical Components

The wastewater treatment plant comprises of (Figure 15)

- a coarse screen and a grit chamber as preliminary treatment,
- Biogas plant
- an Anaerobic baffled reactor as primary treatment,
- Hybrid constructed wetland – two Horizontal Flow (HF) followed by two Vertical Flow (VF) as secondary treatment
- Sludge Drying Bed (SDB) as sludge treatment.

Figure 15: Pictorial representation of Sunga Constructed wetlands

Operation and maintenance

The operation and maintenance of the plant is taken care by the "Sunga Wastewater Treatment Plant Management Committee" (ENPHO 2010c). A care taker is assigned for the operation and maintenance of the constructed wetland in financial support from the Municipality. Regular maintenance works at the wetland comprised of unclogging of the grit, removal of unwanted vegetation from the beds along with cleaning of the inlet/outlet systems and the harvesting of the vegetation. The sludge from the anaerobic baffle reactor has been taken out once to sludge drying bed when it is in working condition.

4.2.6. Constructed wetlands at ENPHO Lab

Background

The constructed wetland located at Environment and Public Health Organization (ENPHO) was constructed in the year 2002. Its objective is to treat the wastewater generated from the office building and laboratory to reduce contaminants and also demonstrate the uses and its application in urban areas as an educational tool to all visitors to the office (ENPHO 2010d).

Technical Components

The constructed wetland comprises of

- a settling tank and a vertical flow constructed wetland

Operation and maintenance

To ensure the proper functioning of the wetland system, regular maintenance works at the involving removal of unwanted vegetation from the beds along with cleaning of the inlet system. Vegetation is harvested twice a year and the sludge from the settling tank is taken out at an interval of 6 months but sometimes sludge is desludged a little earlier.

The top layer of the bed was removed and filled with coarse sand in 2005 because of clogging occurs on the surface of the bed, mentioned in (ENPHO 2010d).

4.2.7. Constructed wetlands at Shuvatara School

The constructed wetland at Shuvatara School, located at Lamatar is constructed in 2004. It treats the institutional wastewater coming from school. The system comprises of settling tank and vertical flow bed. Due to shifting of school from Lamatar to Sanepa height, this system is not operated and maintained by them.

4.3. Guheshwori wastewater treatment plant

Background

Among five municipal wastewater treatment plants around Kathmandu valley (Figure 16), Guheshwori wastewater treatment is only one which is fully functional. The plant involves activated sludge system which is the first implemented process in wastewater treatment plant in

Nepal (Green *et al*. 2003). It is located at the bank of the Bagmati River on the north eastern part of Kathmandu City.

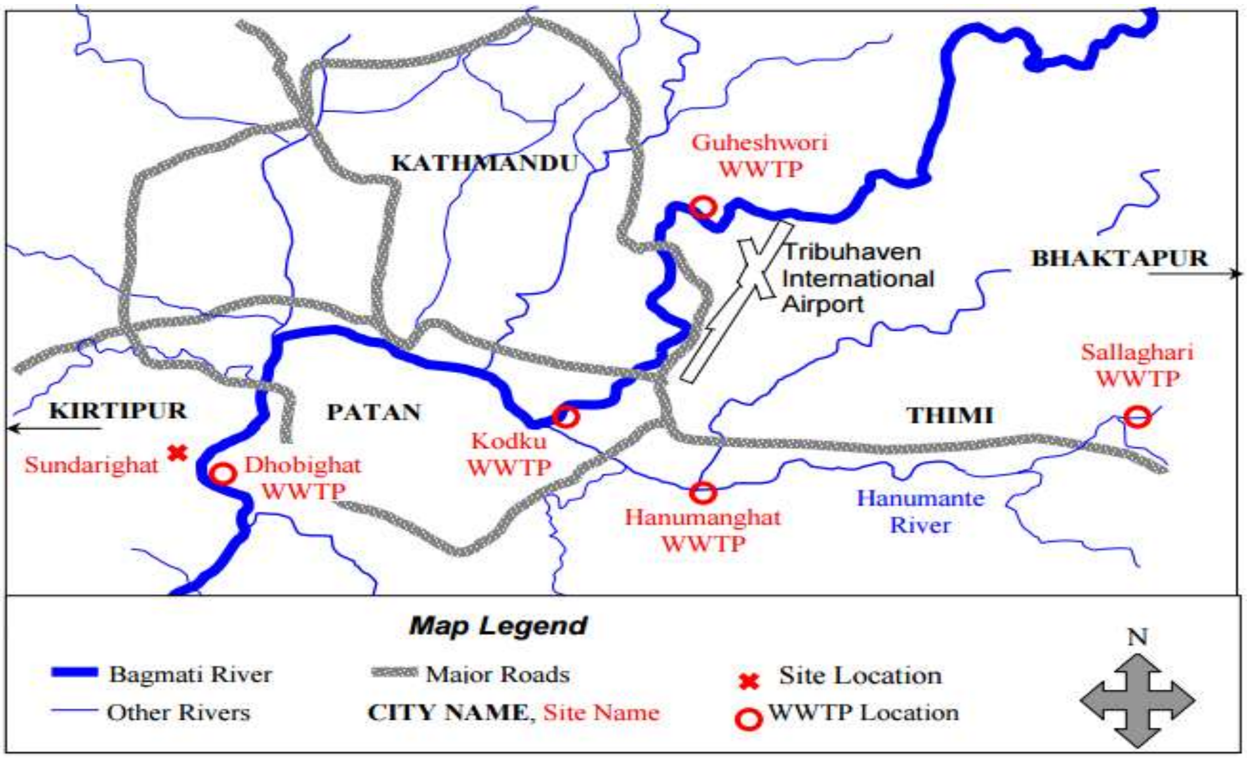

Figure 16: Map of wastewater treatment plant (ADB, 2000 adopted from Green et al. 2003)

The major objective of this plant is to clean up Bagmati River which is constructed in an area of 5 hectares with the initiative from the government. Since untreated wastewater from household are directly drained into the river, this treatment plant treats wastewater generated by the household, industries and other institutions along with storm water of nearby catchment area.

Design and working mechanism

Decomposition of degradable organic chemical in the presence of biomass takes place in the activated sludge wastewater treatment plant. It also involves a settling tank for the removal of solids and biomass from the water, and a recycle of sludge from the settling tank to the reactor to maintain the levels of microorganisms. Mechanical bar rack and a grit chamber present in it help for the pre-treatment and the system lacks primary clarification tanks.

The major components of the treatment plant include the primary and secondary units (Figure 17). The bar rack eliminates large objects from the influent and inorganic particles like sand are removed in the grit chamber zone. The wastewater at Guheshwori WWTP is biologically treated in two carrousel 15 type oxidation ditches, each with three aerators. After the operation in oxidation ditches finished, wastewater flows into two secondary clarifiers for the settling of solids. Up to 2,500MLSS sludge is pumped from the clarifiers back to the oxidation ditches to be metabolized by microorganisms, and any excess sludge is pumped from settling tank to sludge drying beds (Green *et al*. 2003).

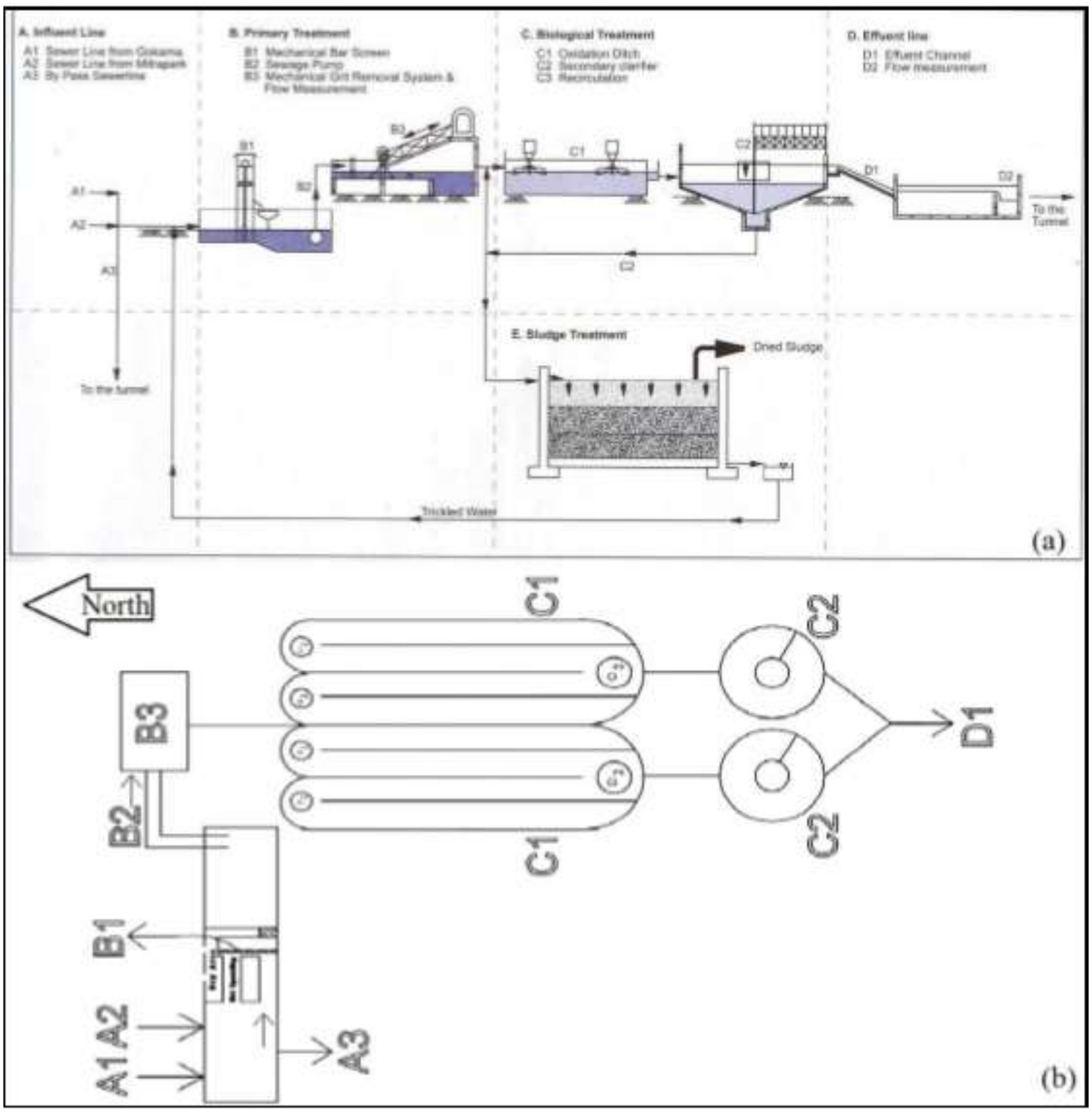

Figure 17: Guheshwori WWTP (a) Flow diagram of the WWTP (b) Bird's eye view of plan (Regmi 2013)

Technical components:

The plant consists of following units and its detail design and operational parameters of Guheshwori WWTP are described in Table 1 and Table 2.

Table 1: Units of Guheshwori WWTP

Units	Operation	
Primary unit	Mechanical bar screening, Sump well, Mechanical Grit chamber	
Biological unit	2 units oxidation ditch (80m *20m)	
Secondary Clarifier	2 units (27 m diameter)	
Sludge treatment	2 drying beds (27m *74m)	
Final effluent and effluent bypass	To avoid excess flow of untreated water during the monsoon into the Bagmati River, the WWTP effluents are diverted to outside of temple boundary through a bypass tunnel	Figure 18: Treatment units of WWTP

Table 2: Design and operational parameters of Guheswori WWTP (BASP 2002; Shah 2002; Darnal 2002; Khatiwada et al. (n.d.) cited in Shahi 2012)

Guheshwori WWTP Details	
General	
Service Area)	5.37 km^2

Service Population (1996)	58,000
Projected Population (2021)	198,000
Wastewater Produced	80 L/cap-d
WWTP Footprint	51 m^2 (164 ft^2)
Energy Consumption	2.3 KW-hr/kg BOD
Annual Operating Costs	$167,000 US
Design Flow	0.19 m^3 /s (4.3 MGD)
Oxidation ditch	
Carrousel type oxidation ditch (80*20m)	2 units
Capacity (m^3)	10400
HRT, hr.	15.2
Total oxygen demand (kg/hr.)	355
MLSS concentration mg/L	3500
F/M	0.34
Re-circulation demand, %	67-100
Power Required to drive Aerator, kWh	375
Secondary clarifier	
Diameter of 27m	2 units
Capacity, m^3	1650 m^3
HRT	4.8 hr.
Drying beds (27m*74m)	2 units
Drying period	2-3 weeks
Sludge production	40 m^3/d
Grit and sand	3 m^3/d
Screening	2-3 m^3/d

Operation and maintenance:

Care operators, Raj Kumar Shrestha along with other are assigned by WWTP for regular operation and maintenance of the plant.

The following operation and maintenance was performed to ensure proper functioning of the system:

- Regular maintenance works at the plant comprised of daily activities of opening/closing the valve of pipe and check flow of wastewater
- Regular monitoring of the treatment units for ongoing treatment and report if any damage on the treatment units and maintain them
- Cleaning of treatment units including oxidation ditch and clarifiers

5. Results and Discussions

The following chapter gives a descriptive analysis of water treatment plant, wastewater treatment plant including constructed wetlands.

5.1. Water treatment plants

5.1.1. Observation and findings

a) Mahankalchaur treatment plant

- Purification and treatment before distribution is better for health purposes.
- The treatment units are properly maintained and were found in a good condition. The plant is well equipped with modern technology.
- Sludge accumulation and pump damage. According to the Basant Kumar Pal, incharge or care operator told the old and leaking pipelines for cross contamination during the supply to consumers.
- Storage facility for bleaching powder is not in good condition (Figure 19).

Figure 19: Condition of chemical storage facility at Mahankalchaur WTP

b) Bansbari treatment plant

- The water treatment processes has been adopted 41 years ago, which shows how important is the water purification.
- Plant is functioning but is in a bad state of operation.
- As the chlorination facility is not working, a temporary chlorination facility is provided at the inflow section of the distribution reservoir.
- The working period of civil work facilities is 41 years since its construction; this plant is at the stage where its reconstruction or renewal needs to be planned.
- No independent power generator is installed despite the long periods of power failure. Therefore, the inability to backwash the rapid filtration basin poses a problem in operation and maintenance.
- Due to power failure, well cannot be operated continuously and also difficult for them to work at night time.
- Storage of chemical powder is not in good state as mentioned by care operator and he also mentioned powder used in sack are also not good that they have to check and sort out unnecessary part before it is used (Figure 20).
- Unnecessary part found in sack thrown side to the sedimentation tank (Figure 20).
- There is no sludge treating facility and cleaning of the reservoir done last year explained by the care operator (17.03.2016)
- Muddy water comes during rainy season, use of disinfectant powder and coagulants are high than normal period about 25- 40 kg depends on turbidity just by their observation.

- Measurement level for measuring water level in reservoir is not clear to judge (Figure 20).

Figure 20: Observation at Bansabari Treatment Plant

c) Lokanthali treatment plant

- Due to power failure, well cannot be operated continuously and thus no continuous operation for water production
- Storage for chemical powder is not in good condition.
- Leakages from boring pipe and algae formation on cascade aerator (Figure 21).


Alage formation in cascade aeration


Leakages from boring pipe

Figure 21: Observation found at Lokanthali WTP

- Cleaning of the reservoir done when it was emptied explained by the care operator (04.03.2016 visit and 18.03.2016 interviewed) and there is no sludge sediment treating facility and therefore sludge is directly drained to the Manohara River.

d) Bhaktapur Jagati treatment plant

- Due to power failure, well cannot be operated continuously and thus no continuous operation for water production
- Algae formation on cascade aerator (Figure 22)
- Cleaning of the reservoir done twice a year explained by the care operator (06.03.2016 visit and 17.03.2016 interviewed) and there is no sludge sediment treating facility and therefore sludge is directly drained to the Sangha River.
- Measurement level for measuring water level in reservoir is not clear to judge (Figure 22).

Figure 22: Field observation at Bhaktapur Jagati Treatment Plant

e) Balaju treatment plant

- During the visit (16.03.2016), the plant was found to be in a pitiable condition. that looks it was not maintained.
- The raw water in the coagulation and sedimentation zone seems it is full of algae (Figure 23) and looks it is not fit for drinking and even frog was also seen.
- There is no cleaning or draining of the rapid filtration facility and no proper store facility for chemical (Figure 23).

Figure 23: Field observation at Balaju Treatment plant

- There is power failure so that it cannot operated continuously.

- Despite the claim made by care operator about the regular monitoring and water quality tests, the water quality, it doesnot seems to be fit for drinking purpose from the treatment plant. But he said, after treatment and purification, it can be comsumable.
- The dilapidated condition of the plant clearly shows the negligence of the water utility responsible for operation and maintenance of the water supply systems in the Kathmandu Valley. The pitiable condition of Balaju Water Treatment Plant has revealed an aspect of deteriorating water supply by KUKL in the Kathmandu Valley.
- However, the purified water of this reservoir is suspected to be not safe for drinking purpose. It's been a long time that the reservoir has not been cleaned (1.5 years ago told by operator).
- An observation showed that there is no sludge sediment treating facility and therefore sludge is directly drained to outside without proper treatment.

f) Dhulikhel treatment plant

- Advantage of roughing filtration is that when the water passes through the filter, particles are removed by both filtration and gravity settling".
- During observation, the treatment plant looks well-conditioned. Store house is damaged due to earthquake.
- Sludge sediment treatment facility is not found here too.
- Observe algae formation in water passway to slow sand filter after roughing filter unit.
- Only one slow sand filter is in operation and other one is kept for cleaning (told by operator interviewed on 22.03.2016)

g) Sinamangal, Tahachal and Kalimati treatment plants

Visit has been made also to Sinamangal, Tahachal and Kalimati treatment plant and some observation was taken, are mentioned in Table 3.

Table 3: Information and observation made for Sinamangal, Tahachal and Kalimati treatment plant

Features	Sinamangal	Tahachal	Kalimati
Background	Small scale water treatment plant	Small scale water treatment	Small scale water treatment

	Responsibility by KUKL	plant Responsibility by KUKL	plant Responsibility under kalimati Vegetables and Fruits Limited
Source	Boring well	Boring well	Boring well
Technical Components	PF, CF	PF, CF	CTA, PF, ACF, ARF, ID, OSF, OG
Status	During visiting the site, it was in operation but staff member from KUKL told it was not in operation	No operation due to damage by earthquake (stated by one local women and police near to the school gate)	No operation due to damage by earthquake
Observation and findings	- Leakages from one tank besides 7 tanks having capacity of 3000 ltrs each (care-operator Shankar Adhikari) (Referred Figure 25)	- Has been closed	- Intake pipe for boring was displaced by earthquake - Leakages from the pipe between CTA and PF - Referred Figure 24 (stated by care operator Man Bahadur Gurung , 20.03.2016)
PF= Pressure Filter, CF= Chlorine Feeding, CTA= Closed Tower Aerator, ACF= Activated Carbon Filter, ARF= Ammonia Removal Filter, ID= In-line Degassifier, OSF= Organic Scavanger Filter and OG= Ozone Generator			

Figure 24: Flow diagram Kalimati Treatment Plant

Figure 25: Observation at Sinamangal Treatment Plant

5.1.2. Comparative technical assessment

Depending upon the source and size of water plant, the treatment unit varies. Among six treatment plant mentioned in Table 4, Mahankal chaur treatment plant is largest for water production. Biological filtration is also found in this plant for ammonia removal. Bhaktapur Jagati and Lokanthali are small scale treatment plant both uses boring water as a source and have similar configuration except for filtration, having Gravity filter and Pressure filter respectively. Both plant have aeration unit since it use groundwater as a source. Roughing filtration can be added prior to other filtration process as the water passes through the filter, particles are removed by both filtration and gravity settling, found in Dhulikhel treatment plant. Bansabari at Bhaktapur as an old treatment plant among the other consists of slow sand filter (SSF) and as the time passes a modern technology has been accepted. Using of rapid sand filter (RSF), have advantage over SSF regarding to the filtration rate (Schutte 2006). All the treatment plant uses chlorine feeding like bleaching powder (Calcium hypochlorite) as a disinfectant agents.

Table 4: Technical description for several studied treatment plants

Name of the system	Unit of treatment plant
Balaju treatment plant	CS, RSF, CF
Bansbari treatment plant	CS, FL, SSF, CF
Bhaktapur Jagati treatment plant	AR, SED, GF, CF
Lokanthali treatment plant	AR, SED, PF, CF
Mahankal chaur treatment plant	BF, CS, RSF, CF
Dhulikhel treatment plant	RFU, SSF, CF

AR- Aeration BF-Biological Filtration CF-Chlorine Feeding
CS-Coagulation Sedimentation FL-Flocculation GF- Gravity Filter
PF-Pressure Filtration RSF-Rapid Sand Filtration SED- Sedimentation
RFU- Roughing Filter Unit SSF- Slow Sand Filter

5.1.3. Operation and maintenance

Operation, maintenance and management of the various studied WTP is completely done by KUKL except for Dhulikhel treatment plant which are under Dhulikhel Khanepani and Cleaning Consumer limited and Kalimati WTP by Kalimati Vegetables and Fruits Limited . During observation, KUKL has not showed proper concern for its operation and maintenance. In case of Bansbari WTP, old infrastructure and lack of regular maintenance are the main problems for maintaining efficient treatment.

During visit to the studied area, there are no established operating and maintenance standards. Facilities are not maintained in an appropriate manner. Responsibility of care operator is also essential part for ongoing O&M which involves routine operation as they are only observant who can inform and take precautions when problems occur.

5.1.4. Response from operator

In this section, care operator for each WTP has been interviewed during site visits. The intention to these interviews was to assess the level of their involvement in the operation and maintenance of WTP as well as the functioning of the system by observing the site. Table 5 illustrates the questionnaire to the care operator.

Table 5: Responses from operator for studied WTP

Items	Contents	Water treatment plants					
		Mahankal chaur	Balaju	Bansbari	Bhaktapur Jagati	Lokanthali	Dhulikhel
	Source of water	Surface water	Surface (Mahadev Khola) boring (Shangala), allele baude during rainy season	Surface water (Mahadev Khola), boring water	Boring water	Boring water	Surface water, (Roshi and Panauti Khola)
Technology	Type of treatment process	Coagulation, Sedimentation, Biological filtration	Coagulation. Sedimentation. Rapid sand filter	Flocculation, Sedimentation, Slow sand filter, disinfection	Aeration, Gravity sand filter,	Aeration, Sedimentation, slow sand filter	Roughing filter unit, Slow sand filter, Chlorination unit
	Filter unit	Rapid sand filter	Rapid sand filter	Slow sand filter (2 unit)	Gravity filter	Pressure filter	Slow sand filter
	Pump used	Gravity flow	Gravity flow	Submersible pump (boring water), good condition	Submersible pump (boring water), good condition	Submersible pump(good condition) , centrifugal pump (alternate)	Gravity flow
	Capacity of reservoir	22 lakh Liters (2 reservoir) 45 lakh Liters (1 reservoir)	51 lakh Liters	25 lakh Liters	1 lakh Liters (1 reservoir, 16 hours to fill)	1.5 lakh Liters (2 reservoir)	5 lakh Liters
Knowled	Level of understand for the system	More with long engagement	More with long engagement	More with long engagement	More with long engagement	More with long engagement	More with long engagement

Items	Contents	Water treatment plants					
		Mahankal chaur	Balaju	Bansbari	Bhaktapur Jagati	Lokanthali	Dhulikhel
	Type of training	General training/information, given by KUKL	General training/information	General training/information (Powder using technology)	General training/information (Powder using technology)	General training/information (Powder using technology)	General training/information
	Coagulants used	Alum (Aluminum sulfate), PAX (Poly Aluminium Chloride)	Alum (Aluminum sulfate), PAX (Poly Aluminium Chloride)	Alum (Aluminum sulfate), PAX (Poly Aluminium Chloride)	Alum	Alum (Aluminum sulfate), PAX (Poly Aluminium Chloride)	Alum (Aluminum sulfate), PAX (Poly Aluminium Chloride)
	Disinfectants	Bleaching powder, caustic soda	Bleaching powder	Bleaching powder	Bleaching powder, potassium	Bleaching powder, chlorine	Bleaching powder, chlorine and potash
	Quantity of disinfectant	Above 20 kg	Above 20 kg 25-30 kg	Above 20 kg	2-5 kg	5-10 kg	10-20 kg
	Dosing interval	Intermittent 100kg.in 1000ltr for 24 hour	Intermittent, Quantity 25-30kg, 1 times per day	Intermittent, around 50 kg during rainy season, between 25-40 kg per day, 2 times a day	Intermittent, quantity 5 kg/day, 2 times per day	Intermittent, 3 times a day, 9 kg/day	Intermittent, between 4-6 times 16 kg/day
Condition	Operation	Satisfactory	Satisfactory, Power cut problem	Its ok	Satisfactory.	Satisfactory	Satisfactory
	Problem, if any	Pump damage and sludge accumulation	Blockage in inlet, power cut problem	Power cut problem, Disinfectant unit is not working disinfectant powder is not good state	Power cut problem	Machinery problem Power cut Problem	Muddy water form source during rainy season

Items	Contents	Water treatment plants					
		Mahankal chaur	Balaju	Bansbari	Bhaktapur Jagati	Lokanthali	Dhulikhel
				muddy water from source during rainy season			
	Tackling problem	Repair maintenance and sludge taken out and disposed off	Cleaning of inlet/bar screen	Use of excessive disinfectant powder, coagulants during rainy season and others	Operated when there is power	Solved by sundarighat mechanical and electrical shagha Operated when there is power	Use of excessive disinfectant and coagulants during rainy season
	Operator allocated	9 persons	3-5 person	2 persons	4 person 1 week per person	3-5 person	3-5 persons
Operation and maintenance	Cleaning of reservoir	Daily	1.5 year ago	Done year ago	Twice a year	Daily	Twice a year
	Cleaning of treatment unit	Daily	Depend upon operation	Sedimentation tank cleaning (last year)	Weekly	Daily	Monthly
	Screen inlet cleaned	Daily	Never	Weekly	Daily	Daily	Daily
	Usage of water in reservoir	Fully used	Fully used	Fully used	Fully used	Fully used	Fully used
	Sample analysis	Daily	Daily	Weekly, (2-3 times)	Daily	Daily	Daily
	Operational and maintenance manual	No here, contact KUKL	No here, contact KUKL	No here, contact KUKL	No here, contact KUKL	No here, contact KUKL	No here, contact dhulikehl khanepani samiti
Health and safety	Safety equipment used	gloves, apron	No	No	No	No	No
	Susceptible to health problem for operator	No	No	No	No	No	No

Items	Contents	Water treatment plants					
		Mahankal chaur	Balaju	Bansbari	Bhaktapur Jagati	Lokanthali	Dhulikhel
	Susceptible to health problem for drinking water to local people	No	No	No	No	No	No
Sludge management	Handling of sludge	cleaning of the tanks and disposed off	Throw outside without treatment	cleaning of the tank sedimentation tank cleaning (last year) and throw outside	cleaning of the tanks and discharge of sludge without treatment to near water bodies (sangha khola)	cleaning of the tanks and discharge of sludge without treatment to near water bodies (manahora khola)	cleaning of the tanks and throw outside

5.2. Constructed wetlands

In this section, comparative analysis of the constructed wetlands visited is presented in terms of technical aspects, operational management (long term management).

5.2.1. Observation and findings

a) Srikhandapur constructed wetlands

Current challenges experience by the plant is fund which could cover O&M of the system. According to the president, the quantity of biogas is low due to low amount of influents coming from the households connected to WWTP. For this he mentioned, they have ongoing plan to connect more household situated opposite to the site area (from ward no.7 area) and also planning to collect wastewater from Banepa area by means of truck to increase biogas production, as this problem is resolved as the quantity of sludge is increased. The issues related to operational and maintenance aspects of the system are listed below:

- Reuse of waste products from the treatment plant in the form of biogas is a cost effective alternative to LPG, which can be benefit for community in terms of economic point of use. Shortage of LPG in the market can also compensate by biogas.
- Treated wastewater being discharged into water bodies is somehow more environmental friendly than it directly discharged, which gives foul odor and unpleasant.
- Good initiative for the people and community about environmental sanitation and being an example as educational place (DEWATS installation) where solid waste management and drainage management is applied for example: students with supervisor from Kathmandu University and other institution visits for biogas integrated with waste management.
- Overgrowth of plant and weed problem
- Blockages in drains and settling chambers during rainy season
- Reduced production of biogas during rainy season due to dilution of wastewater.
- Harvesting of plant is not done, reported that will done later
- Clogging of bed: washed gravel and reuse it
- Sludge from drying bed is not so much in use and cannot even notice it has been taken or not.

b) Kathmandu University constructed wetlands

- Environmental friendly and energy efficient system for management of wastewater which could be an example for demonstrating the system for student engaging in the university
- No use of electric energy due to use of intermittent loading system
- No connection with sewer to treatment plant because of broken pipes and not working at the moment
- Wastewater flow above the settling tank is observed and not seen the position of manhole due to overgrowth of some plants (Figure 11).
- Wastewater coming from around AEC lab is also directly flow into outlet of HFB
- Outlet of VFB and HFB is not clean

- Problem encountered during the O & M of the wetland is diversion of wastewater to the field by farmer before the manhole or the treatment unit reported
- No management of sludge and also the harvested plants which is later burnt and left it there, could make air pollution
- Problems in the maintenance of the intermittent feeding system through hydro mechanical siphon.
- Defect and leakage in the connecting and distributing pipes
- Solid accumulation in settling tank is occur and is solved by throwing just outside
- Clogging of bed problem and maintained by washing gravels and clearing of unwanted plants

c) Dhulikhel Hospital constructed wetlands

- The system is under maintenance and out of operation, after 2 weeks it will be in operation reported by care operator.The treated water is used for irrigation and sludge can also be useful for the production but, if farmer did not use the sludge then it is thrown out incase (care operator Ram Gopal Ranjitkar).
- According to ENPHO (2010b), it has mentioned that there is high storm water infiltration
- No proper lid for inlet (use GI sheet for covering) (Figure 26).
- Since the system is in maintenance, all the wastewater from ABR is by pass directly to outside (field), which has been used by farmers.
- Both two HFB is performing well, but plant from 1st HFB is old and has been thrown out for maintenance and re-planting will do soon.
- In case of two VFB, there is sludge accumulation and also litter from the plant (Figure 26). It has been leftover to dry it and later it will be cleaned. The main reason for the sludge accumulation in the wetlands might be high flow rate above the design flow, which prevents the sludge from settling in the tanks before discharging into the wetlands
- There is also problem of rats, which makes hole and loose the materials.

Figure 26: Observation at Dhulikhel Hospital

d) Constructed wetlands at IOE, Pulchowk

- Treated wastewater before it discharged into environment
- Environmental friendly system for management of wastewater which could be an example for demonstrating the system for student engaging in the university and also as a project work for further investigation related to the treatment efficiency and other findings.
- According to care operator, no any problems have been encountered within this 3 years of operation
- Reeds have not been harvested since its commissioning

e) Sunga Constructed wetlands

There is financial problem regarding to the operation and maintenance. Krishna Lal Shrestha (28.02.2016), care operator requested President, Krishna Lal Badri Shrestha from Municipality to visit the site a week before. He also reported the maintenance work will executed after Municipality finances it. The following are listed of observations:

- Provide a learning opportunity for many students, researchers and professionals and also being an example of application of DEWATS Community based Sanitation.

- The wastewater treatment plant is not in operation due to problem occurring in the vertical flow bed.
- Financial problem for its operation and maintenance
- The biogas generated from the system has been used by nearby school. Bio digester not working after 3 months of operation due to leakage of pipe reported by Krishna Lal Shrestha.
- Directly bypass wastewater to the river without any treatment
- No operation due to dysfunction of VFB so stopped for HFB
- No use of sludge by farmer
- There is other vegetation instead of constructed wetland vegetation (Figure 27).
- Breaking down of main pipe connected to VFB (Figure 27).

Disconnection of pipe from HFBs

Vegetation other than Phragmites Karka

Figure 27: Observation at Sunga constructed wetlands

f) Constructed wetlands at ENPHO

It is under maintenance due to silver jubilee of ENPHO and also they are constructing ECOSAN toilet near to the system (10.03.2016).

5.2.2. Comparative technical assessments

All the sanitation systems are based on DEWATS based. These subsurface flow sanitation systems have various DEWATS configuration. Srikhandapur employs two bio digesters and the Sunga has an ABR and settler for primary treatment while other uses settling tank. For secondary treatment, horizontal flow bed followed by Vertical flow bed systems is at KU, DH and Sunga, whereas IOE and Srikhandapur has only horizontal bed and vertical bed treatment systems in ENPHO.

Biogas integrated CW wastewater treatment technology in Nepal has been introduced in community level wastewater treatment plant like Sunga WWTP firstly and Srikhandapur WWTP. Another technical variation found in Sunga and Srikhandapur DEWATS is the biogas component and concluding example is currently functional and with uncertain success since there is no strict regulation of user service fees on regular basis and also low production of biogas due to insufficient influents quantity. In Sunga, the bio digestor is dysfunctional after 3 months of operation. Beside this technical and management limitations, biogas integrated WWTP is still have some significant potential in context of Nepal. Biogas is an alternative to conventional gas, which is now much interesting nowadays as the condition shortage of conventional gas in Nepal due to the blockades from India.

Accumulated sludge in settling tank is diverted to sludge drying bed in DH, Sunga and Srikhandapur whereas Sludge drying unit is absent in KU, IOE, ENPHO lab. Sludge management is important for environment and depending upon the size of the plant, the management of sludge must be needed to incorporate in management of wetland systems.

Detailed description of technical aspects of constructed wetland studied is elaborated in Table 6.

Table 6: Technical description of studied constructed wetland in Nepal (UN-HABITAT 2008 and WaterAid 2008)

	Kathmandu Universiy	Dhulikhel hospital	Srikhandapur	Sunga	IOE	Enpho lab
Type of Project	DEWATS	DEWATS- SME (Hospital)	DEWATS- Community Based Sanitation + Biogas	DEWATS- Community Based Sanitation	DEWATS	DEWATS- SME (Institutional)
Design capacity (m^3/d)	35	10 (40)*	103/205	50	NA	0.7
No Users	193	250 beds	200 HH (125)	200 HH (82)	NA	7 equivalent

						population based on 45 staff
Influent type	Institutional wastewater	Hospital and staff Quarters Wastewater	Municipal wastewater	Municipal wastewater	Domestic wastewater	Combined laboratory and domestic wastewater
CW Type	Subsurface flow	Subsurface flow	Subsurface flow	Subsurface flow	Subsurface flow	Subsurface flow
CW configuration	Horizontal flow bed followed by Vertical flow bed	Horizontal flow bed followed by Vertical flow bed	Horizontal flow bed	Horizontal flow bed followed by Vertical flow bed	Horizontal flow bed	Vertical flow bed
CW substrate	Coarse sand and gravel	Coarse sand and gravel	Gravel	Coarse sand and gravel	Gravel	Coarse sand and gravel
Pre-treatment	Settlement tank	Settlement tank	Bio digester	Anaerobic baffled Reactor	Settlement tank	Settlement tank
Type of Feeding	Intermittent	Intermittent	NA	Continuous in HFB and intermittent in VFB	NA	Intermittent
Technical components	Manhole 3 chambered settling tank 1 horizontal flow 2 vertical flow wetlands	Diversion tank to spilt flow between systems 2 parallel settlers(1ABR large, 1 settler small) 2 parallel horizontal flow wetlands 2 parallel vertical flow constructed wetlands 1 SDB	Flow diversion from main sewer Grit chamber and bar screen 2 parallel fixed dome bio digesters 6 horizontal flow wetlands 1 SDB	1 Bar screen & grit chamber 1 settler &ABR 2 parallel horizontal flow wetlands 2 parallel vertical flow wetlands 1 SDB 1 fixed dome bio-digester	Settling tank Horizontal flow bed	Brick septic tank 2 PVC settling tanks in series Vertical flow wetlands Collection chamber for reuse
Total surface area of the CW	628 m^2	800 m^2	1240 m^2	1240 m^2		18m^2
Plant species	*Phragmites*	*Phragmites*	*Phragmites Karka*	*Phragmites*	*Phragmites*	*Phragmites*

	Karka	*Karka*		*Karka, Canna latifolia*	*Karka*	*Karka, Canna Ginger Flower*
ABR: Anaerobic baffled reactor, SDB: sludge drying bed, HH: Households, PVC: Poly Vinyl chloride settling tank NA: Not Available						

5.2.3. Operation and maintenance

Table 7 summarizes the various management and financing strategies for O&M of the constructed wetland based systems. All the DEWATS uses financial costs by themselves except Sunga and Srikhandapur, where municipality incorporates for financing the technical issues and O&M requirements in Sunga and user service fee system is for Srikhandapur. In Sunga, the original Wastewater Treatment Plant Management Committee formed in 2005 and dissolved in the same year and the local Municipality took the responsibility of WWTP as the community is supposed someone else would be responsible for financing O&M, hence no user fee is maintained (Davies 2013). For Srikhandapur, the case is just opposite, the Sewage Treatment User Committee is active and also president has full involvement but lack of support from the Dhulikhel Municipality, the committee has insufficient fund for O&M.

Though, DEWATS has advantages on low maintenance solution, it requires financial support to continue the long term management and O&M. In order to achieve the ongoing O&M be affordable and sustainable, the level of community participation and municipality involvement is necessary in community based sanitation systems and respective management committee for other wetlands is necessary to sustain O&M of the DEWATS. Even the local involvement with private sector or institutions plays important role in O&M as in KU, diversion of wastewater before treatment can be solved if local is aware of the importance of constructed wetlands and its importance for O&M.

Responsibility of care operator is also essential part for ongoing O&M which involves routine operation. The operator is an observant who take appropriate actions when problems are arise and conduct necessary monitoring (UN-HABITAT 2008).

Table 7: Comparing management strategies for studied wetlands

	Kathmandu Universiy	Dhulikhel hospital	Srikhandapur	Sunga	IOE	ENPHO lab
O&M management agency	Department of Environmental Science and Engineering	Dhulikhel Hospital with technical support from BOKU Austria	Srikhandapur Sewage Treatment User Committee	Sunga Wastewater Treatment Plant Management Committee	Department of Engineering	ENPHO
O&M Financing	Department of Environment	Self	User service fee	Municipality	IOE	ENPHO
Present operation	No connection with sewer and not working at the moment but going to be maintained	Under maintenance but before works well	Working	Operation stopped	Working	Under maintenance
Operational problem	see related paragraph	see related paragraph	see related paragraph	see related paragraph	see related paragraph	see related paragraph
Life span, yrs.	15	19	8	11	4	14

5.2.4. Performance Analysis:

TP and TN analysis was performing concerning on two major points (first inlet and last outlet) of each treatment plant. In reed bed system of Dhulikhel Hospital (DH) and Sunga, TP and TN of main inlets was only taken due to maintenance in DH and operation is stopped at Sunga wetlands. Inlet containing of TP were 5.33 and 43.53 mg/l respectively and TN were 127.90 and 202.39 respectively. KU, Srikhandapur and IOE, the concentration value for total phosphorous for each inlet was found to be 101.53, 40.49 and 31.42 mg/l whereas the outlets TP were 4.54, 37.31 and 5.27 mg/l respectively (Table 8).

Table 8: Comparison of TP and TN in different constructed wetlands and their performance

Sample sites	Inlet		Outlet		Performance in %	
	TP(mg/l)	TN (mg/l)	TP(mg/l)	TN (mg/l)	TP	TN
KU	101.53	51.53	4.54	2.93	95.52	94.31
Srikhandapur	40.49	261.89	37.31	258.96	7.84	1.11
IOE	31.42	40.29	5.27	4.33	83.22	89.25
Sunga	43.53	202.39	*	*		
DH	5.33	127.90	**	**		
*= No sampling for outlet point due to operation stopped **= No sampling for outlet point due to system is in maintenance						

Inlet concentration for the TP was found to be high in case of KU and high for TN in case of Srikhandapur wetlands (Figure 28). Reduction in TP and TN at Srikhandapur were not so much though it is in operation (Figure 28).

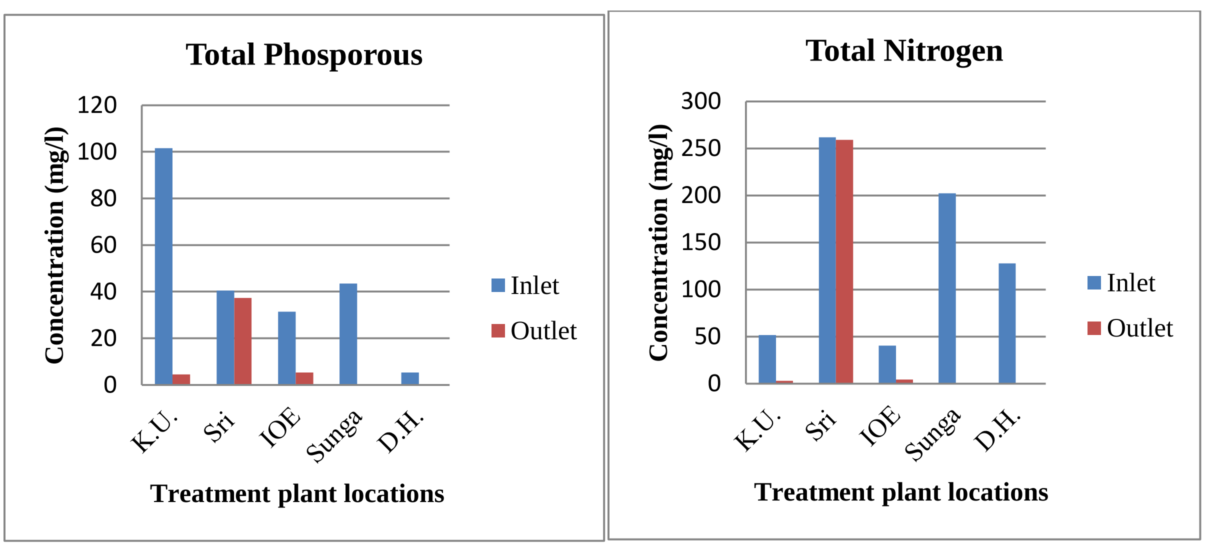

Figure 28: Overall view of inlet and outlet concentration of nutrient for various sites of wetlands

The main factors that concerns to the rate of nutrient removal from wastewater in constructed wetlands are microbial methods including nitrification and denitrification and as well as physiochemical processes such as fixation and precipitation (Mthembu *et al*. 2013). The reed bed system, uptake of nutrient is also associated with the growth of reed plants and also with their development.

The highest nitrogen removal efficiency of KU can be justified because of the reed plants in their growing phase and microbial action that played a significant role. Mthembu *et al*. (2013) stated that plant growth and nutrient uptake is possible at early stage than in later stage since high demand of nitrogen is essential for plant growth and development because nutrient concentration of the plant is increased at an early age of plant development. IOE is found to remove nitrogen related compounds relatively lower than KU (Figure 29 and Table 8) which is because of almost matured reed plants. The uptake of nitrogen in this case is limited only for basic metabolisms rather than the growth of these plants. For IOE and Srikhandapur reed bed system the effective removal of nitrogen related compounds can be done by harvesting the plantation or at least cut off the branched of reed plants to assure growth.

Removal of nitrogen in reed bed systems are mainly depends upon configuration, plant growth, types of wastewater and seasonal effects or temperature (Vymazal 2010; Lee *et al*. 2009; Saeed & Sun 2012).

According to USEPA (2000), amount of oxygen in HFB is low and limited nitrification is found in areas close to the surface or around the roots. HFB is good suited for denitrification as they anaerobic condition where an organic carbon source is needed for reaction and this may be a limiting factor (USEPA 2000). Organic carbon is supplied through decomposition of plant litter on the surface reach into the anaerobic zone by rainfall, or through decomposition of organics within the bed (USEPA 2000). Vymazal (2010) presented VFB is far more aerobic than HFB and are good for nitrification since it is intermittently loaded which allows air to enter after the water has percolated through the media.

In order to achieve effective removal of total nitrogen VFB could be combined with HFB which, in contrast, do not nitrify but provide suitable conditions for nitrate reduction during nitrification in VF beds (Vymazal 2010). This configuration is also found in KU and horizontal subsurface is found in IOE and Srikhandapur.

Phosphorous can have secondary effects by triggering eutrophication within a wetland and algal blooms and other water quality problems are occur due to phosphorous. Phosphorous may be present in the form of dissolved or particulate form while in outlet, its concentration mainly reduces due to leaching into the subsoil and by removal by plants and animal (Reddy *et al.* 1985, 1989 cited in Lamichhane *et al*. 2012). Phosphorous removal efficiency of KU is highest followed by IOE (Figure 29 and Table 8). Primary phosphorous removal mechanism includes adsorption, filtration and sedimentation. The lowest removal efficiency of phosphorous of Srikhandapur can be explained by redox chemistry in which due to lack of proper facility for the aeration and low oxygen content in anaerobic zone in HFB (Bodin 2013) , the phosphorous gets liberated into water from the sediments and soil back into water.

Rani *et al.* (2011) mentioned several studies conducted in Koottatep & Polprasert, 1997; Kantawanichkul *et al*. 2001; Kyambadde *et al*. 2004) showed tropical climates is better for plants growth and its ability to uptake nutrients is significant higher. Excessive growth throughout the year needs harvesting and if not done, the incorporated nutrients will be released again during decomposition of the litter (Rani *et al.* 2011; Mthembu *et al*. 2013). Mthembu *et al*. (2013) reported that some portion of nitrogen is released back to the wetlands during shoot die off that can hamper nitrogen removal efficiency whereas Bodin (2013) reported that decomposed litter or vegetation creates anoxic condition which can cause release of phosphorous since litter compartment is main pool for phosphorous sink (Sundaravadivel & Vigneswaran 2001). Plant uptake is effective only when plants are harvested for all types of constructed wetlands. Harvesting of plant is not done in IOE and Srikhandapur which showed low nitrogen and phosphorous removal compared to KU (Figure 29).

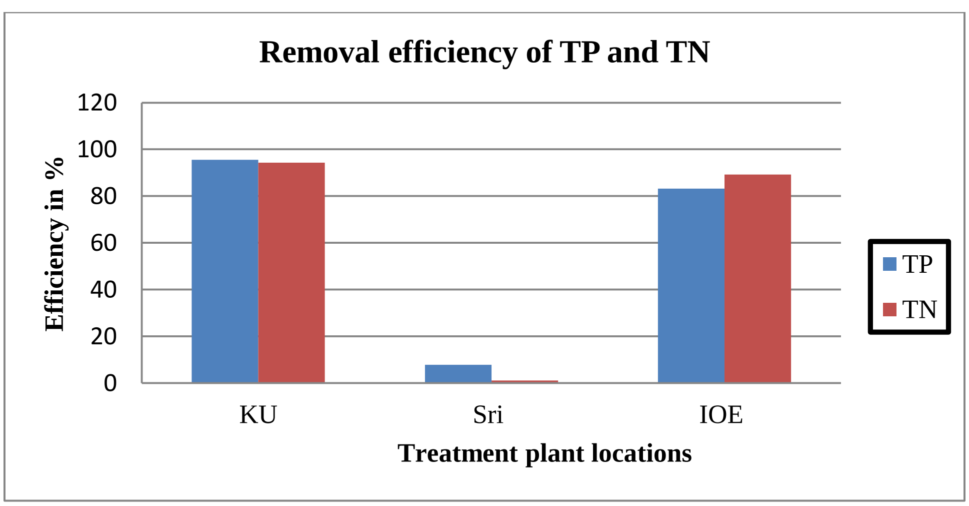

Figure 29: Removal efficiency of nutrients of each wetland

Significant modification in removal efficiency is observed among different type of wetland configuration (Hybrid-KU, HFB-IOE and Srikhandapur) though it has same subtropical climate and subsurface flow CWs. Various types of wastewater (influent type) are treated with varying degree efficiencies for each wetlands.

For better performance of the wetland, it should be assessed time to time. Samples analysis should be assessed to ascertain the treatment efficiencies. Operation and maintenance are the most important aspect of treatment wetlands operation and environmental and operational factors affecting removal efficiency should considered for better results (Lee *et al*. 2009).

5.2.5. Response from operators, farmers user committee and non-user committee

In this section, care operator, farmer, user committee and non-user committee were interviewed in terms to know the knowledge on plant, application of using treated products, operation and management problems and their solution. Detailed information of respective wetlands is described subsequent.

a) Care operator

Care operator for each constructed wetlands are assigned by its section. Table 9 describes the responses about the knowledge on system, operation and maintenance, sludge management for respective wetlands as well as their personnel hygiene while engage.

Table 9: Responses from care operator about wetlands for each studied sites

Item	Contents	Constructed wetlands				
		Srikhandapur	Kathmandu university	Dhulikhel hospital	IOE	ENPHO
Knowledge	Level of understand for the system	Long experience	Long experience working in the system	Long experience which makes him to solve most problems occuring in the	Long experience	Long experience

Item	Contents	Constructed wetlands				
		Srikhandapur	Kathmandu university	Dhulikhel hospital system	IOE	ENPHO
	Training/experience related to wastewater and safety training	No special training including safety is given. Basic cleaning instruction as well as to the committee member just verbal information about the system and the function of the system	No special training including safety is given. Basic cleaning instruction Gain experience for working long period,	No special training including safety is given. Basic cleaning instruction Gain experience for working long period,	No special training including safety is given Applied by himself for his sake and working in a field makes him to understand since he has been incorporated with the students having their project for this system	Basic training including safety

Item	Contents	Constructed wetlands				
		Srikhandapur	Kathmandu university	Dhulikhel hospital	IOE	ENPHO
Condition	Operation	System operates satisfactory, sometime low water then wastewater is distributed in interval, high case it distributed in all bed	System operates satisfactory before, not working since no connection of sewer to the treatment plant as it overflow above the settling tank	System operates satisfactory with adequate influent but now it is under maintenance	System operates satisfactory with adequate influent	No operation due to maintenance in the occasion of Silver jubilee of ENPHO
	Encountered problem	weed problem = cut and throw, clogging of bed= washed gravel and reuse (done annually)	harvesting of plant, weed control, changing of defect pipe, clogging of bed	weed problem = cut and throw, clogging of bed= washed gravel and reuse (done annually)	no problem in between this 3 yrs.	clogging of bed and the top of the layer of bed was removed
Involvment	User committee	Meeting for operation and maintenance, done weekly sometime, sometime monthly	No user committee	No user committee	No user committee	No user committee
Operation and Maintenance	Anaerobic baffled Reactor (ABR) emptied	No ABR	No ABR, settlement tank (1 year)	monthly	No ABR	No ABR

Item	Contents	Constructed wetlands				
		Srikhandapur	Kathmandu university	Dhulikhel hospital	IOE	ENPHO
	Trimming or harvesting	Harvesting	Harvesting	Harvesting	Trimming and harvesting both	Harvesting
	Frequency of harvesting	Annually	Annually	Annually	3 month interval	Twice a year
	Reed bed inspected	Daily	Monthly	Daily	Weekly	Daily
	Flow distribution inspected	Daily	Monthly	Daily	Weekly	Weekly
	Cleaning of materials used in beds	Yearly and also depending on clogging of bed	Yearly	Yearly, depend on clogging of bed	3 or 6 months	Yearly
	Cleaning of Inlet and outlet	When it clogs	When it clogs	When it clogs	When it clogs	When it clogs
	Cleaning of inlet and outlet by	Hand and stick	Hand and stick	Hand and stick	Done by hand	Done by hand
	Weed control	Yes	Yes	Yes	Yes	Yes
	Type of weed control	Cleared by hand and throw outside	Cleared by hand and throw outside and burnt	Cleared by hand and throw outside	Cleared by hand and throw outside	Cleared by hand and throw outside
Sludge Management	Collection of sludge by farmers	Never notice, may use or not	No	Yes, if not thrown out side	No	Removed by tanker and disposed off
	Collection of sludge by other than farmer	Never notice, may use or not	No	Do not know	No	Removed by tanker and disposed off
	Last removal of sludge	No	No	Month ago	Not	Month ago
Safety and Health	Personnel hygiene (wash hand, wash feet and	Yes	Yes	Yes	Yes	Yes

Item	Contents	Constructed wetlands				
		Srikhandapur	Kathmandu university	Dhulikhel hospital	IOE	ENPHO
	change clothes)					
	Use of gloves	No	Yes	No (depend on the condition)	Yes, self	Yes
	Other equipment used	No	No	No	No	No
	Susceptible to any diseases	No	No	No	No	No
	Life span	8 yrs.	15 yrs.	19 yrs.	4 yrs.	14 yrs.

Sunga

- No special training including safety is given to the caretaker but is applied by himself for his sake and working in a field makes him to understand about the system since he has been incorporated with the students having their project for this system.
- No use of safety equipment except gloves while working the field but washing personnel hand and feet is done.

b) Farmer

Farmer from Dhulikhel hospital (DH), Kathmandu University (KU) and Srikhandapur constructed wetlands are asked about advantage the quality of treated water, practice of sludge and their involvement; has discussed following.

Dhuikhel Hospital (DH)

Among five respondents, four respondents feel comfortable to use treated water from the system but they notice considerable bad odor. Respondents using treated water told it is sufficient for irrigation. The treated water is mostly used for irrigation but they think this water have effected downstream. They told us that there is no fish or other aquatic life exists now. Farmers who are asked questionnaire stated there is monitor of water quality monthly except the farmer who is not interested.

Quality of treated water:

All stated that the treated water is not beneficial to their health but is beneficial to the crop among which two farmers think the treated wastewater effect their crop yield.

Sludge:

No information has been provided possibility of using sludge from the treatment plant. All who uses treated wastewater, think it is useful for growth of crop and also do not know whether sludge contains anything that may be harmful. All of four respondents have personal constraints on using sludge though they are using treated wastewater because it comes from human waste. Even they use chemical fertilizers like urea and NPK for production.

Contribution

There is no payment for using the product but out of five respondents, two respondents want to pay contribution to the maintenance costs of the treatment plant to ensure good quality discharge.

Kathmandu University (KU)

Among five respondents feel comfortable to use treated water from the system which is somehow sufficient and does not notice about bad odor. Respondents answered it has affects in downstream aquatic life. Farmers who are asked questionnaire stated there is monitor of water quality but did not notice or seen.

Quality of treated water:

All stated that the treated water is not beneficial to their health and crop production.

Sludge:

No information has been provided possibility of using sludge from the treatment plant. Though they do not use sludge and do not know whether sludge contains anything that may be harmful. Among five, two respondents have opinion on using treated wastewater because they need water for irrigation. They mostly use chemical fertilizers like urea, Potassium and NPK for production.

Contribution

There is no payment method for using the product.

Srikhandapur

Among five respondents, two respondents feel comfortable to use treated water from the system. All respondents except one notice about bad odor. Respondents don't use treated water as it directly discharged in the downstream and has affects in downstream aquatic life. Farmers who are asked questionnaire stated that there is monitor of water quality as explained by the user committee and care operator but they did not notice themself.

Quality of treated water:

All stated that the treated water is not beneficial to their health and crop production.

Sludge:

No information has been provided possibility of using sludge from the treatment plant. Though they do not use sludge, they think it is useful for growth of crop. They do not know whether sludge contains anything that may be harmful. All of 4 respondents have personal constraints on using sludge and treated wastewater but heard that it is useful. They mostly use chemical fertilizers like urea and NPK for production.

Contribution

There is no payment for using the product but biogas consumer (five households) pay NRs 500 per month and household connected to WWTP are required to pay NRs 200 per year (Davies 2013).

c) User committee

User committee from Srikhandapur is interviewed, one is the president and another is member. There is no reuse of wastewater considered before implementation of the reed bed system. It is just discharge outside and finally to the river Purna Mata Khola. There is a presence of toilets at house before the establishment of the system. The system treats the municipal wastewater. The president is only informed about the system and its performance. Since president is much active in the system, he understand the system and its function but the member only know the treated wastewater and biogas is generated but have no knowledge on the performance of the system. The operation and maintenance problems occur in the system like clogging of bed, defects in pipe, overgrowth of plants. The role of operation and maintenance is important for the system and they have bookleaft about the system. They are supposed to use sludge in the farming but yet not utilized and also have shown their interest on product like biogas. There is also arrangement of meetings when it necessary. Both respondents are willing to contribute for its maintenance and operation and also stated this DEWATS is effective for the community.

d) Non user committee

Non user committee from Dhulikhel hospital (DH), Kathmandu University (KU) and Srikhandapur constructed wetlands are interviewed and it has discussed following.

Srikhandapur

Among five respondents, three respondents have visited the site and they have been explained about the system. They all do not notice about the odour. Three responds that it is useful for the community and environment and other don’t show any interest. All want to contribute to keep the system but two respondents have paid NRs 500 for using biogas. All are interested on the product biogas. Some have shown interest to buy vegetables/food produced by using treated wastewater and sludge while other does not.

Dhulikhel Hospital (DH)

Five respondents from non-user committee were asked some question related to the wetlands systems.

Among five respondents, two respondents have visited the site and they have been explained about the system. They all do not notice about the odour. Two respondents stated that it is useful for the community and other do not have interest. Two respondents want to contribute to keep the system but have not paid till. Three respondents are interested on the product treated wastewater and sludge but did not pay money for using it. Two respondents have interest to buy vegetables/food produced by using treated wastewater and sludge and other does not show any concern.

Kathmandu University (KU)

Among five respondents, two respondents have visited the site and they have been explained about the system. They all do not notice about the odour. Two respondents stated that it is useful for the community and other do not have interest. Two respondents want to contribute to keep the system but have not paid till. Three respondents are interested on the product treated wastewater but did not pay money for using it. Almost all do not show interest to buy vegetables/food produced by using treated wastewater and sludge.

5.3. Guheshwori wastewater treatment

5.3.1. Observation and findings

Operating status of WWTP from 2000 up to 2016 is shown in Table 10. During this visit, Mr. Prabhat Shrestha and Mr. Rajendra Prasad Singh staff from WWTP along with care operator reported that the WWTP is now fully operated by solving 24 hours operation using other alternative source of energy.

Table 10: Operating status of Guheshwori WWTP in Kathmandu Valley

WWTP Characteristics		WWTP status			
Location	Capacity	ADB Report, 2000 (Regmi 2013)	MIT Thesis, 2003 (Regmi 2013)	MUAS Thesis, 2013 (Regmi 2013)	UMB Thesis, 2016*
Guheshwori	17.3 MLD	Under Construction	Operating	Partially Operating	Operating
MLD= Million Litres per Day					
*current study for this thesis					

Since the water quality of the Bagmati River is very poor so it helps to clean the untreated water before it discharge into Bagmati Rivers. It can set up an example for students to learn how the system works.

During the field visit (21.03.2016), we observe the following negative outcome of this system.

a) The treatment plant lacks a separate collection system for storm water and sewage (Khatiwada *et al*. n.d.), so during rainy season, volume of wastewater increase and gets overflowed. Hence is mixed directly with the river.
b) The design location of a grid chamber seems inappropriate as the influent water has to use pump to flow from lower level to the higher level (Shahi 2012)
c) The system also lack primary sedimentation tank.
d) Nitrogen and phosphorous removable is not possible because it lack tertiary treatment unit.
e) Observe rust on screen and breaking down due to corrosion and defect in mechanical grit chamber (detritor mechanism with classifier) and not operated was noticed during field visit. But according to care operator, this will be maintained soon.
f) Since Nepal is going through a power crisis, the frequent power cut has also added a big burden in the operation and maintenance of the plant (Shahi 2012).

5.3.2. Technological assessment

According to the care operator, almost all the equipment are Indian technology, the defect in classifier also takes time to maintain due to blockades of Nepal from India. It is old one technology since newer application has been developed in wastewater treatment nowadays.

5.3.3. Operation and maintenance

The major disadvantage of activated sludge systems are high operating costs associated with large energy needs (Green *et al*. 2003) and major challenges is the power cut in Nepal in this current situation. With these entire technical problems, financial problems also exist to challenge the suitability of this plant. According to Regmi (2013), currently the annual operation and maintenance cost of Guheshwori WWTP plant is estimated to about NRS 12.5 million year (approximately euro 112600 per year). With this high cost, it is uncertain for the long run of this plant. The main reason for the high operation cost is due to high rate of electricity cost, which is around 7/kWh- unit and energy consumption of this rate is 2.3 kw-hr/kg BOD (Regmi 2013) as well as the replacement of power with other sources of energy to run this system when there is a power cuts (reported by care operator).

WEPA (2010) mentioned design parameters of water quality for influent and effluent of WWTP are 270 mg/l and 25 mg/l for BOD_5 and 1150mg/l and 250 mg/l for COD respectively. According to lab technician, reduction of BOD_5 and COD are 85-86% and 75-80% respectively. Overall, it seems COD removal efficiency is better than BOD_5. To avoid excess flow of untreated water during the rainy season into the Bagmati River, the WWTP effluents are diverted through a bypass tunnel (WEPA 2010).

5.3.4. Response from operator

Under this section, care operator of WWTP has been interviewed to get general information about his level of knowledge for system, operating condition, sludge management and health and safety which are illustrated in Table 11.

Table 11: Information about WTP through interaction to care operator of each section of WTP

Item	Content	Guheshwori wastewater treatment plant
	Source of wastewater	Combined
Technology	Design capacity	100-300ltr/s (190 ltr/s)
	Type of primary treatment	bar screen mechanical and grit chamber
	Type of secondary treatment	oxidation ditch and secondary clarifier
Level of understanding	Knowledge on system	Enough
	Training given	yes, general training/information
Condition	System condition	Satisfactory
	Odour	High
	Treated water discharge	River
Operation and maintenance	Designed HRT for oxidation ditch	15.2 hrs.
	Designed flow maintained	No due to influent is more than design
	Effluent check	Daily
	Operator allocated	3-5 person

	Inlet cleaning	Daily
	Cleaning of oxidation ditch	between 1 and 2 years
	Operational problem	maximum load than design capacity during rainy season, mechanical problems for the unit, excessive sludge production
	Tackling operational problem	bypass sewer line during rainy season, cleaning of inlet, repairing of machinery
	Operational and maintenance manual	yes,
Sludge management	Sludge option	some amount is recirculate to oxidation ditch and remaining to sludge drying bed
	Amount of sludge recirculate	2500MLSS
	Use of sludge	farmer and nursery
Health and safety	Safety equipment	Gloves
	Site health problems	No

5.4. Comparative study on wastewater, constructed wetland and water treatment systems

This section presents a comparative analysis of water and wastewater treatment plants in order to assess technology, operation and maintenance and its management strategies that have been illustrated in Table 12. However, the water supply facilities have not been appropriately operated or maintained and also found to be out of order or obsolete.

Table 12: Analysis of water and wastewater treatment plant as well with constructed wetlands

Contents	Water treatment plants	Wastewater treatment plants	Constructed wetlands
Energy	Power failure problem occur in every plants	Alternative energy is used to solve power problems to run 24 hrs operation reported by care operator	No need of power in operation
Technology	No available data	Machinary parts are from Indian technology, must be imported.	Local materials are used that makes wetlands accessible to be constructed or even maintained
Management and Finance	Week Management in	Management looks good	Funding is not sufficient for

	almost every treatment plant Storage of chemicals are not in good condition	while observation	operation and maintenance in wetlands though it has an advantage on low maintenance.
Operation and maintenance	Out of 9 plants studied, 2 plants are stopped in operation and one in under rehabilitation. Condition of plant is not satisfactory except Mahankalchaur and Dhulikhel but are in state of operation Facilities are not maintained in appropriate manner	Plant was in good in operation except defect in classifier	Operation for wetlands was not satisfactory. 7 wetlands are studied, during observation only IOE is in operation, others are either in under maintenance or operation was stopped. Facilities are not maintained in appropriate manner
Sludge management	Not all of the plants have proper sludge management and disposed off or discharge into river without treatment	Sludge drying bed is used and is collected by farmers and nurseries	Almost all constructed wetland have sludge drying bed but no proper use of sludge
Health and Safety	Safety equipment has not been used in almost all treatment plants	Safety gloves are used while working	Most care operators used gloves and do personnel hygiene while engaged in wetlands
Others	Treatment of drinking water is not considered unless serious problem.	Perception about wastewater is not much effective among communities	Perception about wastewater is not much effective among communities

6. Conclusion

It is concluded that the Kathmandu Upatyaka Khanepani Limited (KUKL) is the backbone of Kathmandu in the field of water supply. All water treatment plants (WTP) have adopted conventional purification processes. The site observations showed that Kathmandu Upatyaka Khanepani Limited had not given enough concern towards water treatment and supply situation in the Kathmandu Valley. The water of Balaju water treatment plant was not safe for drinking purpose. The Mahankal Chaur and Dhulikhel treatment plants are in good condition and secured. However, it is necessary to take immediate steps towards improving the condition of water treatment systems especially with necessary maintenance, repair as well as strict monitoring of the water quality to ensure safe drinking water to the consumers.

The three different wetland systems, each one showed their importance in removing unwanted nutrients in different ways. KU reed bed system showed higher removal efficiency for total phosphorous and total nitrogen than the IOE reed bed system whereas Srikhandapur showed lowest efficiency, but still have importance in treating municipal wastewater.

Overall wastewater is a complex solution which may contaminate the human environment. Appropriate treatment and disposal of waste contaminants are essential in order to avoid the conditions that can hamper both the public health and welfare. The treatment technology should be of cost efficient, easy to maintain and simple in construction in the context of Nepal.

7. Recommendations

Some recommendations made to make system more effective are listed below:

- A study of the plants and their monitoring after establishment is essential along with systematic operation and maintenance.
- Effluent quality should be checked on regular basis.
- Roofs should be provided in the treatment plants so that it is better protected from things that hamper the water quality.
- Waste generated by the plant needs to be properly managed because it is directly put in nearby river.

- Proper awareness and education must be provided when training caretakers for effective operation of plant
- The public should be encouraged towards saving water. Public awareness regarding wastewater treatment is important for long term operation as well as government and participation of all sectors that are responsible for the generation of wastewater. Challenges regarding operation needs to be addressed.
- Proper policy and legislations must be brought into action in order to address wastewater management issues in municipal, communal and industrial levels.
- Previous experiences and examples from existing constructed wetlands and wastewater plants should be considered when starting new constructed wetland and wastewater treatment plants.

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Appendices

Appendix A: Social interviews and samples collection

Interviews with care operator, user comittee and non user comittee

Sample collection

Appendix B: Questionnaires for water, wastewater and constructed wetland treatment plants

Questionnaire for conventional waste water treatment

Name:

Gender:

Address:

Name of the institution engaged:

1. Which source does this wastewater comes from?

a. Domestic b. Industrial c. Institutional d. municipal

e. Combined f. other

2. What is the design capacity of the plant?

a. Below 100 m3/s b. 100-300 m3/s c. 100-300 ltr/s d. Above 300 ltr/s

e. Above 300 m3/s f. Do not know g. other

3. What type of the primary treatment units are in use?

a. Bar screen Mechanical/manual b. Grit chamber c. Both of them

d. None of them

4. What type of secondary treatment units consists?

a. Oxidation ditch b. Secondary clarifier c. Both of them d. Aerator

e. None of them

5. Where does the treated water discharge?

a. river b. lake c. stream d. ocean e. Pond

6. At what interval the oxidation ditch cleaned?

a. Weekly b. Monthly c. Annually d. Between 1 and 2 years e. More than 2 years

f. Never

7. How do you manage sludge options? ....

Do you have sludge drying bed? Yes------------------ No-----------------------

If yes, who use the sludge after drying?

a. Farmer b. Nursery c. Both of them d. None of them

8. Do ultimate effluent quality is checked before disposing? Yes-------------- No--------------

If yes, how often effluent quality is checked before discharging?

a. Daily b. Weekly c. Monthly d. Annually e. Never

9. Do training/information for working in the site was given? Yes------------------ No---------------

If yes, what types?

a. Safety training/information b. General training/information

c. Specific training/information d. None of them

10. Do any safety equipment were used while working in the site?

a. Gloves b. Mask c. Apron d. Shoe

e. All of them f. None of them

11. How many operators do you currently employee to run your operation?

a. 1 person b. 2 persons c. 3-5 persons d. Do not know

12. How much sensitive on water treatment system?

a. Little b. More c. Enough d. Not so much e. Not interested

13. Do the system works? Yes---------------- No----------------

a. Satisfactory b. Unsatisfactory c. It's ok d. Do not know

14. How often is the screen in the inlet cleaned?

a. Daily b. Weekly c. Monthly d. Annually e. Never

15. How much sludge is recirculating to oxidation ditch to metabolize the microorganisms?

a. 2000- 2500 MLSS b. 2500- 3000 MLSS c. above 3000 MLSS

d. Don't know

16. What is the designed hydraulic retention time for oxidation ditch?

a. less than 10 hours b. 10-15 hours c. Above 10 hours d. Don't know

17. Does the designed flow rate was maintained? Yes---------------------- No-----------------

If No, why?

a. Influent is more than design flow b. Influent is less than design flow

c. Never noticed d. Other

18. Does this wastewater have bad odour?

a. Low b. High c. Ignore d. Not concern

19. Do you ever notice people working in a site have health problems?

Yes--------------- No----------------

If yes, what types?

a. Respiratory problems b. Diarrhea c. Typhoid d. Dysentery

e. Others f. Do not know

20. Do you find any operational problem in any unit in the treatment system?

Yes---------------- No----------------

If yes, what types?

a. Blockages in the inlet b. Maximum load than design capacity during rainy season

c. Mechanical problems for the unit d. Problem in power supply

f. Excessive sludge production g. others g. Not seen

21. What are the solutions do you apply for tackling operational problems?

a. Bypass sewer line during rainy season

b. Cleaning of inlet

c. Repairing of machinery

d. Use of generator

e. others

f. Not done yet

22. Do there any operational and maintenance manual? Yes---------- No----------

Questionnaire for Water treatment

Name:

Gender:

Address:

Name of the institution engaged:

1. What types of coagulants used for?

a. Aluminum sulphate (Alum)

b. Ferrous sulphate

c. Aluminum chloride.

d. Ferric chloride

e. None of them

f. Do not know

2. What type of disinfectants is used for water disinfection process?

a. Alum b. Bleaching powder c. PAX d. Caustic soda

e. Chlorine f. Potassium g. None of them

3. What is the dosing interval? Continuous or intermittent ?

If continuous, what is the flow rate? -----------------------------

If intermittent, what is the flow rate? -----------------------------

4. How many times do you use it?

a. 1 time per day b. 2 times per day c. 3 times per day d. between 4-6

e. None of them

5. What types of pump is in use in the treatment process?

a. Centrifugal pump b. Submersible pump c. Both a & b d. None of them

6. What is the condition of the pump?

a. Good b. Bad c. Never noticed d. Do not know e. Not working

7. How many operators are allocated for operation?

a. 1 person b. 2 persons c. 3-5 persons d. Do not know

8. Which filter are designed in the water treatment plant?

a. Slow sand filter b. Rapid sand filter c. Pressure filter d. None of them

9. How often the reservoir is cleaned?

a. Daily b. Weekly c. Monthly d. None of them e. Do not know

10. How many time does the treatment unit is cleaned?

a. Daily b. Weekly c. Monthly d. None of them e. Don't know

11. How much disinfectant used in disinfection process?

a. 2-5 kg b. 5-10 kg c. 10-20 kg d. above 20 kg e. Don't know

12. Does any training/information for working in the site are given?

Yes------------------ No---------------

If yes, what types?

a. Safety training/information b. General training/information

c. Specific training/information d. None of them

13. Is there any safety equipment used while working in the site?

a. Gloves b. Helmet c. Apron d. Shoe e. All of them f. None of them

14. What is the capacity of reservoir? ----------------------------------

Is it that fully used? Yes----------------- No-------------------

15. What do you do if there is sludge accumulated in tanks?

a. Cleaning of the tanks b. Discharge of sludge with treatment to near water bodies

c. Discharge of sludge without treatment to near water bodies d. Never noticed

e. Don't know

16. What are the sources of drinking water treatment plant?

a. Surface water b. Boring water c. Khola d. None of them

17. When do you take a sample for analysis?

a. Daily b. Monthly c. Annually d. Never e. Do not know

18. What types of treatment does this treatment plant have?

a. Coagulation b. sedimentation c. slow sand filter/rapid filter

d. aeration e. flocculation f. Pressure filter g. Biological filtration

19. Are the operators are familiar fully with plant units? Yes------------- No----------------

Is it Trainings/information? -------------------

What type of training/information is given?

a. Safety training/information b. General training/information

c. Specific training/information d. None of them

20. How much do you have knowledge on water treatment system?

a. Little b. More c. Enough d. Not so much

e. Not interested

21. Do you think the system works? Yes---------------- No----------------

a. Satisfactory b. Unsatisfactory c. It's ok d. Do not know

22. How often is the screen in the inlet cleaned?

a. Daily b. Weekly c. Monthly d. Annually e. Never

23. Do you ever notice people working in a site have health problems?

Yes--------------- No----------------

If yes, what types?

a. Respiratory problems b. Diarrhea c. Typhoid d. Dysentery

e. Others f. Do not know

24. Do you ever notice people drinking water taken from this plant have health problems?

Yes--------------- No----------------

If yes, what types?

a. Respiratory problems b. Diarrhea c. Typhoid d. Dysentery

e. Others f. Do not know

25. Is there any operational problem in any unit of the treatment system?

Yes---------------- No----------------

If yes, what types?

a. Blockages in inlet/ bar screen b. Not working the unit c. Power cut problem

d. disinfectant powder is not good e. powder is settle in a solid f. others

g. Muddy water from source during rainy season h. Never notice

26. What are the solutions applied for tackling operational problems?

a. Use excessive disinfectant powder during rainy season

b. Cleaning of inlet/ bar screen

c. Use of generator

d. replace by good quality of powder

e. others

f. Not done yet

27. Do you have any operational and maintenance manual? Yes---------- No----------

28. Do you treat solid accumulation after cleaning each unit? Yes---------- No----------

If not, what you will do?

a. discharge into river b. throw outside c. not cleaned d. never done

Questionnaire for user's committee

Name:

Age:

Gender:

Address:

Assigned job in institution:

1. Was reuse of wastewater considered before implementation of the reed bed system?

Yes---------------- No-----------

2. What kind of reuse?

a. Gardening b. Irrigation c. Washing d. Flushing toilets e. donot know

3. What was the situation before the implementation of the reed bed system?

- Do you directly discharge the wastewater to the environment?

  Yes------------------- No----------------

  If yes, where do you discharge?

  a. river b. land c. Pond d. stream e. lake

  f. ocean

  - Have you use any domestic treatment mechanism before this?

    Yes--------------- No-----------

  - If yes: What mechanism?

  a. Septic tank b. Oxidation pond c. waste pit d. aerobic method

  e. anaerobic method f. others

  - Did you have a toilet? Yes------------- No-----------

  If No: How far did you have to walk to get to a toilet?

  a. Near to the room b. Outside of house c. five minutes walk d. Open defecation where is it possible

4. Which wastewater does the reed bed system treats?

a. Hospital b. Institutional c. Domestic d. Industrial

5. What training/information is given before entering the committee?

a. General training/information b. Technical training/information c. Specific training/information d. Detailed information

- Does they give demonstration during involvement of the system?

  Yes-------------- No--------------

  - If yes: Which one?

a. Picture demonstration b. Actual field demonstration

c. Both a & b d. None of them

6. Do you understand the system? Yes------------ No------------

If yes: How much?

a. Little b. Much c. Do not understand d. Confused e. Not interested

7. What is your role in the committee?

a. Member b. Coordinator c. Secretory d. Main member e. Others

8. Operation and maintenance

- Have you experienced any problems with the system? Yes-------No---------
- If yes: what types?

  a. clogging of bed b. defects in pipe c. overgrowth of plants

  d. Never e. Others

9. Do you feel the operation and maintenance role is important? Yes---------No-------

10. Do you have any operation and maintenance manual for the system?

Yes-----------No---------

11. Are you interested in any of the products from the system? Yes----------- No------------If Yes: Which one?

a. Treated water b. Sludge c. Biogas d. All of them e. Combination

- Do you do any farming? Yes-----------No-------------
- Do you use sludge in your farming? Yes---------No----------
- Would you consider using sludge? Yes----------No----------

12. Is there any sampling of wastewater for test? Yes----------- No----------

If Yes: How many times?

a. Once a month b. Once a year c. twice a year d. Never

13. Do you know how many meetings for the user's committee have been arranged?

Yes--------------No-----------

If Yes: How many?

a. Daily b. Weekly c. Monthly d. Annually e. Do not Know

14. How many meetings did you attend?

a. less than 3 b. more than 3 c. at least 5 d. None

15. Financing

a. Have you been involved in money contribution or collection of money for maintenance?

Yes--------------No--------

b. Have you payed any fees? Yes--------No--------

How much fee is charged?

a. Less than NRs. 200 b. More than NRs. 200 c. Not paid

16. Does the treatment system have any impact on the environment/community?

Yes------------------ No----------

If yes: what types?

a. Smell bad odour b. Destroy aquatic life in downstream c. Water pollution

d. Others

17. Do you feel the treatment system is effective for the community?

Yes------------ No------------

18. Up to which level you have been involved in making decisions on maintenance?

a. Little b. Most c. Not interested

Questionnaires for farmer

Name:

Age:

Gender:

Address:

Name of the institution:

1. Are you feel comfortable for using treated water from the reed bed system?

Yes------------ No-----------

2. Does this water coming from treatment system have bad odour?

Yes--------------No-----------

3. Do you use treated water for irrigation? Yes--------------No-----------

If yes: Is it ok?

a. Sufficient b. Insufficient c. More than enough d. enough but used e. Not interested

4. Give your opinion of the effect of this water in downstream aquatic life.

a. no exist of aquatic organisms b. no exist of aquatic plants c. Both exists

d. Eutrophication occur e. none of them

5. Have you ever noticed people from respective wetlands monitor the water quality of this stream? Yes-------------------No-------------

If yes: how many times?

a. weekly b. monthly c. annually d. not seen

6. Quality of treated wastewater

a. Do you think the treated wastewater is beneficial for your health?

Yes------------ No--------

b. Do you think the treated wastewater is beneficial to your crop?

Yes------------ No--------

c. Do you think the treated wastewater effect your crop yield?

Yes------------ No--------

7. Have you been informed of the possibility of use of sludge from the treatment plant?

Yes-------------------No----------------

8. Sludge contents

a. Do you think sludge is useful for your crops?

a. Yes b. No c. do not know

b. Do you think the sludge contains anything that may be harmful to your crop?

a. Yes b. No c. do not know

9. Do you have any personal constraints on using sludge/ wastewater? --------------------------

10. What kind of chemical fertilizers you use?

a. Urea b. Potassium c. NPKd. Do not use

- For what purpose?

a. Storing b. Production c. Others

11. Contribution

- Do you pay for treated water used for irrigation?
- Would you pay for treated wastewater? Yes-------------No----------

a. Less than NRs. 200 b. Less than NRs. 500 c. Above NRs. 50 d. Not paid

- Would you pay contribution to the maintenance costs of the treatment plant to ensure good quality discharge? Yes--------------- No---------------

- How much tariff do you pay? -------------------------------
- Payment method? Monthly--------------------- Annually--------------------
- Then, Per household------------------ Per person-----------------

Questionnaires for Non- user's committee

Name:

Age:

Gender:

Address:

Name of the institution:

1. What is your knowledge of the reed bed system?

   - Have you visited? Yes---------------No----------------

   - Have you been explained the system? Yes----------------No------------

2. Does this water coming from treatment system have bad odour?

Yes--------------No-----------

3. What is your perception of it?

a. Positive impact on environment and community   b. Plant is operating well

c. Useful for community   d. All of them

e. Have not shown any interest   f. a& b

4. What contribution would you be willing to give to keep the system?

a. In terms of cash   b. in terms of kind   c. Not interested

- Currently paying any fees?

a. NRs. 200   b. NRs. 500   c. NRs.---------------   d. not paid

5. Do you have interest in any products from the treatment system?

a. Yes b. No c. No interest

6. Which products from the treatment system?

a. Treated water-------------- b. Biogas--------------------------

c. Sludge-------------------- d. None--------------------------

7. How much you pay for using following products?

a. Treated water NRs. ------------------b. Biogas NRs. ---------------

c. Sludge NRs. --------------- d. Not paid

8. Would you like to buy vegetables/food produced by using treated wastewater?

a. Yes b. No c. No concern

9. Would you like to buy vegetables/food produced by using dried sludge?

a. Yes b. No c. No concern

Questionnaire for caretaker/Operator

Name:

Age:

Gender:

Address:

Name of the institution:

1. Do you understand how the reed bed system works? Yes----------------No----------------

2. Do you feel the system is operating satisfactory? Yes-------------No----------------

If No: What are the problems?

3. Do you feel the influent is adequate for operating the system? Yes---------- No-------------

4. Have you ever encountered a problem you didn't know the solution for? Yes------No-------If No: What will you do if it happens?

If yes: What did you do?

5. Do you have given training or have experience related to wastewater treatment?

a. Yes b. No c. Not interested

6. Have you given any safety training for using safety equipment while working in the treatment system? Yes------------------ No---------------

7. Are the members of the user's committee involved in the operation and maintenance? Yes--------------- No---------------------

If yes: in what way?

8. How often do the members of the user's committee visit?

a. Weekly b. Monthly c. Annually d. Never

9. How often is the ABR (Anaerobic baffled Reactor) emptied?

a. Weekly b. Monthly c. Annually d. Never

10. How often is the screen in the inlet pit cleaned?

a. Daily b. Weekly c. when it clogs d. Never

11. How many times the materials used in wetlands beds are washes/ cleaned?

a. Monthly b. Yearly c. depends on clogging of bed d. Never

12. How many times the plants are harvested?

a. monthly b. yearly c. depends on plant growth d. Never

13. Have the reeds ever been cut down or removed? Yes-------------- No------------

If yes: Is it trim or harvest?

a. Trimming b. Harvesting c. Others

14. How often is it done?

a. Weekly b. Monthly c. Annually d. Never

15. How often is the reed beds inspected?

a. Daily b. Monthly c. Weekly d. Annually e. Never

16. How often is the flow distribution inspected?

a. Daily b. Weekly c. Monthly d. Never

17. How often is outlet cleaned?

a. Daily b. Weekly c. when it clogged d. do not know

18. How is inlet and outlet cleaned?

a. Done by hand b. done by stick c. do not know

19. Is there any weed control in the system bed? Yes----------No----------

If so, what type of weed control is it?

a. Use pesticides b. cleared by hand and throws outside c. cleared and leave in the bed

20. Do you think sludge is collected by farmers to use? Yes----------- No-----------

21. Do you think sludge is collected by other than farmer? Yes--------- No----------

22. When was sludge last removed from the bed?

a. Weeks ago b. Month ago c. Year ago d. Not done yet

23. Hygiene

a. Do you use safety equipment like gloves during working in the treatment system? Yes-------- No--------

b. Do you wash your hands after working in the treatment system? Yes----------- No---------

c. Do you wash your feet after working in the treatment system? Yes----------- No-----------

d. Do your change your clothes after engaged in the treatment system? Yes-------- No--------

24. What is the other equipment you are using?

25. What is the life span of constructed wetlands?

26. Are you susceptible to any diseases? Yes------------- No-----------

If yes, what is it?

a. Diahorrea b. Dysentery c. Typhoid d. Other water borne diseases

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