Shakil Regmi

WASTEWATER TREATMENT IN KATHMANDU

Management, Treatment and Alternative

Bachelor's Thesis
Environmental Engineering

April 2013

MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

DESCRIPTION

MIKKELIN AMMATTIKORKEAKOULU Mikkeli University of Applied Sciences	**Date of the bachelor's thesis** 15.04.2013
Author(s) Shakil Regmi	**Degree programme and option** Environmental Engineering

Name of the bachelor's thesis

Wastewater Treatment in Kathmandu

Abstract

Main aim of this thesis was to understand the wastewater situation in Kathmandu, Nepal and its impact in natural water stream, how it is managed and treated. After understanding the scenario of wastewater treatment in Kathmandu, a suitable alternative wastewater treatment system is recommended for future use. Technical as well as managerial problem exists in Kathmandu, thus from my experience in Mikkeli, Finland I came up with the model that is handled by the municipality itself because skill and managerial problem to protect the city can be found in municipal level only. New models are always interesting for people, thus increasing efficiency along with interest.

Bagmati River, partially operating activated sludge Guheshwori wastewater treatment plant and low energy using system to treat wastewater known as constructed wetland wastewater treatment system was studied in detail. Artificial wetland is constructed to treat wastewater through natural method as it happens in natural wetlands. Though this system has huge potential in a country where energy scarcity exists but technical and managerial problem and lack of awareness hampered the success of this system too.

Analysis of physical, chemical and biological parameters that indicate the characteristics of wastewater was done by collecting samples and by reviewing secondary data. Result showed that Kathmandu is in need of development in wastewater management and treatment because the situation has degraded dramatically in the past decade. Therefore, a new method sequencing batch reactor was recommended. It follows the same method as activated sludge but all the treatment processes happens in the same basin. This system proved to be more viable for Kathmandu because it uses less space, energy and money compared to continuous flow system. Compared to constructed wetland wastewater system also this system has high lifespan and can treat large amount of wastewater in less space. Comparison of this system and current status of existing wastewater treatment plants in Kathmandu demands implementation of this new and attractive model.

Subject headings, (keywords)

Wastewater treatment, Kathmandu, Nepal, constructed wetland, activated sludge, sequencing batch reactor, environment friendly

Pages	**Language**	**URN**
54 pages + 9 pages appendix	English	URN:NBN:fi:amk-201305199416

Remarks, notes on appendices

Tutor	**Local Supervisor of the bachelor's thesis**
PhLic. Maritta Jokela	Dr. Bed Mani Dahal (Kathmandu University)

CONTENTS

ACKNOWLEDGEMENT

Interest of nature and environment gained while taking pictures for bird photography contest before 2 and half years led me to Environmental Engineering degree programme. Taking the path which I never thought made me to think and realise that environment can never be created by humans, so try to understand and work for it.

"He is able who thinks he is able" *– Gautama Buddha*

Environmental Engineering is about sustainable development, design and protection of nature. The picture was true with shifting your physical presence and missing your physical place by contributing in carbon content above some kilometres in environment. Finding motivation and enthusiasm to work continuously for several semesters was interesting for me and to succeed and "feel able" as *Buddha* preached was more than interesting. Education and knowledge gained in different culture and setting broadened my vision and this was able only by the support of my mentors, teachers, colleagues and loved ones.

Support I received during my practical placement phase by my teachers and working mentors increased my knowledge in Environment and I would like to express my heartfelt gratitude to them. For this study work, from my topic selection to managing various paper works became possible only from the help of my mentor teacher. I would like to thank my department including all staffs in Mikkeli University of Applied Sciences from where I gained this status to conceive a thesis work.

Personally I would like to thank my supervisor Maritta Jokela for everything she had done for me to enhance my knowledge and complete this thesis, special thanks to Aila Puttonen for sharing her great knowledge and mentoring me. Also thanks to Martti Pouru for providing technical knowledge in the field of wastewater management and Arto Sormunen for managing all the odds throughout my study period. I would also like to thank all the teachers who taught me in Mikkeli University of Applied Sciences and other staff members who helped me in my journey to understand the environment more technically.

I would like to thank specially to my local supervisor Dr. Bed Mani Dahal, from Kathmandu University for his continuous support and sharing of intellect knowledge throughout the study period, which proved to be one of the best learning experience in this study period. Suraj Dhungel, my cousin brother and Senior Quality Control Officer in Deurali Janta Pharmaceutical Company for his support in laboratory analysis, also thanks to the company for letting me to use the lab. My sincere gratitude to Prajwol Shrestha from ENPHO for his help and support, Mukunda Neupane from Advanced Academy for sharing his experience about wastewater treatment facility. Care taker of Sunga Constructed Wetland Wastewater Treatment Plant Krishna Shrestha and helpful staff members from High Powered Committee for Integrated Development of Bagmati Civilization.

Thank you city of Mikkeli for accepting me as an inhabitant, my class mates who helped me in my study process, for their kind cooperation and everyone who have directly and indirectly supported, helped and wished for my success during the study period.

Finally my special thanks to my family and loved ones for your continuous love and support that has helped me to achieve what I aimed to. Also this would not have been possible without my guiding star!

Shakil

15.04.2013

ABBREVIATIONS

ABR – Anaerobic Baffled Reactor

ADB – Asian Development Bank

APHA – American Public Health Association

BOD – Biochemical Oxygen Demand

CFU – Coliform forming Units

COD – Chemical Oxygen Demand

DEWATS – Decentralized Wastewater Treatment Solutions

DO – Dissolved Oxygen

ENPHO – Environment and Public Health Organization

HFB – Horizontal Flow Bed

HP – Horse Power

HRT – Hydraulic Retention Time

ICIMOD – International Centre for Integrated Mountain Development

KW-hr – Kilowatt Hour

MIT – Massachusetts Institute of Technology

MLD – Million Litres per Day

MUAS – Mikkeli University of Applied Sciences

NPR – Nepalese Rupee

NTU – Nephelometric Turbidity Units

SBR – Sequencing Batch Reactor

SDB – Sludge Drying Bed

SSFW – Subsurface Flow Wetland

TDS – Total Dissolved Solids

TSS – Total Suspended Solids

UNEP – United Nations Environment Programme

USEPA – United States Environmental Protection Agency

VFB – Vertical Flow Bed

WWTP – Wastewater Treatment Plant

1 INTRODUCTION

Nepal is located between 27.9389° north, 84.9408° east in South Asia. Nepal is bordered by Tibet (autonomous region of People's Republic of China) in North and by India in East, South and West. Total land area is 147,181 km^2 and is characterized by diverse topography, geology and climatic conditions which favour diverse land uses and livelihoods. 77% of land area falls under hilly and mountainous region and only 23% of the area is flat, which is also known as Terai located in the southern part of the country.

Production and management of wastewater in Nepal is traditional and still in the stage of development. Development of sewer system in the country was started only towards 1920s with a 55 km long brick channel to collect and dispose combined sewer and rainwater runoff in Kathmandu valley. The modernization of water supply and sanitation infrastructure began only after 1972 under the support of the World Bank. [1]

Water pollution caused by direct disposal of untreated wastewater is one common environmental problem found in developing countries such as Nepal. Lack of management of wastewater treatment plant, high cost of spare parts, chemical additives and lack of knowledge has led most of the wastewater treatment plants in Nepal to the state of non-functional system. These types of non-technical and technical problems have hampered the water environment of urban Kathmandu.

Through this research study, I have tried to understand and explain the wastewater status of Kathmandu. Along with this, this thesis will also focus on reason of failure for wastewater treatment plants in Kathmandu, study of partially operating activated sludge wastewater treatment plant (WWTP), study of constructed wetland wastewater treatment plant and its various dimensions and probabilities.

After understanding the current scenario of wastewater treatment in Kathmandu, a proper alternative will be proposed. Proposed alternative system will be more efficient compared to current existing plants in context to environment and economy. Possible details of the alternative system and its efficiency while operating in various parts of Kathmandu is studied and discussed as the final part of this thesis.

1.1 Wastewater Management in Kathmandu

Rainfall, glaciers, rivers and groundwater have been addressing the need of water throughout the country. Out of these sources, river is the most important source of water in terms of volume and potential for social, economical and environmental needs. Rainfall and groundwater are next mostly used sources for utilization of water. Kathmandu receives around 1420mm of average rainfall per year and the whole country has storage of 12 billion m^3 of ground water. [1]

With excess dependency on surface water (river, ponds), proper management of wastewater is a necessity. Production of wastewater in Kathmandu is from domestic, commercial and industrial routes. Sewer system is mainly combined with sewerage and storm water drains. Wastewater produced from domestic circuit mainly composites of grey and black water produced while washing, cleaning, bathing and using for sanitary purposes. According to the International Centre for Integrated Mountain Development (ICIMOD) and United Nations Environment Programme (UNEP) only 40% of the population in Kathmandu has access to sewer facility leading towards river, while others directly dispose their wastewater in the nearby rivers. [1]

Rainwater run-off originating from urban areas and agricultural lands is also considered wastewater but they are not treated and directly routed towards surface water. Whereas, industrial wastewater have also been contributing in degradation of water quality of rivers. Industries such as, brewery and distillery, cement, tobacco, iron and steel, rosin and turpentine, soap and chemical solvent, oil and vegetable ghee, jute, paper and pulp, sugar, leather tanning and carpet industries are major contributors of wastewater in Kathmandu along with wastewater generated from hospitals. [1]

50.9% of total industries of Nepal are located in Kathmandu valley and total wastewater productions from these units are estimated to be 800m^3/day. Wastewater generated from most industries is mixed with the municipal sewerage system and is causing problem for wastewater treatment plant because of high load of oxygen demanding wastes, synthetic organic compounds and inorganic compounds and minerals present in it. Unknown but very small amount of such wastewater is treated and most of it is directed towards the river causing significant degradation of river water in the local level. [1]

Increase in usage of pesticides and run-off of agricultural lands in rainy season is increasing the level of pollutant in sources of water. These run-offs are not treated or considered as wastewater. 250 different types of organochlorides and organphosphates used in agricultural lands are contributing indirectly in toxic wastewater production. In 2011, wastewater production in Kathmandu was estimated to be 69.012 Million litres per day (MLD) out of that only 34.506 MLD was collected. From this collected amount of wastewater, how much wastewater was treated is unknown showing the undeveloped status of wastewater management and treatment in Kathmandu. [1]

1.2 Wastewater Treatment Plants in Kathmandu

Kathmandu valley consists of five centralized municipal wastewater treatment plants and estimated twenty decentralized constructed wetland wastewater treatment plants. Out of these five centralized treatment plants, two are non-aerated lagoons at Kodku and Dhobighat, two are aerated lagoons at Sallaghari and Hanumanghat and one is activated sludge treatment plant at Guheshwori. These plants are not operating as per their design and capacity; their location is shown in FIGURE 1.

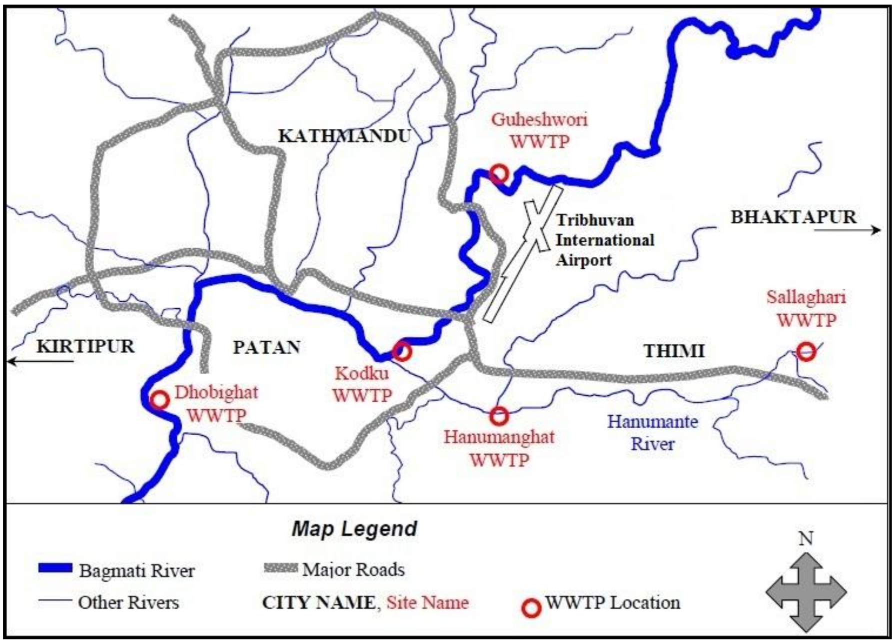


FIGURE 1. Map of Wastewater Treatment Plants in Kathmandu Valley (modified from ADB report of 2002) [7]

Five centralized WWTP are located nearby the main river network of Kathmandu. Lack of expertise and management has lead to the failure of these systems. Partially working treatment plant of Guheshwori, which is an activated sludge system, works only 10 hours per day due to shortage of electricity.

Similarly, WWTP of Kodku is partially operating which consists of 4 non-aerated ponds, see FIGURE 2. This system works by collecting the wastewater of nearby areas and is retained in the collection (first) pond to treat naturally with help of natural oxygen and self occurring bacteria.

FIGURE 2. Kodku Non-aerated Lagoon WWTP; (a) First pond; (b) Second pond; (c) Third pond; and (d) Fourth pond

Retained wastewater is supposed to pass in every pond to go through the same process but out of 4 ponds only 2 are operating, which is also in bad state due to unwanted eutrophication. Third pond is partially in use and fourth pond has become a place for electricity tower. Wastewater from this plant gets directly deposited into the Bagmati

River after simple sedimentation. Hydraulic retention time (HRT) of this system is unknown and it is not contributing in environmental protection.

Tetsuji Arata of MIT Nepal Project team stated after observing Kodku WWTP, “observed in January 2003 that the performance of the facility was doubtful, as effluent discharged into the Bagmati River was bubbling and smelled just like that of sewer water”. [2]

A study of wastewater treatment in Kathmandu was carried in 2003 by students of Massachusetts Institute of Technology (MIT), where they stated the condition of these treatment plants as shown in TABLE 1.

TABLE 1. Operating status of WWTP in Kathmandu Valley

WWTP Characteristics		**WWTP Status**		
Location	**Capacity**	**ADB Report, 2000[7]**	**MIT Thesis, 2003****	**MUAS Thesis, 2013***
Guheshwori	17.3 MLD	Under Construction	Operating	Partially Operating
Hanumanghat	0.5 MLD	Partially Operating	Not Operating	Not Operating
Sallaghari	2 MLD	Partially Operating	Not Operating	Not Operating
Kodku	1.1 MLD	Partially Operating	Partially Operating	Partially Operating
Dhobighat	15.4 MLD	Not Operating	Not Operating	Not Operating
MLD = Million Litres per Day				
* Observation done in this thesis study			** [2]	

The condition of WWTP in Kathmandu has not improved but it has worsened more. Guheshwori plant in 2003 was in operating status but in February 2013 it was observed as partially operating system due to lack of electricity. Other four WWTP have the same status even after a decade. Guheshwori WWTP works only 10 hours per day due to cut-off of electricity in the capital. High demand of electricity in Nepal has not been fulfilled thus resulting in electricity cut-off.

Lack of expertise and mismanagement of these WWTP has decreased the water quality of natural river network in Kathmandu. Concerning this issue, environmental agencies and organizations have developed decentralized wastewater treatment solution (DEWATS) in Kathmandu. The used system in Kathmandu is Reed-Bed Wastewater Treatment Plant also known as constructed wetland system. This concept has been popular in Kathmandu because of economical and environmental matters. It is cheap compared to centralized system and uses no electricity. Thus various organizations, hospitals, educational institutes and communities have started to use this system.

1.3 Motivation and Objective of Research

Interest in environment related issues and knowledge in the same field led me to think clearly about the environmental condition of Nepal. Wastewater, solid waste and air pollution being the major environmental problem of Nepal, I decided to focus my research on wastewater condition of the capital city of Nepal. Traditionally and culturally rivers have high value in Nepal but lack of awareness and proper management has degraded the quality of rivers. River pollution is one of the oldest existing pollution in Nepal occurring due to mismanagement of wastewater and solid waste. State of pollution in river can be directly observed through eyes, making it worse than it actually is and its impact is huge in the country, causing fatal diseases such as: diarrhoea, malaria and cholera.

The knowledge that I gained in Mikkeli University of Applied Sciences motivated me to do research in this field, to understand and to find a solution. Development and use of technology and expertise in Finland in wastewater management also became my inspiration to work in this field in Nepal. The Finnish scenario of wastewater management is highly advanced, the knowledge and experience that I gained while living in Finland will be of great asset for me as I can implement similar kind of technology to improve the wastewater management in Kathmandu. All measures are not compulsory to be the same as in Finland but the motive is same by treating water in any possible way and protecting the environment. With this motive my objective is to:

- Understand the wastewater and its management system in Kathmandu;
- Understand the current situation of activated sludge WWTP in Guheshwori and find out the best possible way for improving quality of effluent, when the plant is not in operating status;
- Understand the situation of constructed wetland in Kathmandu and its usage;
- Create a concept for improving water quality in Bagmati River by restoring the river; and
- Design and propose an environment friendly and economical WWTP.

2 MATERIALS AND METHODOLOGY

For this study one round of sampling was conducted to collect primary data. Sampling was done from Sundarighat for Bagmati River as its earlier data was also available. Similarly, samples were collected from Guheshwori WWTP and Sunga constructed wetland WWTP. Primary data was collected in order to evaluate the current status of sites compared to its earlier status. Motive to collect primary data was also to find out the suitability of constructed wetland in context to environment as well as economy.

Samples were collected by following grab methodology. Samples from each site were collected in 2 BOD bottles and 1 normal 1135 ml bottle. Samples of BOD bottles were used to calculate DO and BOD whereas sample from 1135 ml bottle was used for other tests. Date, time and weather condition at the time of sampling is presented in TABLE 2.

TABLE 2. Description of Sampling Condition

Site	Date	Time	Weather
Bagmati River (Sundarighat)	5, 17 & 20 March 2013	9:30	Sunny and Dry
Guheshwori WWTP	28 March 2013	11:20	Cloudy and Dry
Sunga Constructed Wetland	27 March 2013	8:50	Sunny and Dry

All the analysis was performed in Quality Control Laboratory of Deurali Janta Pharmaceutical Company, Kathmandu. Being a pharmaceutical company there were no standards for wastewater analysis as they lack their own system. In this case, proper standards were studied and analysis methodology were extracted and developed. The developed methodologies were firstly used in the normal water of the lab, this test showed that the procedure in theory was working practically and generated results also. After that a sample from Bagmati River was taken and analysed. The results obtained in first analysis were not realistic thus samples from the river were taken more than once. Later when methodologies were successful and gave realistic results, the sampling from other WWTP were done in regular and less time interval.

Samples from Bagmati River were taken from Sundarighat area from the bank of river, see FIGURE 3. Samples from Guheshwori WWTP and Sunga constructed wetland WWTP were taken from influent and effluent tank.

FIGURE 3. Taking sample in Sundarighat area of Bagmati River

Equipment, apparatus and analysis space was provided by Deurali Janta Pharmaceutical Company. Analysis methods were referred from Standard Methods for the Examination of Water and Wastewater of American Public Health Association (APHA) and analysis of Nitrate was done by following the standard of the pharmaceutical company. Analysed parameters and standard process followed for analysis are listed in TABLE 3. Out of these parameters, comparable parameters with the secondary data were selected for the analysis of each sampling point.

TABLE 3. Analysed parameters and their analysis method

Parameter	**Standard Method**
pH	Electro meter
Dissolved Oxygen (DO)	Winkler method (APHA standard)
Biochemical Oxygen Demand (BOD)	Titrimetric method (APHA standard)
Chemical Oxygen Demand	Open Reflux Method (APHA standard)
Nitrogen (Ammonia) [$N\text{-}NH_4$]	Nesslerisation Method (APHA standard)
Phosphate [PO_4]	Stannous Chloride Method (APHA standard)
Turbidity	Secchi Disk Method
Total Dissolved Solids (TDS)	Gravitimetric Method (APHA standard)

Total Suspended Solids (TSS)	Gravitimetric Method (APHA standard)
Nitrate	Comparing sample with standard 100ppm Nitrate solution (Deurali Janta Pharmaceutical standard)
Total Organism Count	Soyabean Casein Digest Agar and Potato Dextrose Agar
Feacal coliform Count	Membrane filtration technique
Escherichia coli Validation	MacConkey Broth, MacConkey Agar, Indole Test

Above mentioned parameters in TABLE 3 were selected according to its indicator characteristics and more than that these parameters were analysed previously in other studies making it possible to compare with obtained primary data. The obtained result of parameters may include unidentified errors due to human and instrumental errors. Secondary data and other information used in this thesis study were obtained from various personal and internet sources.

3 RESULT

To compare the effect of wastewater in river, the analysis of Bagmati River was performed in Sundarighat area. Similarly analysis of Guheshwori WWTP and Sunga constructed wetland WWTP was done in more detail to understand its efficiency and suitability. These results are presented in this section. Based on this analysis appropriate wastewater treatment system for Kathmandu has been recommended.

3.1 Bagmati River

Bagmati River originates from below the summit of Shivapuri Hill and is fed by springs and monsoon rainfall along with its tributaries. It flows through the Kathmandu Valley, passing from the core urban area and exits through the gorge in southern part of the valley. Total area of Bagmati River basin in Nepalese territory, before flowing towards India, is 3638 km^2. Its tributaries are shown in FIGURE 3. [22]

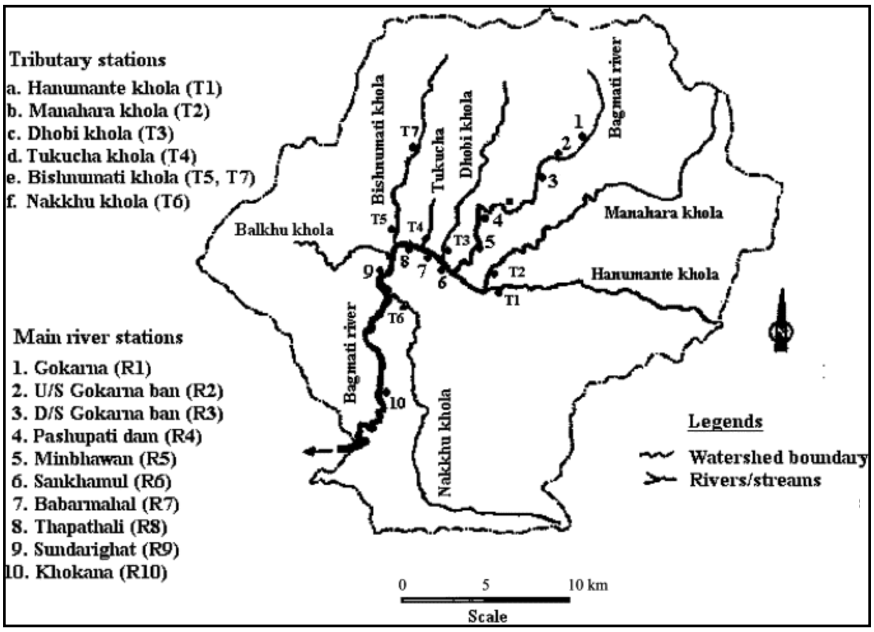


FIGURE 4. Bagmati River basin in Kathmandu Valley with its tributaries [23]

Present situation of wastewater management has decreased the quality of natural water stream in Kathmandu valley. Lack of basic domestic and industrial wastewater management has been devastating the quality of local rivers, namely the Bagmati and Bishnumati Rivers [2]. Bagmati River is the largest river flowing throughout the city with many sub-rivers including Bishnumati River and streams connected to it.

3.1.1 Current Status

Rivers have high aesthetic and cultural value in Nepalese tradition but over centralization in Kathmandu has led to rapid pollution of rivers flowing throughout the urban area. Due to mismanagement of wastewater in Kathmandu, Bagmati River has turned into a pollution hub, see FIGURE 5.

Extremely Polluted (saprobic class IV) and Very Polluted (saprobic class III-IV) region in FIGURE 5 is the core urban area of the valley. Its effect can be seen directly in FIGURE 5 because high but unknown amount of domestic and industrial wastewater is directly deposited in the river system without proper or preliminary treatment.

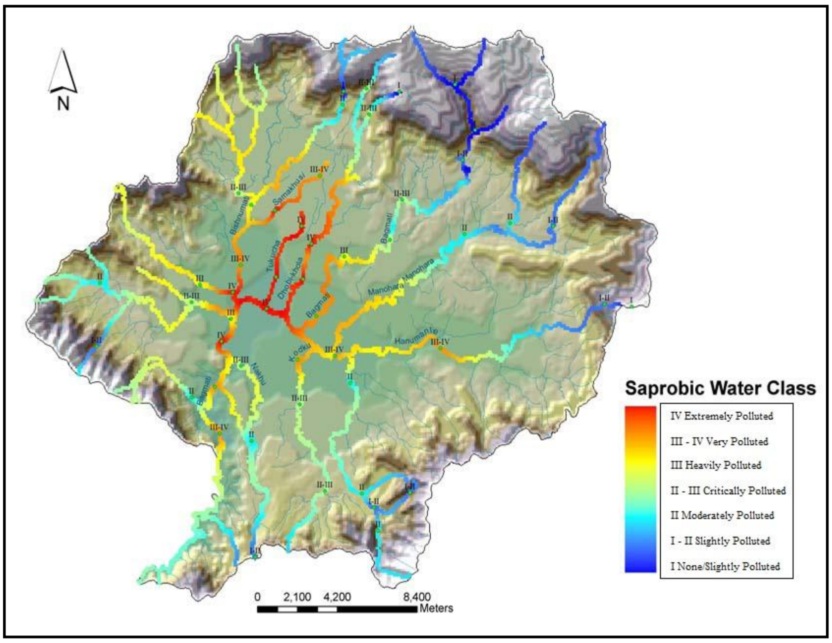


FIGURE 5. Map of Kathmandu Valley and its pollution state of river system [10]

Current condition of Bagmati River as seen from TABLE 4 is degrading continuously since last two decades. This is explained by the parameters that show presence of untreated wastewater in Sundarighat area of Bagmati River. TABLE 4 shows the data since last two decades with an interval of a decade in each set of data.

TABLE 4. Condition of Bagmati River in Sudarighat area

Bagmati River (Sundarighat)			
Year	1992 [17]	2002 [18]	2013*
Month	February	May	March
DO (mg/L)	2.6	0.7	0.9
BOD (mg/L)	44.5	240	296
COD (mg/L)	68.8	317	320
Ammonia Nitrogen (mg/L)	4.57	18	110
Phosphate (mg/L)	1.3	1.7	2.3
Total organism (cfu/100ml)	Not Observed	Not Observed	2×10^{10}
Faecal coliform (cfu/100ml)	7.5×10^{7}	2.3×10^{6}	1.8×10^{4}
Turbidity (NTU)	Not Observed	100	183
TSS (mg/L)	Not Observed	166	115
TDS (mg/L)	Not Observed	260	559
Nitrate (mg/L)	Not Observed	0.6	18
pH	Not Observed	7	7.2
* Data obtained through analysis in this thesis study			

Main source of organic contamination parameters, BOD and COD has increased whereas DO content has decreased. This fact is also observed in the river as foaming occurs continuously. Foaming represents chemical contamination in the river and lack of industrial wastewater treatment. Foaming prevents the surface water to intake atmospheric oxygen into it.

FIGURE 6. Foaming and accumulation of solid waste in Bagmati River

Major nutrients that deplete the oxygen content of the natural stream, ammonia nitrogen and nitrate have increased dramatically in this decade. Over urbanization leading to over-production of untreated domestic and industrial wastewater has caused this situation. Similarly, the level of phosphate is also increasing continuously. This rapid increment of nutrient level is causing blooming of phytoplanktons and eutrophic condition in the river, eventually encouraging the turbidity of river to worsen more than its current state in upcoming future with further depletion of oxygen.

There is not much change in the Total Suspended Solids (TSS) between 2002 and 2013, with slight decrease of TSS in 2013 but the level of Total Dissolved Solids (TDS) has increased dramatically insuring high level of pollution in the river water. Faecal coliform concentration resembles the value of TSS, as more sewerage wastewater is coming in dissolved form and the existing faecal coliform is decreasing due to anaerobic or anoxic condition in water along with predation factor arising due to high level of total organisms including other pathogens. Faecal coliform is decreasing steadily due to this factor, but increase in number of total organism compared with total coliform count (cfu/100 ml) of 1992, which was 9300000, has had an alarming increase rate in last two decades. *E. coli* was also found to be positive in the sample of Bagmati River.

Though the pH of river water seems neutral, other parameters explain that pollution level is high. Parameters that indicate the presence of wastewater contamination prove that untreated wastewater in Kathmandu is degrading the natural water stream in every possible ways. Low oxygen level in the water has increased the odour problem throughout the river bank area effecting residents nearby and is continuously decreasing the aesthetic value of river.

3.1.2 Restoration Need and Technique

Above mentioned information shows that Bagmati River has to be restored in order to maintain satisfactory water quality level. The restoration of Bagmati River must be done either by increasing the numbers of wastewater treatment in the urban areas or by increasing the immunity power of the river by facilitating it with required system or by increasing the discharge volume of water in river system. Increasing discharge volume might not be practical hence remaining two options must be focused.

Increasing proper kind of WWTP in Kathmandu is discussed below in section 3.4 whereas restoration technique for the river is discussed in this section. Restoration technique itself is not sufficient for cleaning the entire polluted area but with help of some treatment plants in nearby areas, along with private treatment facilities for industries, will surely improve the condition of Bagmati River.

Restoration needs can be addressed by designing the flow and increasing the surface area of the river which will increase the amount of oxygen in the river leading to decomposition of organic matters in aerobic condition. If industries are to treat their generated wastewater by themselves then the wastewater produced from domestic purpose can be managed by simple treatment plants and restoration technique in the river.

Nature’s capacity to heal itself can be utilized intelligently with proper design, management and implementation. For this the wastewater through drainage must be made free from non-river materials. Materials such as different kinds of plastic pieces, bottles, papers and rags fall under this category [11]. This can be done by fencing the wastewater through iron-net before it passes to the river.

After this check dams can be constructed in different sections of the river. Check dams are capable to maintain flow and increase water surface area. Thus, the first section of the river will retain large amount of water in it, this will help the water to spread throughout the riverbank. As the water spreads to river bank, the surface area of river will increase compared to current situation. Then greater amount of water is able to dissolve atmospheric oxygen into it. This will increase DO in that section of the river. Now this water will flow from above the dam to another section, as the falling water hits the surface of another section of river greater amount of atmospheric oxygen is dissolved. This waterfall area can be given an inclined shape of rough surface which will increase the friction and will dissolve more oxygen. [11]

As soon as the water falls to new section a barrier can be constructed which is attached to next dam with a gap within it, connected only at the edge of dam for structural support. This will cause the water to turnover just within the surface increasing the dissolved oxygen in the water. In this way the flow of water throughout the polluted area of the river can be designed. This will cause aerobic condition and decomposition of organic matters can be achieved to restore and clean the river water. Aerobic condition will also remove existing odour problem of the river and will also remove industrial wastes such as phenols and volatile gases [11].

Cross-section plan of this flow design is show in FIGURE 7.

FIGURE 7. Cross section Model of Bagmati River with Check Dams and Barrier Dams to increase Aeration, Surface Area and Flow of River

This design will always maintain the flow of river water with high volume even in dry season. Increase in flow rate will also wash out solid waste from the river and aesthetic value will increase as the river water becomes clean. In several places, under the bridge these kinds of dams already exist, thus the flow in these areas can be designed according to this method. With help of check dams, flow rate can also be checked and maintained.

FIGURE 8. Concrete check dam under the bridge, where flow can be designed for river restoration

In large section before the water fall, sedimentation process will occur and sludge from the wastewater will settle down. This will decompose with time and will also be flowed away in the monsoon season [11]. As water level and flow rate increase rapidly in rainy season the remaining sludge will flow away with the water and will be decomposed later by natural process itself. This will create space for the sludge to be settled in upcoming dry season and use the same mechanism for river clarification.

This is one of the best alternatives for restoring the polluted rivers of Kathmandu. This process can be implemented without disturbing the river ecosystem because there is no aquatic life in the polluted area of the river due to low DO content. Thus natural process can be used to restore the river in Kathmandu, as it is environment friendly and is also an economical solution for the current problem.

This recommendation must be analysed and implemented only after proper calculations of the flow rate, dam height and other factors. Calculations of these parameters are not discussed in detail in this thesis because this study is mainly focused in wastewater treatment system of and for Kathmandu.

3.2 Guheshwori Wastewater Treatment Plant

Guheshwori WWTP is located in the north-eastern part of Kathmandu valley in the bank of Bagmati River. Bagmati River holds great cultural and religious significance but its protection and conservation has not been considered wisely. This WWTP was designed in 1996 and came to operation in 2001 [2]. This plant serves nearby areas of Guheshwori and is mainly designed to clean the water flowing through the bank of Pashupatinath Temple, as seen below in FIGURE 9, regarded as the holiest temple of Hindus all over the world. All kind of wastewaters including domestic, industrial and storm water are collected and treated in this system.

FIGURE 9. Polluted Bagmati River flowing through the bank of Pashupati Nath Temple [15]

3.2.1 Design and Working Mechanism

WWTP of Guheshwori is the first and only existing activated sludge WWTP system in the country. Activated sludge includes aeration in presence of microbial community for decomposition, settling tank for solid, biomass and liquid separation and recycling sludge actively from settling tank back to the reactor or oxidation ditch to maintain level of microorganism [3]. Design of Guheshwori WWTP is shown in FIGURE 10.

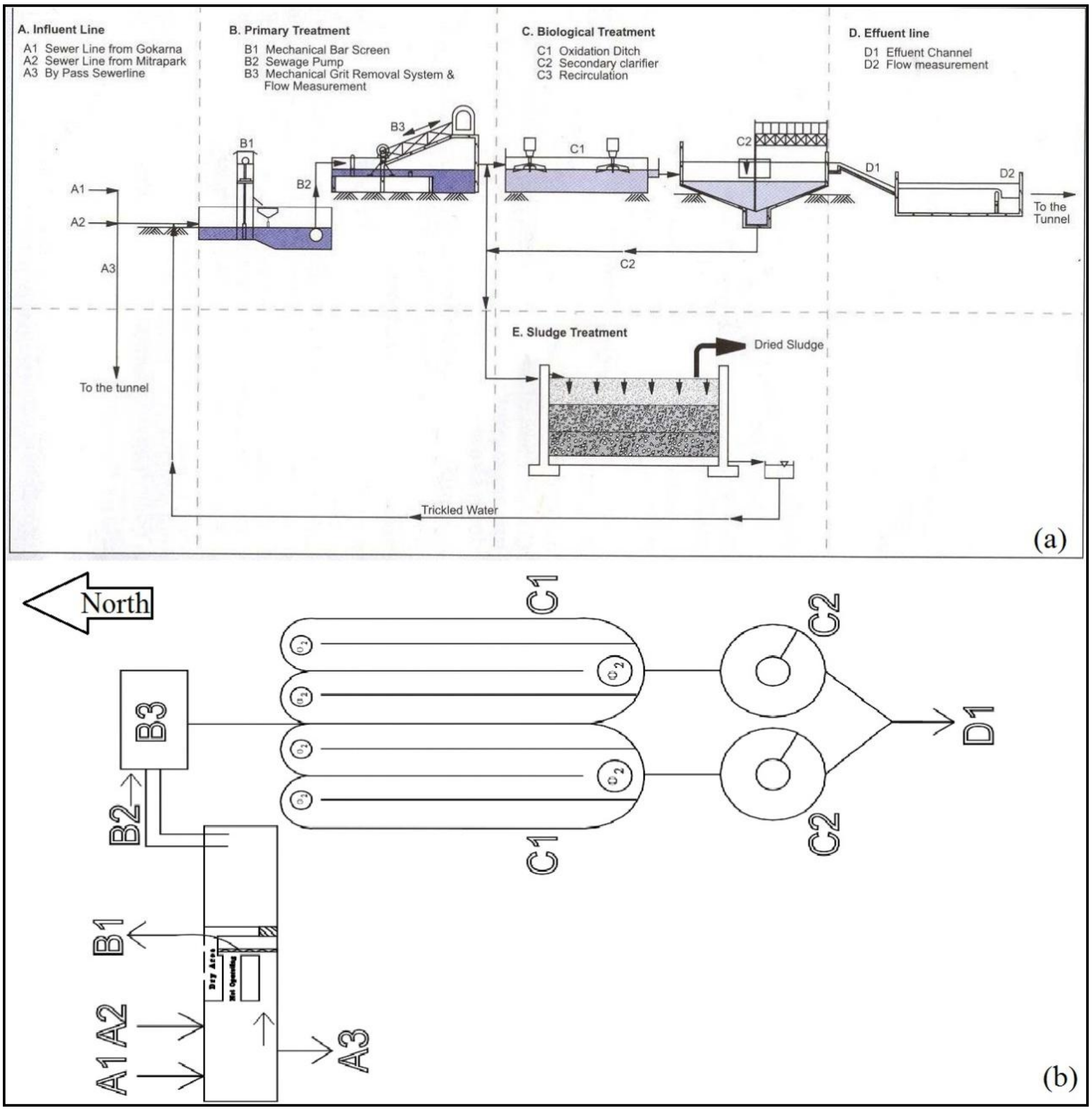


FIGURE 10. Guheshwori WWTP; (a) Cross-sectional view of plan [12]; and (b) Bird's eye view of plan

Pre-treatment of wastewater is done by mechanical bar rack and grit chamber. Bar rack removes large suspended solids and dumps the solid particle in the ground. There is also facility of manual bar rack if the mechanical one fails. Then the wastewater is transferred to grit chamber where inorganic particles such as sand are removed and dumped. Here water is settled and is pumped to oxidation ditch. There is lack of primary clarification tank in this WWTP which is common in small WWTP [2]. In the oxidation ditch 10,400m^3 wastewater is treated, where oxygen demand is 355 kg/h.

This oxidation ditch consists of two carousel type oxidation ditches, each consisting of three aerators. 60 Horse Power (HP) is required to operate these aerators. [4]

From oxidation ditch the wastewater flows to secondary settling tank, where flock is formed and settles in the form of sludge, which is pumped back again to oxidation ditch. While pumping the sludge back to oxidation ditch, around 2500 Mixed Liquor Suspended Solids (measure of biomass) is pumped to oxidation ditch to ensure proper decomposition of waste [4]. Whereas excess sludge is pumped from settling tank to sludge drying bed (SDB), but till now there is no record of pumping extra sludge out from the system. Picture of this WWTP is shown in FIGURE 11, which shows oxidation ditch and settling tank.

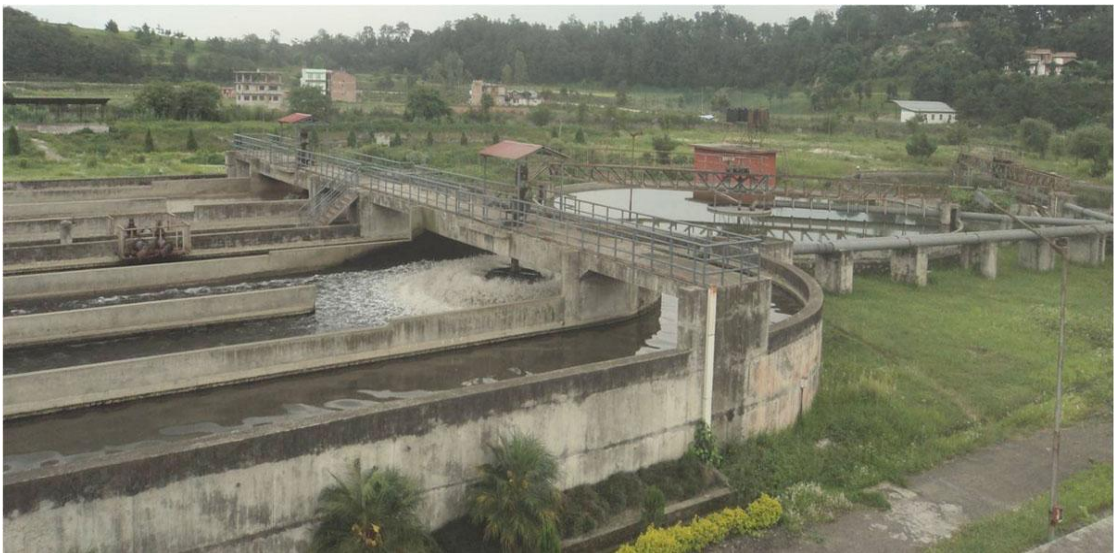


FIGURE 11. Activated sludge WWTP of Guheshwori [8]

This WWTP covers a total area of $5.37km^2$ with flow of $0.19m^3/s$ maintaining food to biomass ratio of 0.34. In wet seasons, the amount of wastewater exceeds $0.19m^3/s$ and reaches till $0.5m^3/s$, in this case extra wastewater is bypassed and is mixed directly with the effluent without any treatment. [4]

3.2.2 Efficiency

To analyse the efficiency of the system, available secondary data of 2002, 2003 and 2012 obtained from High Powered Committee for Integrated Development of the

Bagmati Civilization is compared with the generated primary data [26]. Result of Guheshwori WWTP is described below.

pH maintained by the WWTP of Guheshwori in 2013 is satisfactory as it holds neutral value of 6.89 in influent whereas 7.44 in effluent. This is due to the presence of excess amount of domestic wastewater compared to industrial wastewater. pH in other years was not observed thus making it imposible to compare.

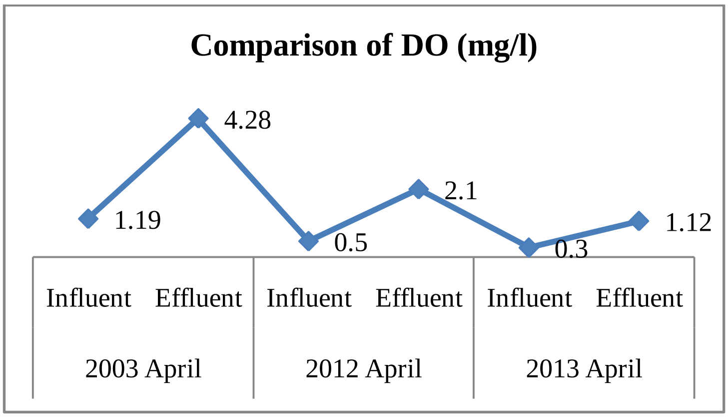


FIGURE 12. DO comparison of Guheshwori WWTP

DO of the system is degrading as seen in FIGURE 12 with dramatic reduction between 2003 and 2012, with further reduction in 2013. Similarly state of pollution is increasing with stable but continuous increase in TSS, see FIGURE 13.

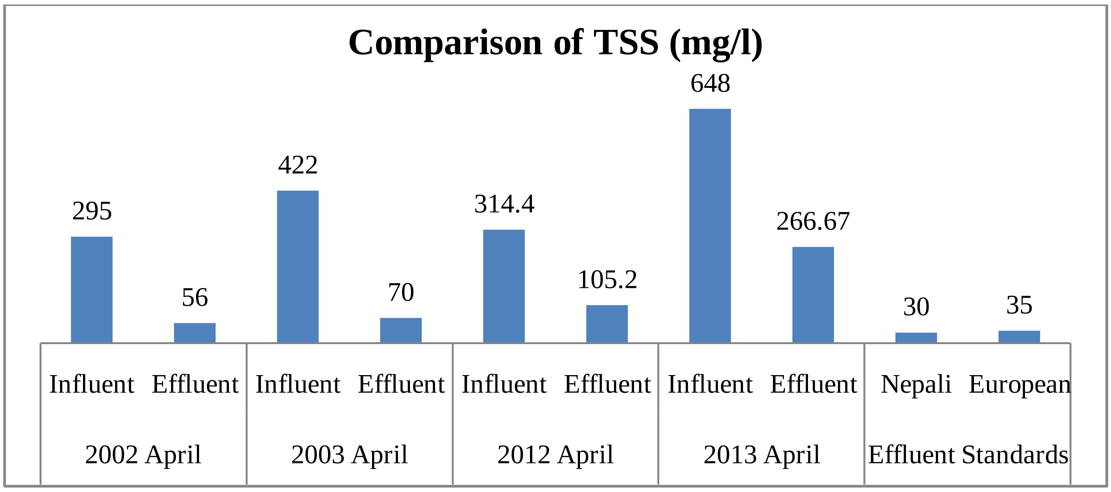


FIGURE 13. TSS comparison of Guheshwori WWTP

TSS in influent is increasing since 2002 with some steadiness, steadiness can be observed in the data of 2003 and 2012. Where difference between influent TSS is not high compared to that of 2013 and other years. From this data it can be mentioned that TSS is continuously increasing since 2002 where rapid increase of TSS in 2013 is observed. In starting years the reduction efficiency of TSS was satisfactory though the effluent values did not meet either Nepalese or European standards.

Later in 2012 the reduction rate of TSS decreased to 66.5% from 83.4% of 2003, the trend continues in 2013 with reduction rate being only 58.8%, none of the effluent values complying with the standards. TDS was not observed earlier, thus comparison cannot be done but the reduction rate of TDS is not satisfactory either indicating a problem in the treatment facility of the system. 566mg/l of TDS flows out as effluent with reduction rate of only 28%.

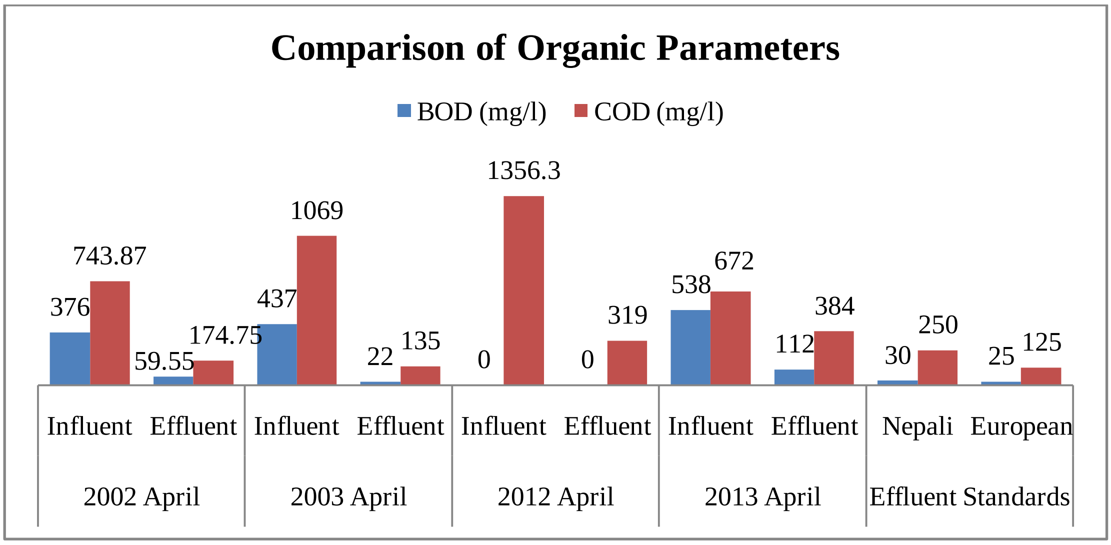


FIGURE 14. Organic parameter comparison of Guheshwori WWTP

In 2003, when electricity cutoff was not a huge problem as it is today, the treatment efficiency of the system was satisfactory. This situation can be observed in FIGURE 14. The amount of BOD as influent has increased in the past four observations, with decrease in treatment efficiency in 2013. Main reason for reduction in efficiency is due to lack of electricity, creating more and more anoxic environment in the system which slowly deplets the DO even when the plant is operating partially. Thus reduction rate of BOD has decreased to 79.1% in 2013 from 95% in 2003. In 2003, the effluent BOD did not exceed the standard because it was in complete operating status but in the starting year of 2002 when operation was developing and in 2013 the effluent BOD value is exceeding the standard.

Continuous increase of COD in influent till 2012 has dropped in 2013 but in the same way the reduction rate of COD is also decreasing since 2003 while reduction rate was still developing in the starting year of 2002. In early years, the effluent values were under Nepalese standard but in the recent 2 years, the effluent values are exceeding Nepalese standard with decrease in treatment efficiency.

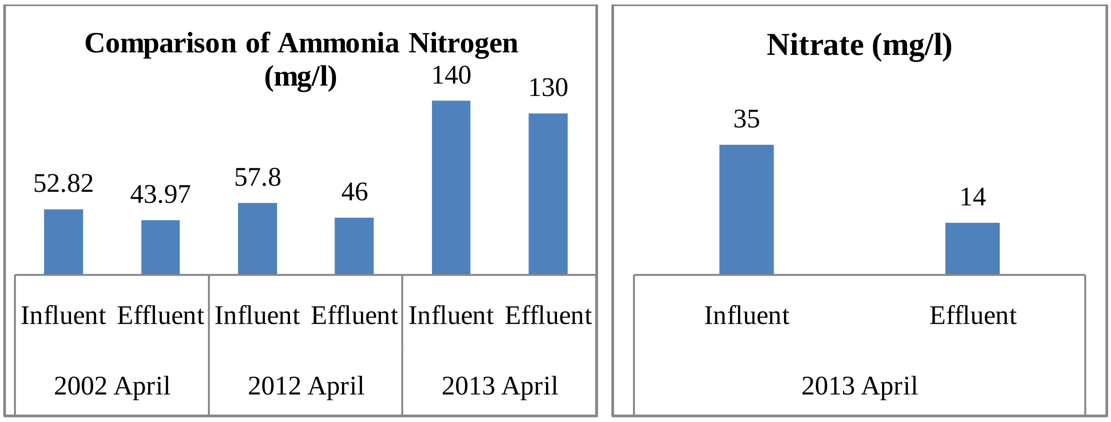


FIGURE 15. Comparison of ammonia nitrogen and status of nitrate in Guheshwori WWTP

Ammonia nitrogen shows dissatisfactory result because influent concentration is increasing continuosuly in observed years, with dramatic reduction of treatment efficiency from 20.4% in 2012 to 7.1% in 2013. Ammonia nitrogen is formed by anaerobic as well as aerobic bacteria from organic nitrogen, thus presence of these both in environment throughout the plant is causing a problem for reduction. Ammonia nitrogen is further transformed to nitrate in aerobic condition but aerobic condition is obtained only during aeration in oxydation ditch.

HRT of wastewater compared to aeration time is much higher thus limited amount of ammonia nitrogen is transformed to nitrate, having low reduction rate. Nitrate is further denitrified by anaerobic bacteria in anoxic or anaerobic condition, which can be achieved in secodnary settling tank. Thus 60% of nitrate is denitrified but more aeration is required for ammonia nitrogen to be transformed to Nitrate. Furthermore, electricity cutoff is having negative impact on creating aerobic condition.

Pathogen removal happens by straining in suspended bio-films, predation and sedimentation. No extra disinfection technology is used thus relying completely on natural biological method.

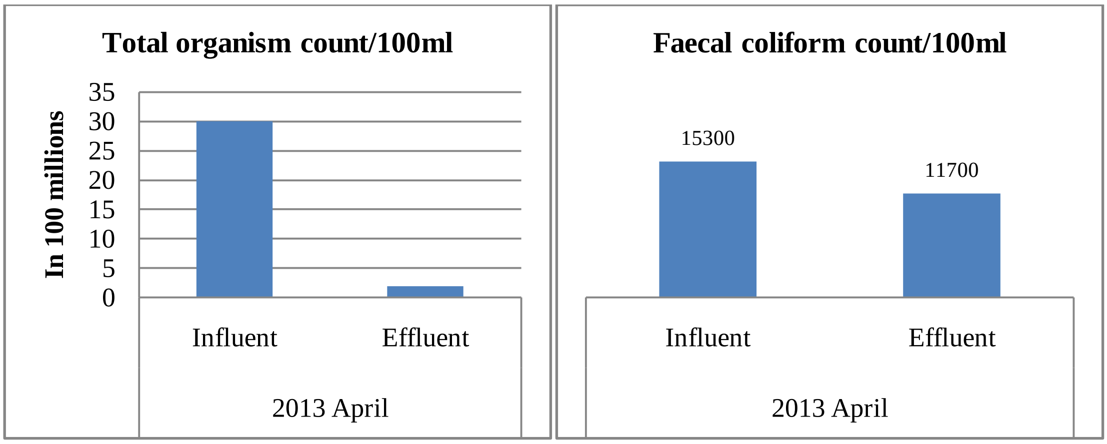


FIGURE 16. Coliform comparison of Guheshwori WWTP

When there is lack of electricity the influent is directly bypassed decreasing the amount of food for the microbes, reducing capacity of bio-film and system itself for the next treatment. The system has to face this situation in every 6-7 hours when electricity cutoff happens twice a day. After the treatment starts in interval of 6-7 hours the available biofilm can decompose the total organism but specifically decomposing individual family of coliform (faecal) becomes difficult for the existing microbes including other removal methods. This fact can be seen in the reduction rate of the system in FIGURE 16, where total organism reduction rate is 93.3% whereas reduction of faecal coliform is only 23.5%. These parameters where not observed earlier thus conclusion cannot be drawn from its comparison. *E. coli* was also found to be positive in influent as well as in effluent of the system.

3.2.3 Relation of Efficiency with Operating Condition

Importance of this system is unquestionable in context to environmental condition of Kathmandu but its suitability can be questioned without doubt. Mukunda Neupane, currently an environmental science lecturer in Advanced Academy, Kathmandu and previously an instructor in the planning stage of Guheshwori WWTP memorizes that, “I asked the officials not to build this treatment system in Kathmandu, instead build an oxidation pond which does not requires extra energy. I told this because domestic and industrial wastewater is not separated in sewer line and it will increase chemical contamination decreasing bacterial growth thus decreasing cleaning efficiency and will also cause problems such as foaming.” He added, “But the officials replied saying that lets try this experiment and I said this experiment will be very expensive.” This statement by Neupane was spoken in planning stage of this WWTP which means around 1997-98.

Today after 15 years the same problems as he stated have been observed in the treatment plant of Guheshwori. Lack of electricity is the major problem that the 60 HP aerators are not operating during power cut-off period per day, currently for 14 hours/day. Foaming problems were also reported by Amanda Richards in her thesis in 2003 titled as, Effects of Detergent Use on Water Quality in Kathmandu, Nepal [4]. Although the problem of foaming in Guheshwori WWTP exists (see FIGURE 33), the same foaming has started to develop in the river streams (see FIGURE 6) too. This means, the wastewater generation has increased and cannot be handled by partially operating WWTP in Guheshwori.

FIGURE 17. Different units of Guheshwori WWTP; (a) Usage of pump to pass the water through grit chamber; (b) Grab screen to remove large materials; (c) Blower aerators in action; (d) Feather like structures in settling tank; and (e) Settling tanks

Part a, b and c of the FIGURE 17 can be operated only when there is supply of electricity and because of power cutoffs the efficiency of the plant is low when there is no electricity.

While doing survey of the plant, feathers in settling tank and oxidation ditch were also observed (see FIGURE 17 d). Feathers have been drained along the sewer line through its source mainly slaughter houses. These feathers can act as media for harmful microorganisms to develop, and can be harmful for the treatment plant as well as for the effluent receiving water body [4]. These kinds of materials are currently removed in form of scum from the WWTP but there is no primary process employed to remove feather and feather like structures. When there is no supply of electricity the influent wastewater follows its pattern in the plant and gets out as effluent without any treatment. In this case, development of the plant is necessary as it will take unpredictable time to fulfil the electricity need of the system.

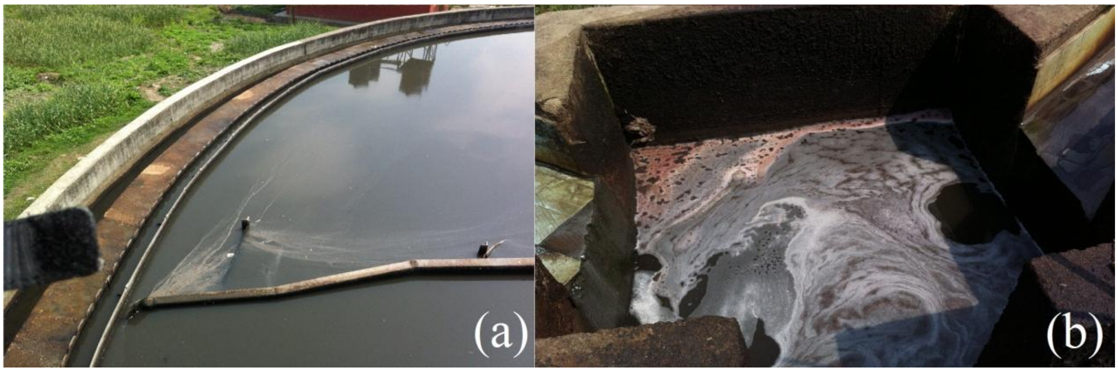


FIGURE 18. Secondary units of Guheshwori WWTP; (a) Scum removal in secondary settling tank; and (b) Foaming in effluent from Guheshwori WWTP

With these entire technical problems, financial problem also exists to challenge the suitability of this plant. Currently the annual operation and maintenance cost of Guheshwori WWTP is estimated to be about NPR 12.5 million/year (approximately €112,600/year) [12]. With this cost, it is unclear for how much longer this plant will be in operation. The main reason for operation cost of this plant to be high is because of the electricity rate, which is around NPR 7/KW-hr (unit) and energy consumption rate of this plant is 2.3KW-hr/kg BOD.

3.3 Constructed Wetland Wastewater Treatment Plant

Constructed wetland WWTP is a system based on natural processes and can be built from local materials with low cost compared to conventional systems. Conventional and centralized WWTP did not succeed in Nepal thus various local organizations, mainly Environment and Public Health Organization (ENPHO) started to implement this system in various places of the country. This system is not centralized in Nepal and is mainly used in small scale, thus it is also known as decentralized wastewater treatment solution (DEWATS) in Nepal.

Operation and management of this system is simple compared to other complex plants and is a good option for developing countries. Subsurface flow wetland (SSFW) system is used in Nepal, thus this system is studied in this thesis work. SSFW is divided into horizontal flow bed (HFB) and vertical flow bed (VFB). While constructing constructed wetland WWTP, one out of these flow beds can be used or both beds (hybrid) can be used to treat the wastewater. [5]

In HFB the influent wastewater flows horizontally, while in VFB the wastewater flows vertically. These two flowing systems create different treatment processes of influent wastewater but prior to injecting wastewater to these beds it has to be pre-treated in order to remove the excess suspended solids in form of sludge out of the system. This sludge is then treated and used for agricultural purposes.

3.3.1 Design and Working Mechanism

Previously in developing stage, constructed wetland with one settling tank to settle the solids was used and the retained liquid was flowed through HFB and VFB. These days more pre-treatment options have been started to use. One of its examples is Sunga WWTP in peri-urban area in Thimi, Kathmandu Valley. This treatment system is designed to serve 80 households with wastewater production of 30 l/day per capita. Average flow of this plant is $10m^3/d$, which can be seen in FIGURE 19. [5]

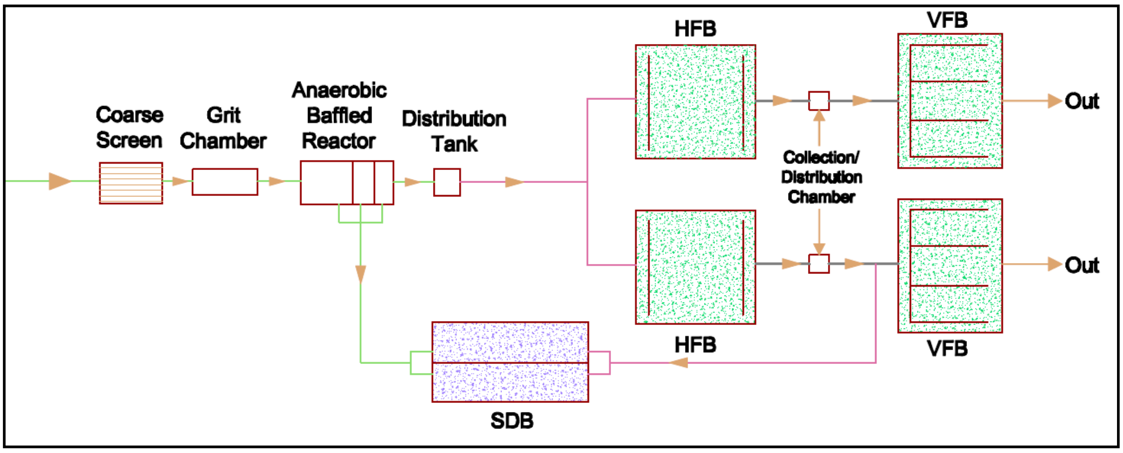


FIGURE 19. Plan of Sunga constructed wetland WWTP showing all components [modified from 4 cited from 19]

The preliminary system consists of coarse screen and a grit chamber, where suspended solids are removed. If the pit fills, the wastewater is diverted to a different pipe and is bypassed from the system. The pre-treatment component consists of anaerobic baffled reactor (ABR) connected with sludge drying bed (SDB) and HFB. ABR has an effective volume of $42m^3$ with an average flow of $10m^3/d$ and HRT of 4.2 days [5]. Then the water is transferred to two parallel HFB, which has the total area of 150 m^2 with depth of 0.4 – 0.5m, having total volume of 60 – 75 m^3 and HRT of 6 days [5]. Cross section of HFB is shown in the FIGURE 20.

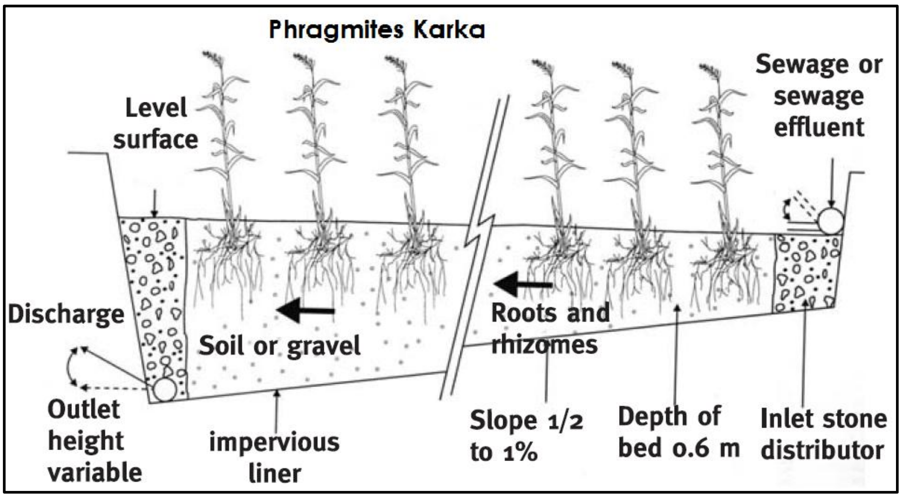


FIGURE 20. Cross section of HFB [9 cited from Cooper et al., 1996]

The wastewater from the pipe comes out equally from every hole utilizing all the parts of HFB and flows accordingly. This process is shown in the FIGURE 21.

FIGURE 21. Bird's eye view of HFB

The used plant is *Phragmites Karka* and is inexpensive to use. The effluent from this component is settled in a tank and is intermittently transferred to two parallel VFB with an area of 150 m^2 and depth of 0.55 m, making a total volume of 82.5 m^3 [5]. The cross section of VFB is shown in the FIGURE 22.

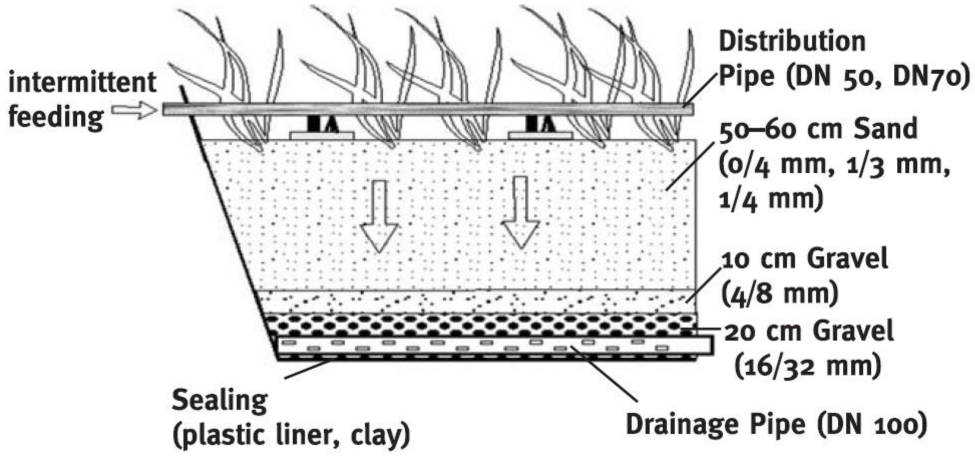


FIGURE 22. Cross section of VFB [9 cited from Shrestha 1999]

VFB is fed intermittently in a large batch flooding the entire surface. After this the bed drains completely and the air is refilled in the bed. This phenomenon leads to good oxygen transfer, which is shown in the FIGURE 23. After this the effluent is ready to be discharged in a nearby water stream. [5]

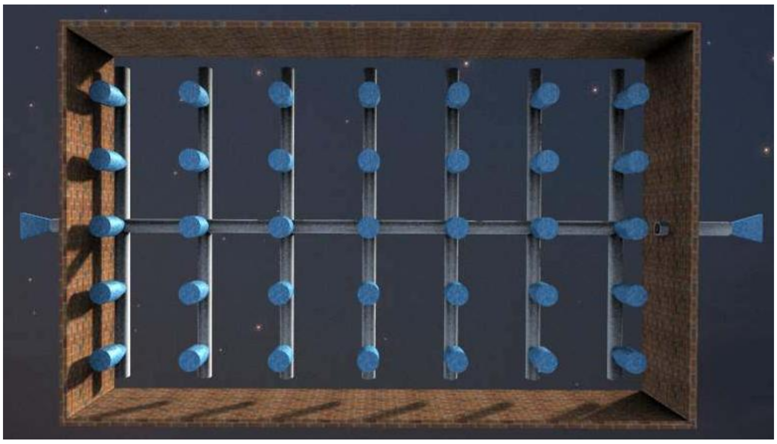


FIGURE 23. Bottom eye view of VFB showing process of flow of water (left to right) excluding bed materials

Sludge produced from ABR is dried in SDB for 6 months before using it as a fertilizer and leaching fluid produced from the sludge is again transferred to VFB for further treatment [5]. Effluent from WWTP should be of high quality which can be discharged into the waterways. Thus to obtain high quality water various components of this WWTP play an important role which is explained below as its working mechanism.

3.3.1.1 Pre-treatment

Domestic wastewater consists of excessive suspended solids which need to be pre-treated. If this is not done, the solid particles will quickly settle or filter out as the wastewater in the system. This will cause clogging of the bed material within few metres of the inlet and reduce efficiency and lifetime of the system. With reduced efficiency, clogging leads to leaching of wastewater in HFB and in VFB clogging would hamper oxygen transfer and hence the efficiency is reduced. Pre-treatment of wastewater will enhance the sustainability of the system. The used system in this plant is normal screen and grit chamber that removes large suspended waste particles. After this the ABR is used. This unit is quite similar to septic tank but the flowing function of water is improved in the reactor. This reactor has several baffles which increases the hydraulic retention time for both floating of wastewater and settling of sludge. [5] Cross section of ABR is shown below in FIGURE 24.

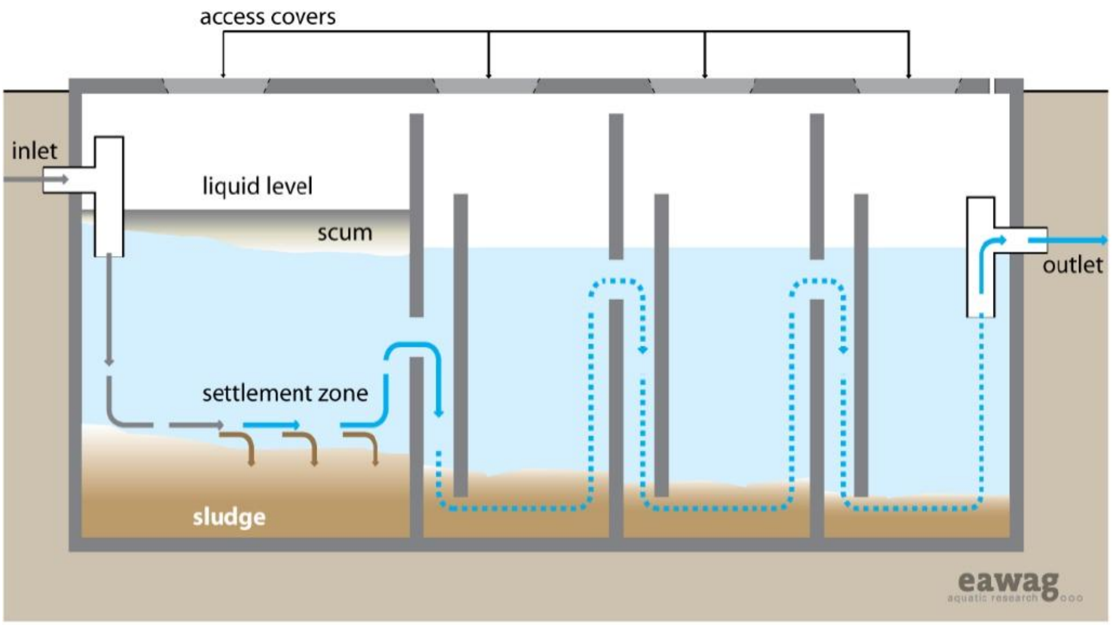


FIGURE 24. Anaerobic baffled reactor [6]

The settled sludge is then transferred to SDB for further treatment. Pre-treatment system mainly focuses on removing sludge from the wastewater to be treated. ABR has been adopted in this system because of its high HRT.

3.3.1.2 Removal process in Constructed Wetlands

Constructed wetland uses two kinds of removal mechanisms. First is liquid/solid separation by using gravity separation, filtration, adsorption, ion exchange, stripping and leaching. Then transformation of constituents occurs, such as chemical transformation, including oxidation/reduction reactions, flocculation, acid/base reactions and precipitation. These reactions are known as removal mechanisms but actually they just detain the contaminants over a period of time. [5]

Another mechanism used in treatment of wastewater is biochemical transformations of organic compounds creating gases such as carbon dioxide and methane. These processes are also capable to produce biomass and organic acids that affect the level of contamination in the effluent. Biomass can be transformed to volatile suspended solids and further change through bacterial reaction which causes leakage of soluble carbon compounds to the water. Further more detailed removal and working procedure of constructed wetland is explained below. [5]

Removal of Suspended Solids

Suspended solid is the solid retained on a standard fibre filter that typically has nominal pore size of 1.2 μm. Measured suspended solids in wastewater are typically termed as Total Suspended Solids (TSS). TSS is removed from the mechanism of “inertial deposition” and “diffusional deposition” in finely grained media. Inertial deposition is the mechanism of particles impacting in bed particles while the later one represents random processes which causes particles to move and thus possibly interact with submerged surface. In gravel bed TSS removal process works on “flow line interception” process, where flowing particle is intercepted, trapped and diffused in naturally occurring biofilms. In deep bed (>40cm) roots of plants and associated biofilms in the upper part limit the flow and cause blockage, whereas in the lower zone there is possibility of better flow. [5]

TSS will settle if HRT is high. Removal efficiency is relatively high in HFB because of low velocity and high surface area of media allowing for TSS to be removed by gravity sedimentation, straining and physical capture and adsorption to media and root biofilm. While in VFB the presence of biofilm is as same as the HFB, in this component the oxygen enters in the bed and decomposes the extra TSS of the influent. [5]

Removal of Organic matter

Organic content is measured by Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD is the amount of oxygen required by microorganisms to decompose the organic matter, and COD is the amount of chemical oxidant required to oxidize the organic matter. Along with these parameters, degradable carbon also exists in wastewater which is decomposed to produce organic carbon. Organic carbon is utilized in wetland process through its cycle of growth, death and partial decomposition resulting in gas, dissolved organics and solids with help of atmospheric carbon. When unwanted substances are decomposed carbon is released in atmosphere and water. [5]

Removal of particulate organic matter in HFB is similar to removal of TSS. Solids will undergo decomposition through hydrolysis and will transform to soluble organic matter. These organics will be absorbed or adsorbed to biofilms. Less oxygen in HFB leads to methanogenesis, sulphate reduction or denitrification which reduces BOD. Through intermittent loading in VFB, air penetrates and enhances aerobic decomposition of organic matter. Majority of microbial biomass is located in the top layer of VFB ensuring the organic decomposition likely to occur in this area. [5]

Removal of Nitrogen

Nitrogen is essential to be removed from the wastewater because its deposition without its removal can lead to eutrophication in the water body and reduces oxygen content as well as is harmful for aquatic life. Nitrogen is mostly present as organic nitrogen or ammonia. Organic nitrogen is converted to ammonia through biological processes in both aerobic as well as anaerobic conditions. Ammonia, due to its positive charge adsorbs with both organic and inorganic material. However this bonding is loose but typically occurs in treatment system. Ammonia is also removed by uptake of plants, but this occurs only when the plant is growing, which is less compared to nitrogen content in the influent wastewater. [5]

Remaining ammonia is flowed through the system and is converted to nitrite and further to nitrate through nitrification. This occurs in the presence of bacteria which require aerobic conditions and low carbon: nitrogen ratio. Then nitrate is converted to nitrogen gas by bacteria in anaerobic condition in presence of organic substrates. This is known as denitrification process and releases nitrogen gas back to atmosphere. Aerobic condition is poor in HFB and nitrification is limited but suits well for denitrification process. Denitrification process requires organic carbon also, which is provided by decomposing plant litter in the surface, which then leaches into the bed through rainfall. [5]

VFB is normally intermittently loaded, this allows the air to enter and creates aerobic environment within the bed. This condition suits quite well for nitrification compared to HFB.

Removal of Phosphorous

Phosphorous occurs in wastewater and natural water in the form of phosphates such as orthophosphates, condensed phosphate and organically bound phosphates. It occurs in both particulate form or in solution. Phosphorous is present in wastewater as residues of food and human waste. Phosphorous is limited nutrient for freshwater, as excess phosphorous can lead to eutrophication of the recipient freshwater. Removal mechanism of phosphorous in constructed wetland is from sorption, settling of TSS and associated phosphorous, filtration, interception and uptake by plants. All these mechanisms are only temporary removal methods. If the influent consists of high amount of TSS then huge amount of phosphorous easily settles down with solid matter but accumulation of phosphorous is not sustainable due to loss of porosity and hydraulic conductivity. [5]

Removal by sorption also depends upon the property of media and concentration of phosphorous. Surface chemistry is the most important media property because it consists of various matters and factors such as pH, temperature and reduction-oxidation (redox) conditions also have an impact on sorption of phosphorous. Large surface area gives more sorption but removal is limited by lower hydraulic conductivity. When this same phenomenon is repeated continuously in the constructed wetland, the system reaches to equilibrium. Where no more phosphorous is adsorbed or absorbed and is neither able to settle. At this condition the phosphorous concentration of influent will be equal to that of effluent. For high phosphorous removal, appropriate phosphorous-sorbing media with sufficient surface area must be chosen. Loading rate of VFB is higher than that of HFB and retention time is less in VFB thus making HFB more effective for removal of phosphorous from the influent wastewater. [5]

Removal of Pathogens

According to USEPA, pathogens include helminthes, protozoan, fungi, bacteria and viruses. The most common way to monitor human waste contamination in wastewater is by analyzing faecal coliform bacteria. Pathogens are suspended in water or are attached with TSS. These attached pathogens are mainly removed by the same process that removes TSS. Suspended pathogens are removed by sorption with biofilm and competition with other microorganisms. Similarly, processes such as filtration, interception and predation and sorption with clay particles also remove pathogens. [5] Removal efficiency by predation varies amongst pathogens, because each has their own characteristics. Viruses and protozoan are more resistant and removal mechanism is slow in case of these organisms. Due to size also the removal efficiency between bacteria and viruses differ. Removal of pathogens always do not lead to degradation of the organisms, instead they might get attached to the bio-films and later may be released to the environment causing harmful effects. Removal rates of parasites in HFB ranges from 79 – 100%, for VFB the data does not exist but removal rate is expected to be much higher. [13]

Removal of pathogens completely depends upon the present condition of the constructed wetland, therefore no generalization can be done between HFB and VFB as the flow paths and conditions differ greatly from each other. [5]

Exposure of pathogens in environment has to be monitored closely but in case of virus this has not been done as it is expensive to monitor [13]. Excreted pathogens in wastewater have long persistent time in environment and they possess harmful impact for the humans. Thus pathogen removal mechanism should be a high priority in wastewater treatment. Its impact and persistent time is presented in TABLE 10 at appendix section.

3.3.2 Efficiency and Suitability

To analyse the efficiency of the system secondary data of 2010 obtained from ENPHO is compared with the generated primary data [25]. Result of Sunga CONSTRUCTED WETLAND WWTP is described below.

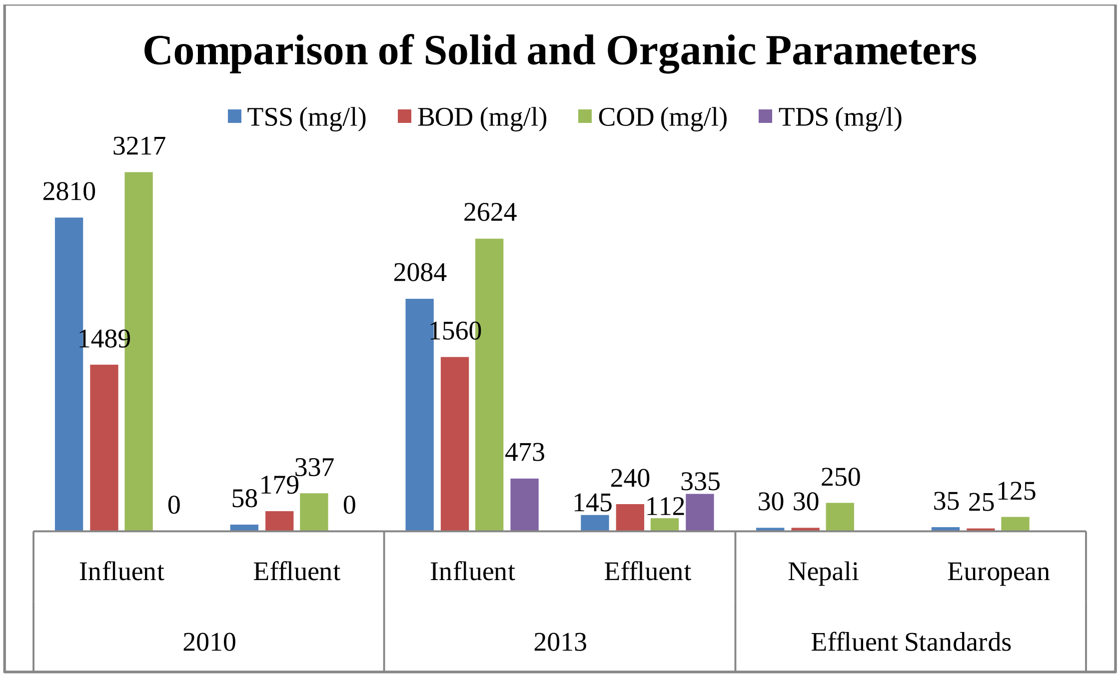


FIGURE 25. Comparison of solid and organic matters between 2010 and 2013

As seen in FIGURE 25, TSS is reduced significantly in both 2010 and 2013 but reduction rate of TSS was 98% in 2010 whereas in 2013 it is reduced by 93%. This shows that the efficiency of bed materials used in HFB and VFB to filter and store solid particle is decreasing. Reduction rate for TSS is satisfactory but effluent value is not satisfactory as it does not meet the Nepalese standard in 2013. Effluent TSS can range from 30-100mg/L, which is achieved in 2010 but not in 2013. Reduction rate of TDS is an issue to question the system because only 29.17% is removed, with 335mg/L of dissolved solids flowing to the natural stream.

Both BOD and COD values are dropped significantly throughout the process. Removal of BOD and COD mainly occurs in ABR. Amount of BOD contamination has increased in 3 years with decrease in reduction rate from 88% in 2010 to 84% in 2013. COD contamination has decreased in last 3 years with increase in reduction rate from 90% in 2010 to 96% in 2013. Effluent values of BOD in both 2010 and 2013 do not meet the standards but effluent value of COD in 2013 has met both Nepalese and European standard improving its condition from 2010.

Removal of ammonia nitrogen and nitrate follows the nitrification process as explained in *Removal of Nitrogen* above. Organic nitrogen is converted to ammonia nitrogen in aerobic as well as anaerobic condition (ABR, HFB & VFB), then nitrification occurs in aerobic condition (VFB) and converts it to nitrate, but nitrate needs anaerobic condition to denitrify, which is not present after VFB as the wastewater comes out as effluent. This phenomenon can be observed in FIGURE 26.

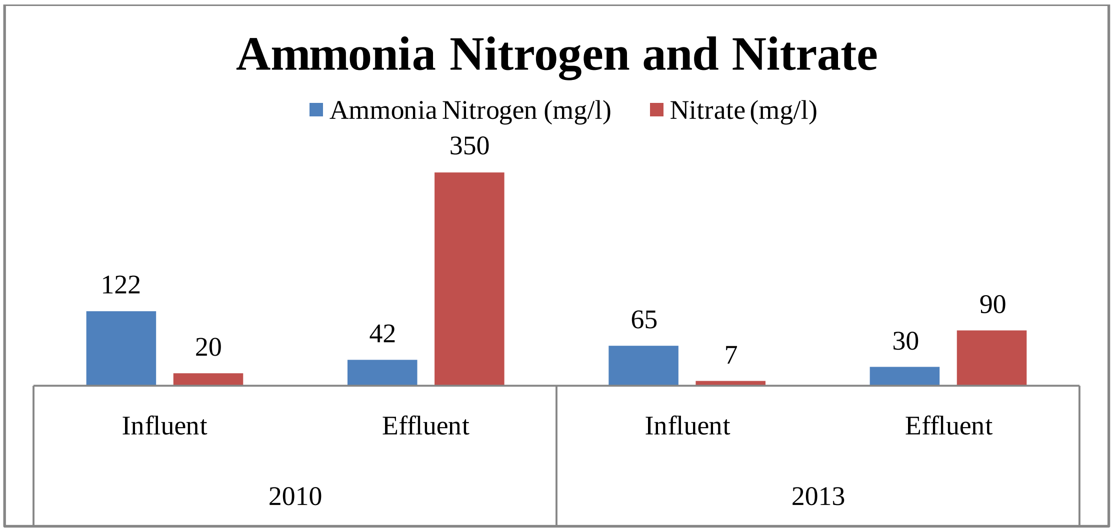


FIGURE 26. Comparison of ammonia nitrogen and nitrate in Sunga constructed wetland WWTP

Ammonia nitrogen occurs in aerobic as well as anaerobic zone, thus having low removal rate throughout the system, where ammonia nitrogen is converted to nitrate in aerobic zone (VFB) thus increasing the value of nitrate from influent to effluent. While constructing Sunga constructed wetland WWTP, the material was not chosen based on the chemical properties of bacterial cells for the sorption. Thus removal of total organisms and faecal coliforms is likely to happen only by filtration, straining in bio-film (plant roots) and predator factor. Removal of total organism has achieved 97.5% in 2013 by following the above mentioned process but removal of faecal coliform is in bad state as only 19.77% is removed.

TABLE 5. Comparison of microbiological parameters of Sunga constructed wetland WWTP

Coliform count parameters	2010		2013	
cfu/100ml	Influent	Effluent	Influent	Effluent
Total organism count	Not Observed	Not Observed	4×10^7	1×10^6
Faecal coliform count	1.6×10^8	2.5×10^7	2.63×10^4	2.11×10^4

Most of the time the influent wastewater is bypassed directly to the nearby stream as caretaker does not clear the grit regularly. This creates low food for microbes in bio-film and harms the wetland, and the following treatment efficiency for removal by straining will be decreased for some bacteria, in this case faecal coliform. Thus continuous operation and maintenance of system is necessary. While treatment efficiency for faecal coliform in 2010 was in good state but has degraded dramatically in 2013. This shows that filtration efficiency of plant is decreasing as bed materials are getting old thus removal of pathogens by straining must be focused. Presence of *E. coli* was also indentified in both influent and effluent wastewater.

To enhance the treatment of wastewater, HFB followed by VFB has been used in Sunga treatment plant as well as in other treatment plants of Nepal. However, many researchers suggest the constructed wetland to be connected in an opposite way, VFB prior to HFB. This is done to enhance denitrification within the system, as nitrification occurs easily in aerobic zone of VFB followed by denitrification in anaerobic zone of HFB. When HFB is connected before VFB, as in this treatment plant, the removal of organic matter happens in HFB followed by proper oxidation of wastewater in VFB, which enhances nitrification later in VFB. This is done to nitrify the content and avoid disposal of ammonia in the fresh water stream. [5]

Excess amount of ammonia is harmful for natural stream, so is nitrate as it decreases the DO content of the natural water causing phytoplanktons to bloom. With excess nutrient such as nitrate the natural stream might degrade thus denitrification must be ensured before deposition of effluent in the stream. For this VFB should be used prior to HFB. This will increase the suitability of constructed wetland WWTP and reduces the amount of excess nutrient in the stream. These kinds of small scaled WWTP are necessary to improve environmental condition as well as to increase awareness about mismanagement of wastewater but proper management of the system has to be done.

3.3.3 Importance and Usage of Constructed Wetland WWTP

Constructed wetland is an artificial wetland constructed to treat wastewater in the same process which occurs in natural wetlands without using any additional energy. Fact that no additional energy is required to operate this system makes it a matter of interest. With no additional energy, construction of this system is also simple and can be done by local materials. Operation and maintenance is simple compared to large conventional WWTP, gives good result and is cost effective.

With low capital cost, this system can be installed and used by various small communities, institutions and organizations. This will eventually help in environmental protection of the area. In Nepal constructed wetland is mainly used in small scale but its management is questionable. For example, constructed wetland WWTP of Kathmandu University stopped to operate shortly from its construction date. Sunga constructed wetland WWTP showed good efficiency in cleaning but many problems do exist in the system.

At the time of visit to Sunga constructed wetland WWTP, influent was not passing through the grit chamber because of accumulation of solid waste in the inlet. In this case the wastewater was directly being bypassed from the system to a nearby stream, which is used for irrigation purpose. The wastewater in the ABR was also detained for long period of time without any reason and when the water was passed through ABR to HFB, the flow rate was very high causing the wastewater to flow from the surface of the bed but not from inside the surface of the bed.

FIGURE 27. Sunga Constructed Wetland WWTP; (a) Caretaker cleaning the grit chamber; and (b) Over flow of wastewater from the top of HFB surface

Situation seen in FIGURE 27 (a) explains that only the wastewater entering the bed is being treated without any removal of scum but most of the wastewater is flowing to the nearby stream without any treatment. Situation that exists in FIGURE 27 (b) will settle the sludge of wastewater, flowing from top of the bed, in the surface of the bed causing more problems such as ponding effect of wastewater in the bed and sludge accumulation throughout the bed. Ponding occurs even due to saturation of bed materials. Ponding effect is the accumulation of wastewater in the top surface of the bed. Creating these situations frequently in the system will cause ponding and ponding effect was also observed in this system, see FIGURE 28.

FIGURE 28. Ponding effect in Sunga constructed wetland WWTP; (a) HFB; and (b) VFB

Constructed wetland in Kathmandu is a very important factor to protect natural water environment but its usage and maintenance has not been done wisely and properly. These systems are small scaled and definitely contribute for environment protection but the lack of awareness in the local people has created a challenge for this system also. Initiative shown by various organizations and institutions by installing this system is appreciable and increase in number of these systems throughout small communities and organizations will have a positive impact on the natural water environment of Kathmandu.

3.4 Alternative WWTP Technology for Kathmandu

Analysing the condition of one conventional and another DEWATS in Kathmandu assures that current condition is not enough to improve the wastewater management and natural environment protection of the valley. To overcome this scenario alternative method and models must be accompanied, both by the government and private sector. Activated sludge WWTP in Guheshwori consumes 2.3KW-hr/kg BOD with WWTP footprint of $51m^2$ to treat $0.19m^3$ of wastewater per second, this fact is crucial in city area where there is limited land and electricity.

Whereas constructed wetland WWTP is a good option but is only viable for small community. There are two factors that make constructed wetland WWTP less suitable for large scale operation, one of them is its life compared to other WWTP. This is a crucial factor because wastewater management need in Kathmandu is increasing with rapid production of wastewater and to address this issue sustainable life of the city must also be taken into account.

Secondly, the ratio of land usage and wastewater treated is not satisfactory because to treat huge amount of wastewater it requires huge amount of land too. To treat $10m^3/d$ of wastewater constructed wetland WWTP will require around $300m^2$ of land area for both HFB and VFB excluding ABR and storage tanks [5].

Limitation of constructed wetland WWTP also includes lack of development and design criteria according to different types of wastewater. Thus, it will be less scientific to use this system for treating huge amount of municipal wastewater, as the treatment capability of constructed wetland WWTP also depends upon seasonal variation which is not studied in detail till date. Thus to reconstruct the non-operating lagoons to constructed wetland WWTP as Bagmati Action Plan's proposal [13] in different parts of Kathmandu will not be a good option.

Moreover, constructed wetland WWTP was initiated due to uncertain future of activated sludge system of Guheshwori and expensiveness of similar kind of system to construct, operate and maintain but the initiated alternative has also not been successful due to lack of management and awareness about the wastewater and its impact in the environment. Constructed wetland WWTP are mainly constructed in institutional and community level where environment does not fall in their first priority, this situation has aroused due to lack of awareness and strong legislations.

Caretakers of constructed wetland WWTP thus do not take this initiative seriously which eventually leads to the failure of the system. Thus WWTP should be made under government in municipal level or in industries following strong legislations with proper kind of system and design as explained below.

3.4.1 Location and Purpose

More WWTP like of Guheshwori and other non-aerated lagoon WWTP are in need of development in Kathmandu Valley. However, in context of Nepal and due to different problems for smooth operation of these systems, as discussed in earlier chapters, this study proposes some possible alternative. The alternative can be located in the existing areas by replacing the old system, along with probable industries and large housing communities.

This proposed system can be located in urban area to treat communal as well as huge amount of municipal wastewater. Main purpose of this system will be to create quality effluent by using less land, minimum energy and less money.

3.4.2 Alternative WWTP

Alternative for WWTP will be the sequencing batch reactor (SBR). It is in use since 1920s and is a good option for municipal and industrial wastewater treatment. It follows the same process as activated sludge system but all the steps of activated sludge is combined in one basin, thus known as sequencing batch reactor. [21]

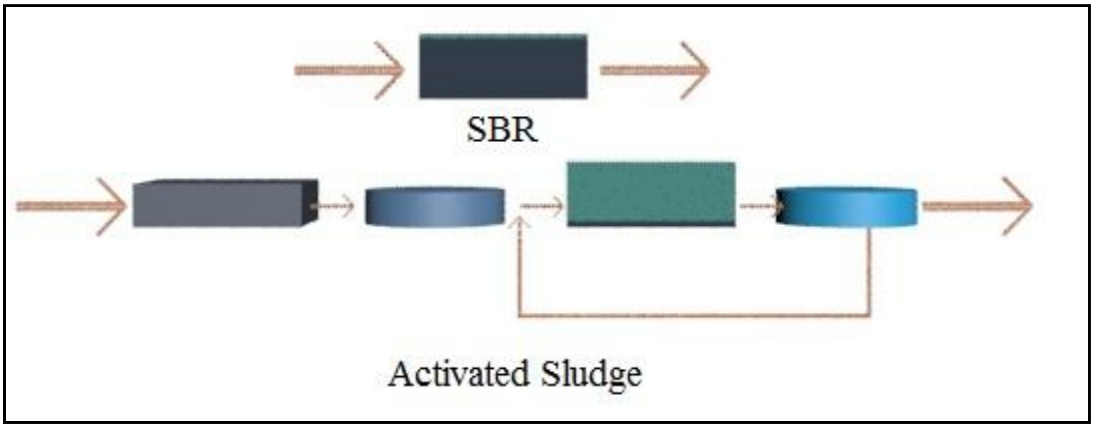


FIGURE 29. Comparison between space used by SBR and Activated Sludge Wastewater Treatment System

USEPA report of 1999 explains SBR as no more than an activated sludge plant that operates in time rather than space. Advantages of SBR over activated sludge system are:

- Uses less land space as treatment takes place in single basin with smaller footprint.
- Treatment cycle can be designed to undergo anaerobic, anoxic and aerobic process to remove organic matter and nutrient including nitrification-denitrification process in the same tank.
- Older wastewater treatment facilities can be converted to SBR as basins already exist to decrease energy consumption and operational complexity.

Process chart of SBR is shown in the FIGURE 30. All the phases presented in FIGURE 30 occur in same basin or tank.

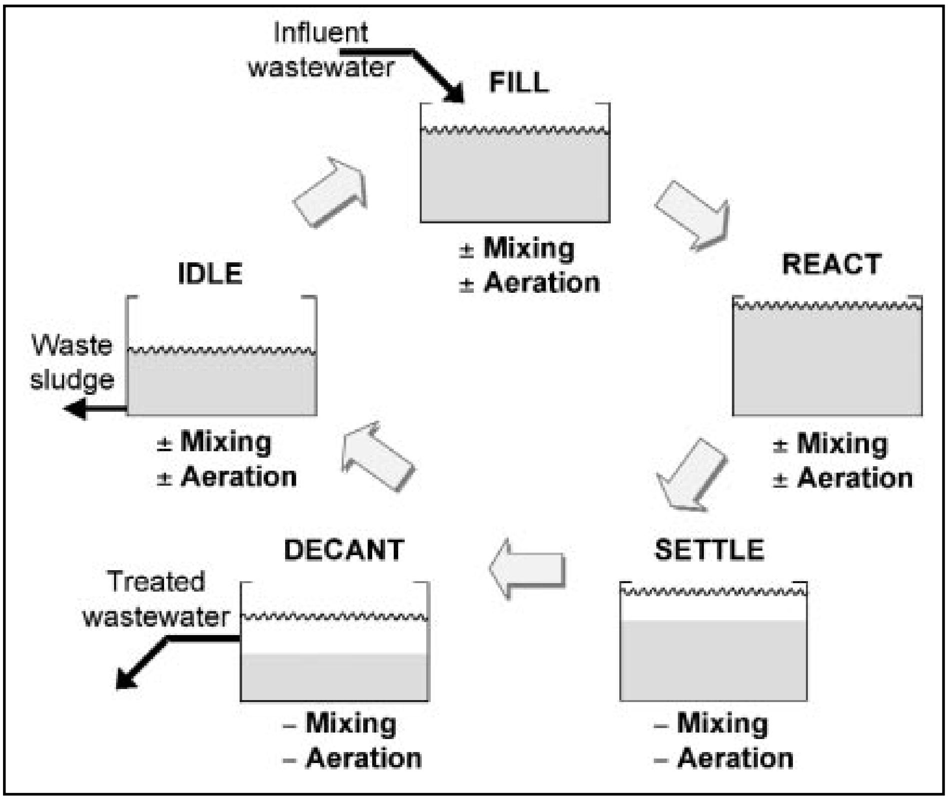


FIGURE 30. Major phases of SBR operational cycle occurring in same basin [21]

Detail explanation of all 5 phases and its occurrence in single basin is explained as follows.

Fill

In this stage, the basin receives influent. Existing microbes feed in the organic matter present in the influent and starts the biochemical reaction process. Fill phase can be **static fill**, where influent is drawn into the basin without any mechanical activities. **Mixed fill**, where influent is mixed thoroughly using mechanical mixer. This produces uniform blend of biomass and as aeration is not done, it creates anoxic environment that helps in denitrification. **Aerated fill**, where both aerators and mechanical mixers are active. This can be done to achieve nitrification and later aerators can be switched off to achieve denitrification. But out of these three processes, mixed fill is the preferred one if Guheshwori WWTP is to be retrofitted to SBR. [21]

React

In this phase no wastewater enters and aerators are switched on. As no volume of wastewater and organic loading is added, rate of organic degradation happens dramatically. Removal of BOD and nitrification occurs in this phase and released phosphorous at mixed filling phase is taken up. [21]

Settle

Activated sludge is allowed to settle under inert conditions as no influent is added nor aeration or mixing is provided. Sludge settles as flocculent mass and clear supernatant of wastewater is formed. [21]

Decant

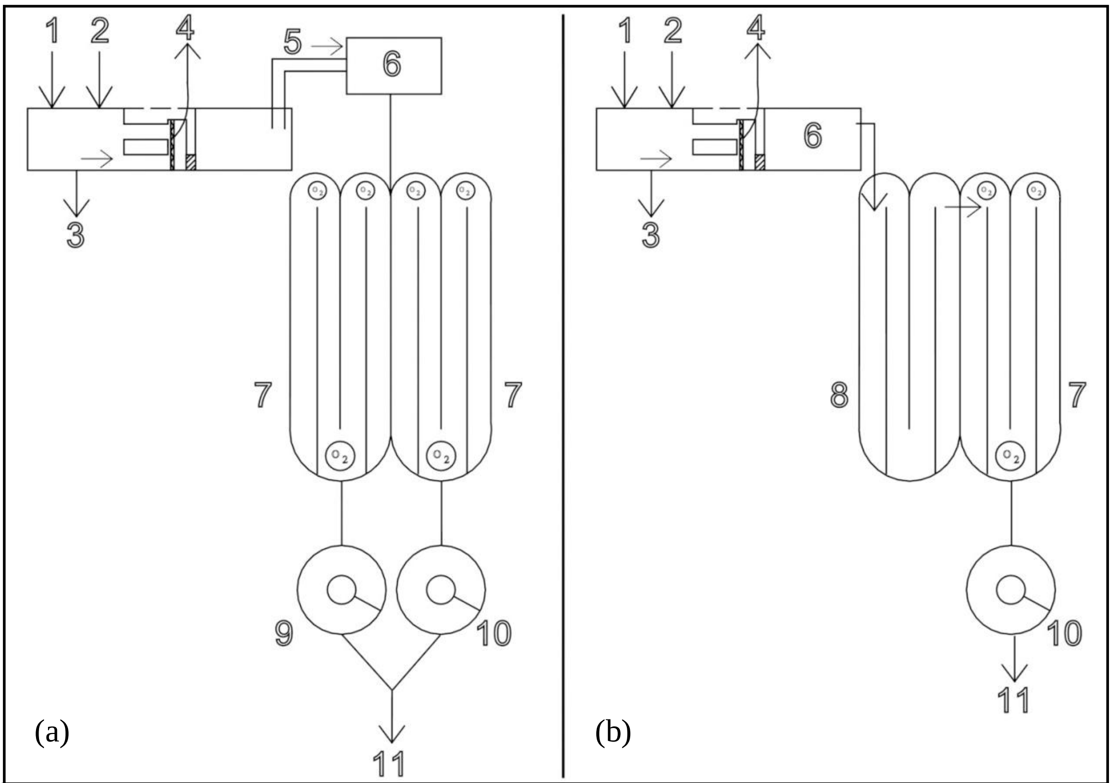
Clear supernatant is decanted in this phase. Several kinds of decanters can be used (see ***Decanting*** below) in this phase. Distance between decanter and sludge blanket must be maximized in order to prevent poorly settled solids to decant as effluent. [21]

Idle

Idle state of sludge is maintained between decant and fill phase. Time of idle state can vary based on influent flow rate. During this stage small amount of activated sludge at the bottom of the basin is pumped out, which is known as wasting. [21]

3.4.3 Design of SBR: As an Alternative

Development or restoration of Guheshwori WWTP as SBR is described below, see FIGURE 31, in comparison with its existing activated sludge design.



1, 2 – Influent; **3** – Bypass; **4** – Grab Screen; **5** – Pump; **6** – Grit Chamber; **7** – Oxidation ditch; **8** – Influent equalization tank; **9, 10** – Settling tank; **11** – Effluent and $\mathbf{O_2}$ – Aerator.

FIGURE 31. Guheshwori WWTP; (a) Bird's eye view of existing activated sludge design; and (b) Bird's eye view of proposed SBR design

From the above plan it can be observed that usage of space and energy can be minimized by converting the existing system to SBR in Guheshwori. All of the above mentioned phases in FIGURE 30 occur in basin 7 as seen in FIGURE 31 (b). Design specifications of each unit and its state in various stages are explained below.

Screening Influent

Grab screen will be used at first to remove unwanted large solid particles from the wastewater. By removing solid particles before the wastewater reaches the main basin will increase the efficiency of treatment process and the settling phase. This will also increase in high quality sludge as excess debris will not be present to interfere in the settling phase with the sludge. Screening will also protect pipes from corrosion. Screening in Guheshwori SBR WWTP will occur when influent passes through label 4 and 6. [21]

Influent-Flow Equalization

Flow of wastewater is not always constant and nor organic mass is constant. Influent flow equalization tank will help to overcome problems that might arise due to these factors. Performance of this tank will also improve nitrification and denitrification process. Size of this basin must be designed properly because oversized basin might cause negative downstream-treatment-process impacts. In Guheshwori, basin labelled as 8 in FIGURE 31 (b) will be influent flow equalization basin. Importance of influent flow equalization tank is listed below:

- SBR basin size can be minimized since influent flow equalization tank will provide space or storage;
- Scum and grease can be removed before entering SBR by fixing scum and grease removal system. This will eventually increase efficiency of the SBR;
- Allows equal flow volume into the SBR basin, keeping food to microbe ratio stable.

If SBR technology does not include influent flow equalization then it must use at least 2 SBR basins and supply of essential spare parts onsite will be compulsory. This will assist in repairing the damaged components of the plant and will not effect on treatment capacity of the plant. Mixing unit must be installed in this basin as it will suspend all the solids and will not let them to settle. Mixing will also separate scum and grease and SBR can work to its full efficiency. For maintenance this basin must have a provision of dewatering but as suspended solids are all piped to SBR, it should require less maintenance. This tank must be able to hold peak flows to ensure the treatment process to be completed in SBR basin. [21]

Alkalinity Addition

Alkalinity observance and addition must be initiated in every SBR WWTP. Addition of alkalinity should be done on the amount measured during the decant phase. Alkalinity maintained between 40-70 mg/L as $CaCO_3$ before the decant phase will ensure that nitrification cycle has completed. If alkalinity drop is not compensated by adding Sodium Bicarbonate then pH in SBR basin unit will drop and interrupt the wastewater treatment process. [21]

Basin Design

SBR technology with one influent-flow equalization basin and two SBR basins is optimal to get good efficiency, but in the case of Guheshwori one basin will be optimal as extra construction is not required due to the size of the basin. Two basins will increase the efficiency of working condition allowing for maintenance, high flows, seasonal variation and storage. If one basin is not working or is not in the state to work then other can compensate the treatment system. Also if the microbiology of one basin is depleted, the biomass from the other basin can be transferred and used to increase efficiency of both basins, for this internal piping must be arranged. [21]

In high flow conditions the wastewater is always diluted by rain and in this case "react" step from the treatment cycle can be shortened. Also "fill" and "idle" phase can be shortened in high flow conditions. In context of seasonal variation, when there is low flow of influent one basin can be taken off and energy can be saved throughout the time. This time can be utilized to clean the basin and when operation of both basin starts, biomass in the cleaned basin can be reseeded from the operating basin. [21]

In case of Guheshwori, basin 8 will be influent flow equalization tank and basin 7 will be SBR tank. Time taken to fill basin 7 with current flow rate of influent ($0.19m^3/s$) will be 7.6 hours, the same amount of influent can be stored in basin 8 and basin 7 can be emptied if needed and maintenance can be done before passing the influent from basin 8 to 7. At this moment, existing aerators in basin 7 can be operated and by decreasing the time of each phase the effluent can be bypassed through continuous flow system. This situation will not occur frequently thus, one basin will be enough for Guheshwori WWTP to conduct SBR wastewater treatment process. It is recommended that maintenance shall be done in rainy season when influent is diluted and one batch can be bypassed to the river with minimum time used in every phase.

Flow-Paced Batch Operation

There are two kinds of operation conditions, time-paced and flow-paced. In time-paced condition, each basin receives different volumetric loading and organic loading in every cycle. This decreases the treatment efficiency of the basin because after each loading the basin has to undergo the whole set of treatment conditions, this will make the job more difficult. [21]

In flow-paced batch operation, the plant receives the same volumetric loading and approximately the same organic loading during every cycle. The basin has already stabilized supernatant in idle phase before decantation, which dilutes the batch of incoming influent and increases efficiency as contamination level decreases. [21]

Aeration Design

One blower per basin is not preferred compared to several small blowers per basin. Several blowers will increase the operational efficiency of the system. In case of Guheshwori two to three blowers will be enough per basin and in diluted condition of the influent fewer blowers can be operated in order to save energy. As aeration is required only in “react” phase, the system can be designed in order to aerate when there is supply of electricity and at state of loadshedding “settle” and “decant” state can be operated. In this way, higher efficiency of treatment and energy can be obtained by converting activated sludge WWTP to SBR WWTP in Guheshwori. [21]

Decanting

Operating under flow-paced batch operation, no more than one-third of the volume contained in the basin should be decanted. This will prevent the sludge blanket to get disturbed and decrease the effluent quality. For optimal operation condition, the decanted volume must be equal to the volume added in fill phase. Length of decanter can have upward forces caused by the discharge of water that can pull the poorly settled solids out as effluent. [21]

Thus, proper decanter mentioned as below must be used:

- Fixed decanters including submerged outlets pipes with automated siphon control valves, and air-locked multiple pipe arrangements; or
- Moving devices including weir troughs, floating weirs and pipes connected to flexible couplings, titling weirs, and floating submersible pumps. [22]

Bottom Slope

Bottom slope in rectangular basins should be slightly sloped to one corner and in circular basins the mid part should be slightly sloped. This will help to empty the tank completely by fixing drain in that point. This will reduce time taken to clear the tank and start maintenance as well as cleansing process. [21]

Secondary clarifiers are existing structures in Guheshwori WWTP, thus it can be used or not used according to the situation. Above given design specifications of the SBR can be used to derive the conceptual design and working conditions of the system. However, detail study is recommended using the above given information as base before constructing the SBR.

Operation Condition in Guheshwori

Calculation of operation condition of Guheshwori WWTP as SBR is included in this part. Different parameters used for calculation is derived from Alvin C. Firmin's paper on Comparison of SBR and Continuous Flow Activated Sludge for Nutrient Removal [16] and Amanda Richard's thesis on Foaming at Guheshwori WWTP [4].

- Normal flow rate = 0.19m^3/s
- Capacity of two oxidation ditch = 10,400m^3, thus capacity of each oxidation ditch = 5,200m^3
- One oxidation ditch will be influent flow equalization tank and another will be SBR tank.
- Thus time taken to fill one oxidation ditch with normal flow rate = 7.6 hours.

According to Alvin C. Firmin, the batch time for SBR = 300minutes. Various phases of the batch period are shown in TABLE 6.

TABLE 6. Cycle time of different phases of SBR [16]

Phases of Batch	Batch Time
Mix Fill	23 minutes
React Fill	67 minutes
Total Fill Time	90 minutes
React	122 minutes

Total Aeration Time	(67 + 122) minutes = 189 minutes
Settle	28 minutes
Decant	45 minutes
Idle	15 minutes
Total Batch Time	300 minutes (5 hours)

When one basin with capacity of 5,200m^3 is transformed to influent flow equalization then,

- Total time taken to treat one batch of wastewater = 5 hours.
- In 5 hours, influent flow equalization tank will store = 3421m^3 of wastewater.
- In every 5 hours, the stored water at influent flow equalization tank can be passed to SBR basin for treatment.
- Then the same process of storage and treatment can be repeated as a cycle.

In rainy season, when the flow of wastewater increases to maximum 0.5m^3/s, the influent flow equalization tank will fill in 2.9 hours. In this case the batch period can be reduced to 2.9 hours, since the wastewater itself is diluted by rain.

- Average amount of oxygen transfer required for 3421m^3 (at normal flow condition) of wastewater in SBR is approximately 119 kg/hour.
- Current oxygen demand of existing plant of Guheshwori is 355 kg/hour.
- This demand is fulfilled by six 60HP blower aerators.
- Therefore aeration required in SBR to transfer 119 kg of oxygen/hour in Guheshwori can be fulfiiled by 2 aerators in 1 hour but as the aeration time is 2 hours the oxygen flow will be approximately 238 kg/hour in normal flow rate using 20HP, since this situation will occur in a batch basin the amount of oxygen will be more compared to that of continuous system increasing efficiency as more than required oxygen is transferred to the basin.
- Aeration can be done when there is supply of electricity and during power cut-offs other phases of SBR can be operated.

Benefit due to operation of SBR instead of activated sludge Guheshwori WWTP and construction of new SBR for conventional treatment of wastewater compared to DEWATS of constructed wetland WWTP can be observed in TABLE 7.

TABLE 7. Comparison of Guheshwori as proposed SBR with existing systems based on available secondary information

Parameter	**Guheshwori (Current)**	**Sunga constructed wetland WWTP**	**Guheshwori (SBR)**	**Remarks for SBR**
Influent Flow Rate	16416 m^3/day	10 m^3/day	16416 m^3/day	High flow rate than constructed wetland WWTP
Treatment Type	Continuous Flow	Continuous	Batch	One oxidation ditch used for influent flow equalization tank
Time for Treatment	24 hours	24 hours	5 hours/batch	3420m^3 wastewater treated per batch
BOD removal rate (in 2013)	79.18%	84.61%	97.4% [27]	High efficiency rate, shows the studied existing plants are not operating to its full capacity
COD removal rate (in 2013)	42.85%	95.73%	84% [28]	High efficiency rate than current plant of Guheshwori
TSS removal rate (in 2013)	58.84%	93.04%	93.6% [27]	High efficiency rate will improve turbidity and pollution condition of the effluent receiving river
Faecal coliform removal rate (in 2013)	23.52%	19.77%	96% [29]	Comparatively the best option to protect environment and farmers who use untreated and poorly treated wastewater for irrigation
Number of Blowers for Aeration	6	Not Applicable	2	Requires less energy
Time for Aeration	24 hours / day	Not Applicable	Approximately 10 hours/day (2 hours/batch)	Design of operation time of aerator can be designed according to power cut-offs
Required Horse Power for blowers	60	Not Applicable	20	Extra HP and Aerator can be utilized in other SBR (if constructed)
Usage of Electrical Energy	2.3 unit/kg BOD	None	0.77 unit/kg BOD	Economical Benefit
Land Area	5370000 m^2	400 m^2	3759000 m^2 (70% less than Continuous Flow)	Usage of less land area
Ratio of wastewater treated to amount of land	0.003 m^3 wastewater/m^2 land/day	0.025 m^3 wastewater/m^2 land/day	0.004 m^3 wastewater/m^2 land/day	Constructed wetland WWTP cannot operate in large scale and has low life span, SBR can be used to treat large amount of wastewater in less space compared to continuous

As the water level may vary, by treating only 3421m^3 wastewater in the basin, the blower aerator might not come in contact with the wastewater completely. For good contact between blower aerator and wastewater, either the height of blower aerator must be fixed or more amount of wastewater must be treated in the basin by changing all the above mentioned numbers. SBR are likely to be unique in each design, thus operating condition might differ from one SBR to another SBR. Operating condition is calculated with reference to the research conducted by Alvin C. Firmin on Comparison of SBR and Continuous Flow Activated Sludge for Nutrient Removal [16]. Thus above mentioned parameters should be analysed and calculated in detail with accordance with the present situation to find out accurate result. Due to limitation of time and cost, these two factors were not considered in this thesis.

In this same way, other non-operating WWTP can be transformed to SBR or new SBR can be constructed in Kathmandu. Operation of non-aerated lagoons at low energy has failed and environmental status is degrading. Thus to gain something by using negligible amount of energy is far from the reach of third country such as Nepal. Proper and suitable technology such as SBR must be used with good managerial approach. This system can be stated as a hybrid in case of energy consumption.

3.4.4 Potential Effect

Construction of SBR at municipal level will ensure proper management and usage of SBR will not be hampered by ongoing power cut-offs. Even in industries assigning responsible person for management of SBR will help, but in community level, lack of interest and awareness will hamper the SBR. Smooth operation even at power cut-off is the main advantage of SBR in context of Kathmandu. As main process occurs in the same basin via influent equalization tank, extra construction cost can be minimized. Energy consumption can be reduced by deciding the amount of aeration required in different situations. Footprint will decrease and operation flexibility and control will increase. One non-scientific factor in context of Nepal will also be that, if new technology is used people will have more interest on the subject and thus efficiency will increase.

Long term operation of the plant can be achieved as power cut-off and economical factor will not be a burden for the system. By creating specific environment such as, anoxic environment and maintaining alkalinity level in settle phase, proper nitrification and high quality effluent values can be achieved. While comparing with continuous flow activated sludge system, SBR is cost effective as primary and secondary clarifier along with return of activated sludge can be avoided. More than this, operation cost can be minimized by calibrating the use of aerators and with all these advantages environment protection can also be done. Constructed wetland WWTP has less lifespan and requires more space to treat the amount of wastewater compared to SBR. Thus with proper development of SBR in Kathmandu, the problem of wastewater management and river water degradation can be addressed.

4 CONCLUSION

Goal was to develop wastewater management but the situation is deteriorating continuously since past decade. This situation has decreased the aesthetic value of river water flowing through the core urban area of the city. River resources can be used for various recreational purposes and for mental peace where life is too fast to handle in city areas, but the city authorities are failing to incorporate the beauty of river in the historical city.

Drainage management was also the key issue because more than half of the city residents do not have access to drainage facility and it is contributing in river pollution. Although wastewater generated by the people with proper drainage facility is also directed towards river, proper drainage facility will help to collect wastewater easily and treat in the upcoming future. Condition of Bagmati River has worsened more than the last decade and number of WWTP is decreasing too.

Existing treatment plant in Guheshwori is in partially operating state due to power cut-off and its efficiency is not satisfactory at all. Chemical wastewaters from nearby industries are directed towards this plant and chemical contamination might have affected the biomass in the system to reduce efficiency. This fact can be observed from the high COD value in influent of Guheshwori WWTP. Several other factors such as foaming, ineffective removal of feathery particles and lack of proper monitoring and maintenance has hampered the system. Drastic increment in TSS value might have occurred due to lack of water in nearby areas. Water is not easily available thus flush per toilet visit might have not been done. Due to this reason high concentration of load flows with low amount of water causing TSS to increase dramatically, as shortage of water has started to hamper Kathmandu since last 5 years.

Treatment efficiency of Guheshwori WWTP has decreased since the past decade and this suggests that all dimensions affecting the efficiency of the system, including economical, technical, social and personal issues must be addressed. People fear that working with wastewater might not be seen as a good job in the society, thus interest is lacking and personal responsibility must also be understood for the betterment of environment. These four dimensions are also applicable for constructed wetland WWTP. Lack of awareness and interest has pushed this system to non-working state. An example can also be taken from Kathmandu University; the operation of constructed wetland WWTP was interrupted by local community people because they wanted to use raw wastewater in their agriculture field for better yield of crops.

Similarly, caretaker of Sunga constructed wetland WWTP was taking the plant lightly by bypassing most of the influent directly towards nearby stream because he had work at this home. Distance between his home and the plant was not more than 200 metres but still these kinds of managerial problems will arise in community level until and unless awareness has been spread. Due to good awareness level, community forests have succeeded in Nepal, but the same concept cannot be transformed to wastewater sector without proper awareness in communities. Treatment efficiency of Sunga constructed wetland WWTP has also decreased since 2010 but restoration can be done by the community with help of ENPHO. Wastewater overflowing from the top of HFB in Sunga constructed wetland WWTP was the saddest scene for the author realising that people who have resources are also not able to use it due to lack of education and awareness. This kind of activity will eventually collapse the plant and such capacity to protect environment will be lost.

Programmes at local level about wastewater and river protection are necessary in Kathmandu and new concept and model under municipality level must be started. Wastewater plants are highly engineered systems thus proper skilled person must take care of its operation and maintenance. For this SBR has come out as a good alternative in case of Kathmandu.

According to recent announcement of ADB Nepal Government is going to receive grant for development of 5 WWTP in Kathmandu to manage the existing problems of wastewater management and river environment protection. With this announcement new hope of wastewater development has aroused but management will be the most crucial factor along with technology. For this SBR technology will be a good option because developing such systems in municipal level will not only protect environment but it will also be an economically sound project along with good technology. Cost effectiveness, footprint and effluent standards are the main aspect of SBR to be considered and studied.

With development of proper WWTP the city rivers can breathe where restoration technology can be more beneficial. Designing the flow of river with help of check dams and barriers will also maintain the water quality as level of DO will increase and turbidity will decrease. This will remove the odour problem that exists in river water today. These check dams can be constructed under the bridge because, the concrete structure already exists and high flow in the river under the bridge will increase the landscape beauty of the area.

Five conventional WWTP according to the plan of ADB, industrial WWTP in industries and small scaled WWTP in interested communities and housing units can improve the water and wastewater environment of Kathmandu Valley.

5 RECOMMENDATION

Historical importance and natural beauty of Kathmandu is being lost by current wastewater management approach. For this situation to be improved certain recommendations, as mentioned below, might be helpful.

- Construction of small scaled activated sludge system such as of Guheshwori in different areas of Kathmandu, this system is familiar to the authorities thus approval of design and method won’t be a problem. Small manageable and efficient plants will ensure that even if one plant stops to operate then the river water quality won’t be hampered;
- Modification of existing activated sludge WWTP of Guheshwori to SBR and construction of new SBR WWTPs as discussed above in section 3.4;

- Restoration of river by constructing recreational parks throughout the river bank including constructed wetland WWTP in the park;
- Existing but not operating non-aerated and aerated lagoons in different part of Kathmandu (see FIGURE 1) can be used to recharge the ground water by collecting and depositing the storm water from nearby areas, this will help to protect the ground water depletion in Kathmandu;
- Fusing bio-gas plant with constructed wetland WWTP, this primary clarifier will increase the value of WWTP in communal level, as the formed gas can be used for cooking as well as for electricity;
- Proper awareness and education programmes must be spread along with training for caretakers to effectively operate constructed wetland WWTP;
- Selection of caretakers must be done based on the awareness and level of interest about the programme;
- Proper policy and legislations must be brought into action by law makers in order to address wastewater management issues in municipal, communal and industrial levels;
- Existing systems should not be neutralized, but it should be developed and proper model and technology according to the capacity and need of Kathmandu must be used;
- Organizations developing community based constructed wetland WWTP should assess and understand the situation and need of community in terms of their priority and suitability.
- Previous experiences and donor demand should be a secondary aspect to be considered while starting constructed wetland WWTP development project in a community. Proper attention must be given to cost benefits and payback period based on the volume of produced treated water which can be used for various purposes.

5.1 Future Works

This study can be expanded by concentrating on one particular thing to get more accurate results. For this, more data in particular interval of time should be collected. Further recommendation study can be:

- Detail study of design and operating condition to transform activated sludge Guheshwori WWTP to SBR;
- Health effect in workers and consumers due to usage of poorly treated wastewater and not treated wastewater in irrigation;
- Accumulation of heavy metals and pathogens in *Phragmites Karka* and its treatment characteristics by developing anti-microbial substances;
- Detail study of design and operating condition to construct 5 economically and environmentally feasible SBR to protect natural water environment as planned by the ADB in partnership with Nepal Government.

This study was limited to analysis of data on cost, human resources, secondary information and technical inputs. Also, this study used only Microsoft Excel for data analysis process. Thus, usage of well packaged system including database information on wastewater, more study of microbiological parameters, statistical analysis tools, different aspects of energy and updating cost will help to receive more accurate and expanded results.

BIBLIOGRAPHY

1. Shukla, Asutosh, Timilsina Raj, Uttam & Chandra Jha, Binod 2012. Wastewater Production, Treatment and Use in Nepal. PDF – document. http://www.ais.unwater.org/ais/pluginfile.php/232/mod_page/content/120/Nepal_CountryPaper.pdf. Referred 6.2.2013
2. Green, Hillary, Choon Poh, Saik & Richards, Amanda 2003. Wastewater Treatment in Kathmandu. Massachusetts Institute of Technology. Department of Civil and Environmental Engineering. Degree programme of Civil and Environmental Engineering. Master's Thesis. PDF-publication. http://web.mit.edu/watsan/Docs/Student%20Reports/Nepal/NepalGroupReport2003-Wastewater.pdf. Referred 8.2.2013.
3. Water and Wastewater Engineering. Activated sludge Process. WWW-published. http://nptel.iitm.ac.in/courses/Webcourse-contents/IIT-KANPUR/wasteWater/Lecture%2024.htm. Referred 27.2.2013.
4. Richards, Amanda 2002. Effects of Detergent Use on Water Quality in Kathmandu, Nepal. Massachusetts Institute of Technology. Department of Civil and Environmental Engineering. Degree programme of Civil and Environmental Engineering. Master's Thesis. PDF-publication. http://web.mit.edu/watsan/Docs/Student%20Theses/Nepal/Richards2003.pdf. Referred 26.2.2013.
5. Ellingsen, Mona 2010. Sustainability of a Decentralized Wastewater Treatment System in Kathmandu Valley, Nepal – Technical and Social Challenges. Norwegian University of Life Sciences. Department of Plant and Environmental Sciences. Master's Thesis. PDF-publication. http://brage.bibsys.no/umb/bitstream/URN:NBN:no-bibsys_brage_29201/1/MonaEllingsen.pdf. Referred 21.2.2013.
6. Akvopedia 2011. Anaerobic Baffled Reactor. WWW-published. http://www.akvo.org/wiki/index.php/Anaerobic_Baffled_Reactor. Referred 21.2.2013.
7. Asian Development Bank 2000. Pipeline Update Nepal. Country Assistance Plan (200-2002). Referred 3.12.2012.
8. High Powered Committee for Integrated Development of the Bagmati Civilization 2012. Guheshwori Wastewater treatment plant. WWW-pages. http://www.bagmati.gov.np/. Referred 27.2.2013.

9. Wateraid 2008. Decentalised wastewater management using constructed wetlands in Nepal. PDF-published. http://www.wateraid.org/~/media/Publications/decentralised-waste-water-management-constructed-wetlands-nepal.pdf. Referred 18.2.2013.
10. Pradhan, Bandana, Bajracharya, Rajan & Rajbhandari, Lokap 2005. Water Quality Classification Model in the Hindu Kush – Himalayan Region: The Bagmati River in Kathmandu Valley, Nepal. PDF – document. http://geoportal.icimod.org/UserFiles/Image/MethodsTools/bagmatiriver.pdf. Referred 13.3.2013.
11. Dahal, Bed Mani 2000. Restoring the Bagmati River. Kathmandu Post, Volume VIII, 104. PDF – document. http://www.ku.edu.np/env/pdf/BMD/Restoring%20the%20Bagmati%20river.pdf. Referred 18.3.2013.
12. BASP introduction information 2002.
13. Astra Development Network, GeoSpatial Systems & Innovative Solution Pvt. Ltd. 2008. Bagmati Action Plan. PDF – document. http://demo-menris.icimod.org/bagmati/BagmatiActionPlan/Bagmati%20Action%20Plan.pdf. Referred 21.2.2013.
14. Kadlec, R.H, & Wallace, S.D. 2009. Treatment wetlands. Second edition. Boca raton CRC Press.
15. Kim, Joon Young 2005. Bagmati River. WWW – published. http://commons.wikimedia.org/wiki/File:BagmatiRiver.JPG. Updated 4.11.2005. Referred 10.4.2013.
16. Firmin, Alvin. C. Comparison of SBR and Continuous Flow Activated Sludge for Nutrient Removal. PDF – published. http://www.ncsafewater.org/Pics/Training/AnnualConference/AC07TechnicalPapers/Wastewater/AC07WW_Tues0900_Firmin.pdf. Referred 3.4.2013.
17. His Majesty's Government of Nepal 1996. Department of Hydrology and Meteorology, Hydrology Division, Sediment and Water Quality Laboratory. Water Quality Data of Rivers of Kathmandu Valley 1992 - 1995.
18. ENPHO 2003. South Asian Trans-Boundary Water Quality Monitoring. Data of Bagmati River (Sundarighat) 2002.
19. Singh, S., Haberl, R, Moog, O., Shrestha, R.R., Shrestha, P. & Shrestha, R. 2009. Performance of an anaerobic baffled reactor and hybrid constructed wetland

treating high-strength wastewater in Nepal – A model for DEWATS. Ecological Engineering, 35 (5): 654 – 660.

20. Feachem, R.G, Bradley, D.J., Garelick, H. And Mara, D.D. 1983. Sanitation and Disease: Health Aspects of Excreta and Wastewater Management. PDF – document. http://www.clw.csiro.au/publications/technical97/trl-97.pdf. Referred 11.4.2013.
21. New England Interstate Water Pollution Control Commission 2005. Sequencing Batch Reactor Design and Operational Considerations. PDF – document. http://www.neiwpcc.org/neiwpcc_docs/sbr_manual.pdf. Referred 28.3.2013.
22. Slater, Nigel 2006. Sequencing Batch Reactors: Cost Effective Wastewater Treatment. PDF – document. https://awwoa.ab.ca/home/content/pdfs/Sequencing%20Batch%20Reactors.pdf. Referred 28.3.2013.
23. Paudel, Arjun. Environmental Management of the Bagmati River Basin. PDF – document. http://www.unep.ch/etu/publications/37)%20269%20to%20279.pdf. Referred 18.2.2013.
24. Kannel, Prakash, Raj, Lee, Seockheon, Kanel, Sushi, Raj & Khan, Siddhi, Pratap 2007. Chemometric application in classification and assessment of monitoring locations of an urban river system. Analutica Chimica Acta. Volume 582, Issue 2, 390 – 399.
25. ENPHO 2010. DEWATS in Nepal. DEWATS for Sunga Community, Sunga, Madhyapur, Thimi.
26. High Powered Committee for the Integrated Development of Bagmati Civilization 2013. Data of Guheshwori WWTP 2002, 2003 and 2012.
27. Kader, Amr.M. Abdel 2009. Comparison Study between Sequencing Batch Reactor And Conventional Activated Sludge By Using Simulation Mathematical Model. PDF – document. http://water-observatory.net/sources/iwtc2009/8-3.PDF. Referred 12.4.2013.
28. Classen, John. J. Alternative Natural Technologies Sequencing Batch Reactor Performance Verification. PDF – document. http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase2report05/cd,web%20files/sbr%20Final_Report_v3.1C.pdf. Referred 12.4.2013.
29. Ng, W.J., Sim, T.S., Ong, K.Y., Ramasamy, M & Tan, K.N. Fate of Coliforms and coliphages in the SBR. Referred 13.4.2013.

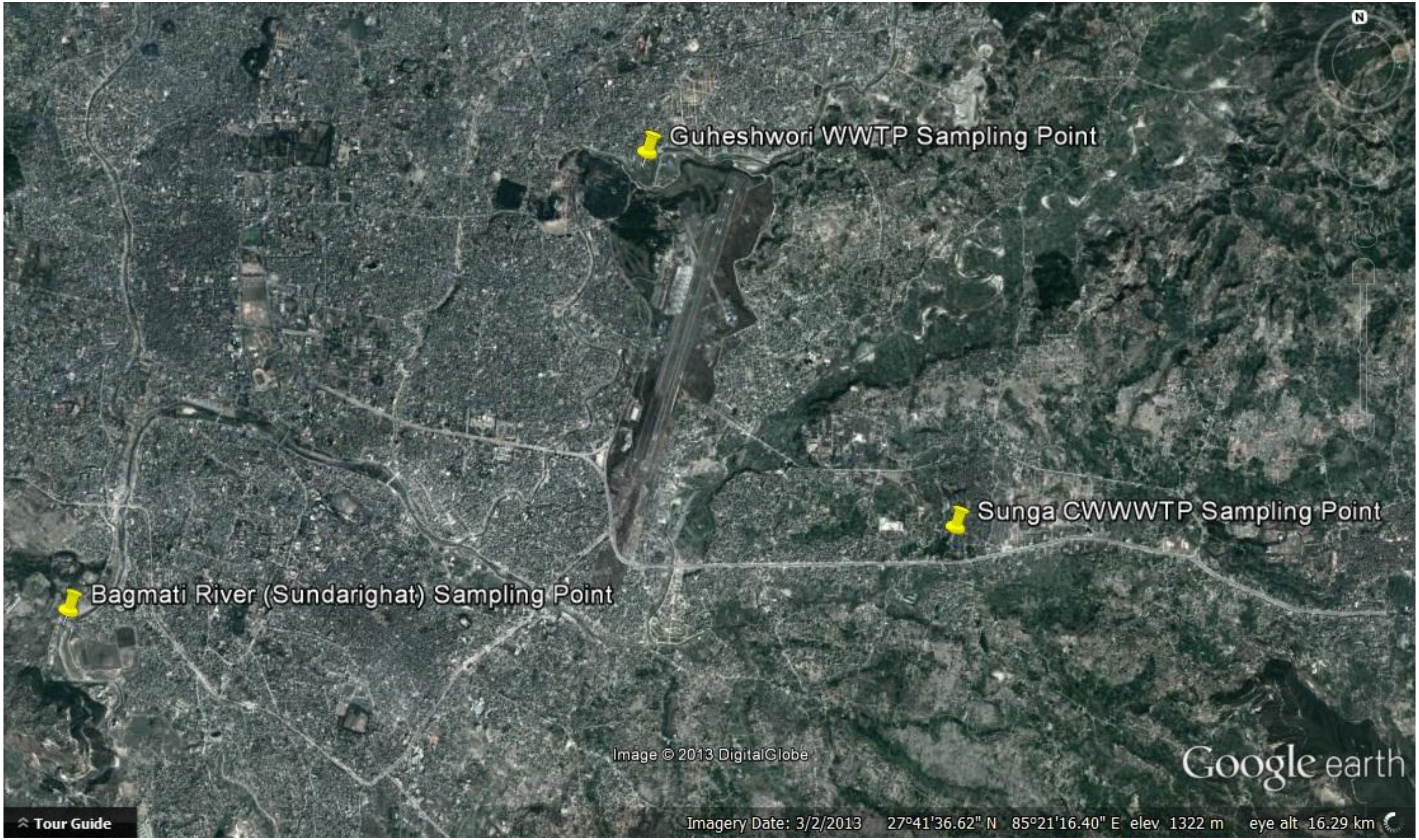


FIGURE 32. Satellite view of sampling points for the study

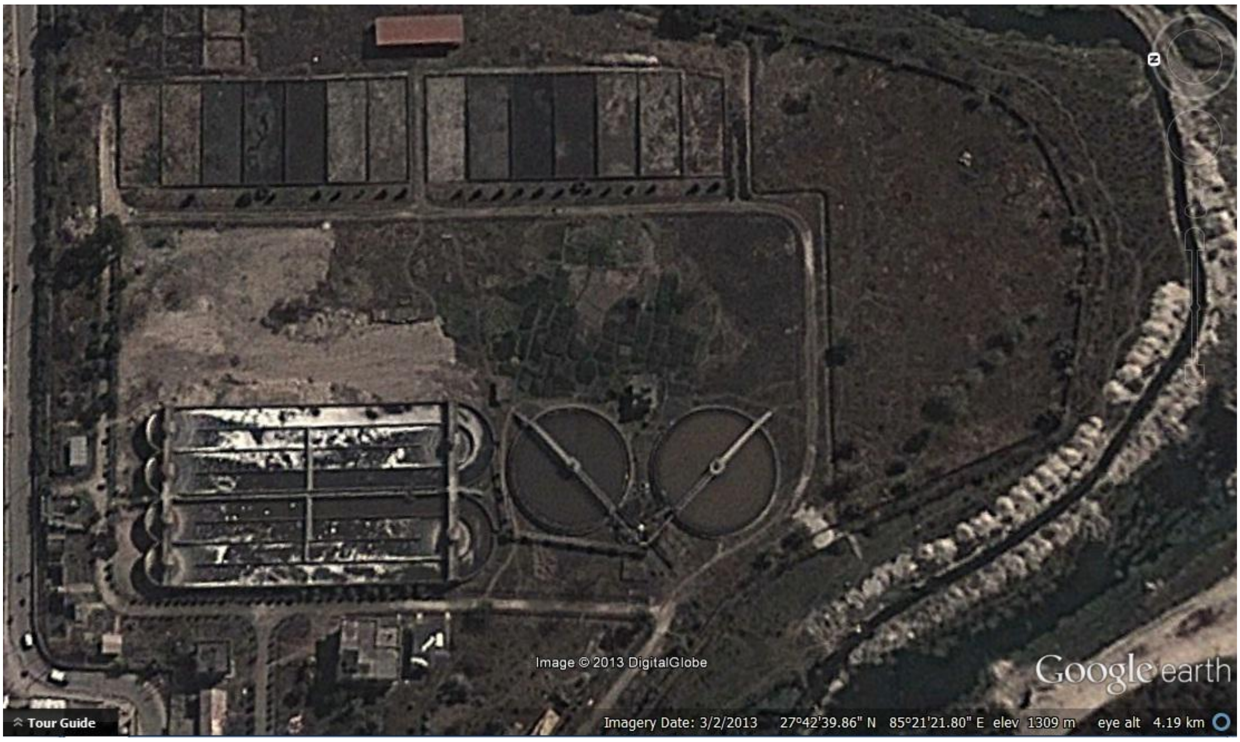


FIGURE 34. Satellite view of sampling point of Guheshwori WWTP

FIGURE 33. Satellite view of sampling point of Sunga constructed wetland WWTP (inside red circle)

FIGURE 35. Satellite view of Bagmati River (Sundarighat area) inside red circle

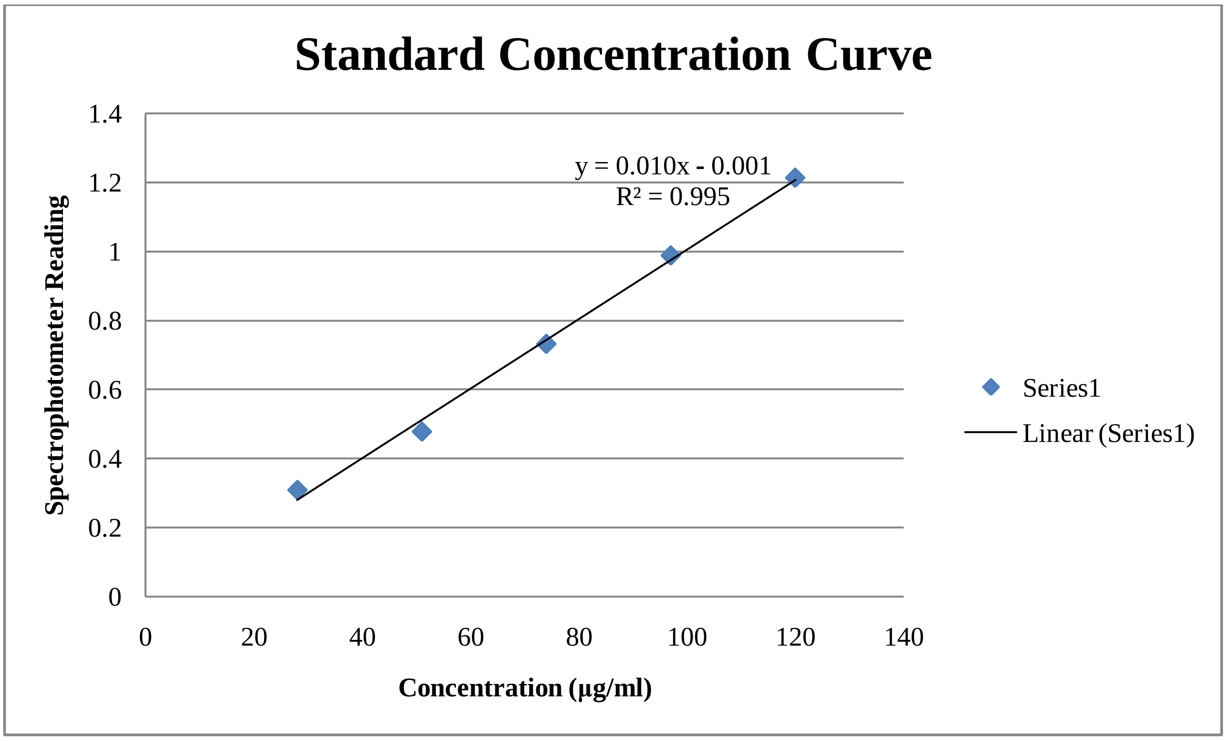


FIGURE 36. Standard Curve of Ammonia Nitrogen at 410nm, used to analyse value of ammonia nitrogen

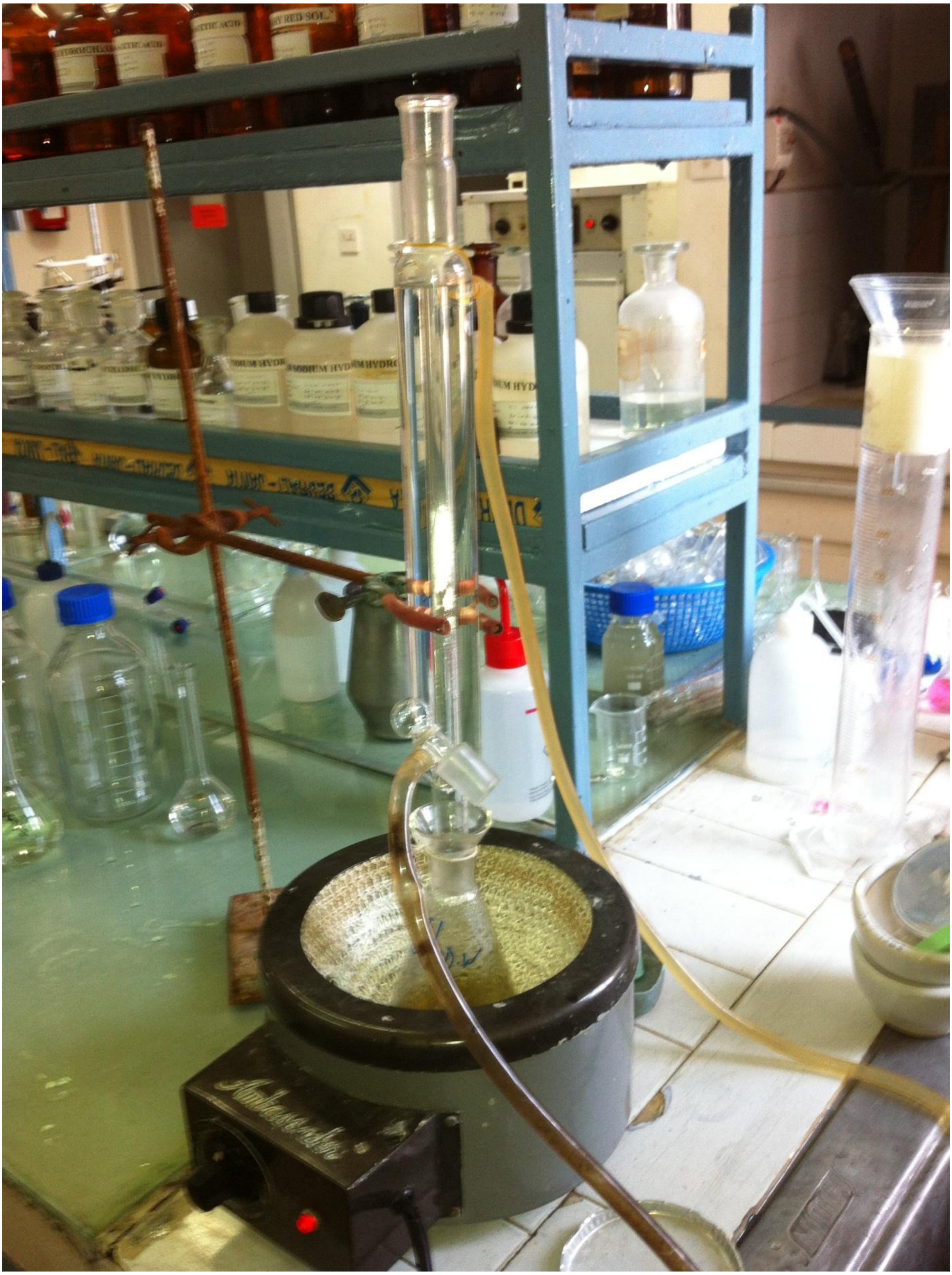


FIGURE 37. Ongoing Open Reflux method for COD test

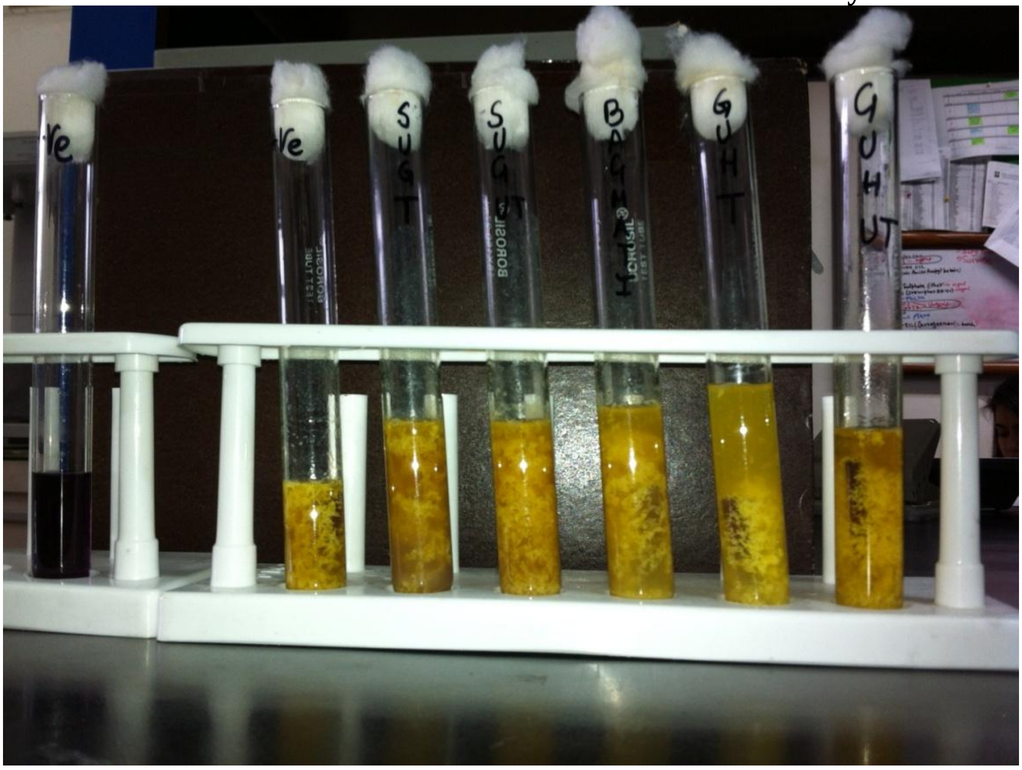


FIGURE 38. MacConkey Broth Test for *E.coli* validitation

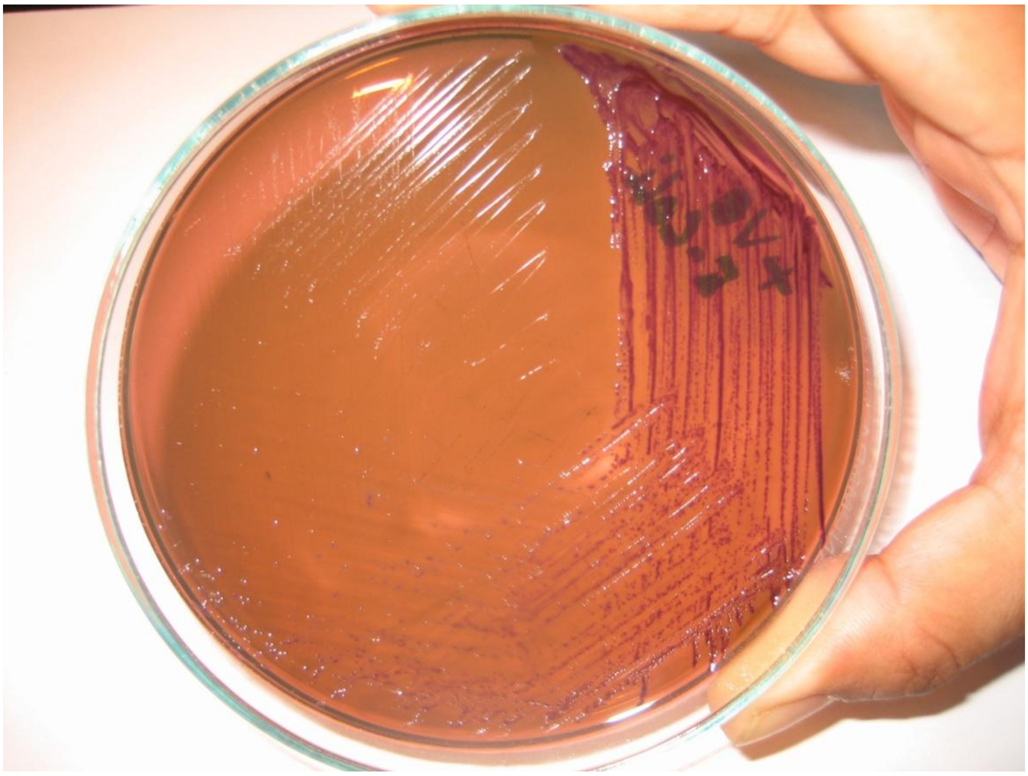


FIGURE 39. MacConkey Agar Test for further *E.coli* validitation

TABLE 8. Secondary and Primary Data of Guheshwori WWTP

	2002 April		2003 April		2012 April		2013 April		Effluent Standards		Reduction Efficiency (%)			
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Nepali	European	2002	2003	2012	2013
pH	N.O.	N.O.	N.O.	N.O.	N.O.	N.O.	6.89	7.44	N.A.	N.A.	N.O.	N.O.	N.O.	N.O.
NH_4 (mg/l)	52.82	43.97	N.O.	N.O.	57.8	46	140	130	N.A.	N.A.	16.75502	N.O.	20.41522491	7.142857
TSS (mg/l)	295	56	422	70	314.4	105.2	648	266.67	30	35	81.01695	83.4123223	66.5394402	58.84722
BOD (mg/l)	376	59.55	437	22	N.O.	N.O.	538	112	30	25	84.16223	94.9656751	N.O.	79.18216
COD (mg/l)	743.87	174.75	1069	135	1356.3	319	672	384	250	125	76.50799	87.3713751	76.48012976	42.85714
TDS (mg/l)	N.O.	N.O.	N.O.	N.O.	N.O.	N.O.	787	566	N.A.	N.A.	N.O.	N.O.	N.O.	28.08132
NO_3 (mg/l)	N.O.	N.O.	N.O.	N.O.	N.O.	N.O.	35	14	N.A.	N.A.	N.O.	N.O.	N.O.	60
DO	N.O.	N.O.	1.19	4.28	0.5	2.1	0.3	1.12	N.A.	N.A.	N.O.	-259.663866	-320	-273.333
Total organism count (cfu/100ml)	N.O.	N.O.	N.O.	N.O.	N.O.	N.O.	3.00E+08	2.00E+07	N.A.	N.A.	N.O.	N.O.	N.O.	93.33333
Faecal coliform count (cfu/100ml)	N.O.	N.O.	N.O.	N.O.	N.O.	N.O.	1.53E+04	1.17E+04	N.A.	N.A.	N.O.	N.O.	N.O.	23.52941
N.O. – Not observed & N.A – Not Available														

TABLE 9. Secondary and Primary Data of Sunga constructed wetland WWTP

	2010		2013		Effluent Standards		Removal Rate	
	Influent	Effluent	Influent	Effluent	Nepali	European	2010	2013
pH	8	7	8.15	7.9	Not Available	Not Available		
Ammonia Nitrogen (mg/l)	122	42	65	30	Not Available	Not Available	65.57377049	53.84615385
TSS (mg/l)	2810	58	2084	145	30	35	97.93594306	93.04222649
BOD (mg/l)	1489	179	1560	240	30	25	87.97850907	84.61538462
COD (mg/l)	3217	337	2624	112	250	125	89.52440162	95.73170732
TDS (mg/l)	Not Observed	Not Observed	473	335	Not Available	Not Available	Not Observed	29.17547569
Nitrate (mg/l)	20	350	7	90	Not Available	Not Available	-1650	-1185.714286
DO	Not Observed	Not Observed	0.4	1.63	Not Available	Not Available	Not Observed	-307.5
Total organism count/100ml	Not Observed	Not Observed	4.00E+07	1.00E+06	Not Available	Not Available	Not Observed	97.5
Faecal coliform count/100ml	1.60E+08	2.50E+07	2.63E+04	2.11E+04	Not Available	Not Available	84.375	19.77186312

TABLE 10. Infection dose and survival time of selected pathogens excreted from wastewater [20]

Microbial Type	Major disease(s)*	Concentration in wastewaters	Infectious dose**	Survival Time		
Viruses				In Soil	On crops	In Freshwater and sewage
Enteroviruses				<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Poliovirus	Poliomylitis			<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Enterovirus	Gastroenteritis, heart anomalies, meningitis			<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Echovirus	Gastroenteritis, heart anomalies, meningitis			<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Coxsackievirus	-			<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Hepatitis A virus ***	Hepatitis	Medium - High	Low	<100 but usually <20days	<60 but usually <15 days	<120 but usually <50 days
Adenovirus	Respiratory disease, conjunctivities			-	-	-
Reovirus	Not clear			-	-	-
Calicivirus	-			-	-	-
Norwalk agent	Gastroenteritis, diarrhoea, vomiting, fever			-	-	-
SSRV	Gastroenteritis			-	-	-
Rotavirus	Gastroenteritis			-	-	-
Astrovirus	Gastroenteritis			-	-	-
Bacteria						
Vibrio cholerae	Cholera		High	<70 but usually <20 days	<5 but usually <2 days	<30 but usually <10 days
Salmonella typhi	Tyohid, salmonellosis		High	<70 but usually <20 days	<30 but usually <15 days	<60 but usually <30 days
Escherichia Coli	Gastroenteritis	Medium - High	High	<70 but usually <20 days	<30 but usually <15 days	<60 but usually <30 days
Camplylobacter jejunei	Gastroenteritis		High	-	-	-
Shigella dysinterae	Dysentry		Low	-	-	-
Yersinia enterocoliticia	Yersiniosis		High	-	-	<30 but usually <10 days
Protozoa						
Giardia intestinals	Giardiasis		Low	-	-	-
Crptosporidium parvum	Diarrhoea, fever	Low - Medium	Low	-	-	-
Entamoeba histolytica	Amoebic dysentry		Low	<20 but usually <10 days	<10 but usually <2 days	<30 but usually <15 days
Helminths						
Ascaris lumbricodes	Ascariasis		Low	Many months	<60 but usually <30 days	Many months

Ancylostoma spp.		Low	Low	<90 but usually <30 days	<30 but usually <10 days	-
Trichuris trichiura	Trichuriasis		Low	Many months	<60 but usually <30 days	-
Strongiloides stercoralis	Strongloidasis		Low	-	-	-
* Listed pathogens are capable of causing other inections in some situations						
** Low indicates low amount of viral particles/cells/cysts/eggs required to cause infection, High indicates high amount or numbers to cause an infection						
*** Position of Hepatitis A virus in the enterovirus group is still to be confirmed						