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Temperature Variation Effect in Nutrient Removal by Constructed Wetland.

by

Binod Gnawali

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The undersigned certify that they have read, and recommended to the institute of engineering for acceptance, a thesis entitled **"Temperature Variation Effect in Nutrient Removal by Constructed Wetland"**, submitted by Mr. Binod Gnawali in partial fulfillment of the requirement for the degree of Master of Science in Environmental Engineering.

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ABSTRACT

Most of the water bodies nearby the cities are getting polluted due to untreated wastewater disposal. This problem is expected to increase in future due to rapid urbanization if suitable measures are not taken. In the developed countries, centralized wastewater treatment system is in practice but in the countries like Nepal such system are uneconomical and unsustainable. Constructed wetland is natural, low cost, environmentally friendly biological wastewater treatment system which resembles with natural wetland ecosystem.

Main objective of the study was to know the effect of change in ambient temperature on removal efficiency of constructed wetland. Study was carried out in the existing wetland of IOE. During the study, different parameters like NH_4-N, NO_3-N, NO_2-N, PO_4-P and BOD were analyzed. Removal efficiency of NH_4-N, NO_3-N, NO_2-N, PO_4-P and BOD during winter season, when average ambient temperature was 12.75^oC, was found to be 20.13, 11.51, 29.46, 27.03 and 48.57 percent respectively. Similarly, removal efficiency of NH_4-N, NO_3-N, NO_2-N, PO_4-P and BOD during summer season, when ambient temperature was 25.5^oC, was found to be 90.24, 40.36, 54.95, 53.22 and 68.42 percent respectively. In addition, reaction rate constant K_{T20} was found to be 0.166, 0.0646, 0.6793, 0.2586 d^{-1} and θ was found to be 0.83, 0.87, 0.93, and 0.94 for NH_4-N, NO_3-N, PO_4-P and BOD respectively.

Nitrogen and phosphorus are primary micronutrients for plant growth. During winter season, various biological activities like growth of plant and rhizome, microbial activity is very low, as a result of which removal of nitrogen and phosphorus was found to be low. As temperature rises, all the biological activities and number of new plants increase which results in increase in removal of nutrients.

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LIST OF ABBREVIATIONS

AN	-	Ammonia Nitrogen
BOD	-	Biological Oxygen Demand
COD	-	Chemical Oxygen Demand
Conc.	-	Concentrated
CW	-	Constructed Wetland
IOE	-	Institute of Engineering
JICA	-	Japan International Cooperation Agency
N	-	Nitrogen
N/L	-	Nitrogen per Liter
TKN	-	Total Kjeldal Nitrogen
TN	-	Total Nitrogen
%	-	Percentage
^{o}C	-	Degree Celsius
gm	-	gram
mg	-	milligram
mg/L	-	milligram per liter
ml	-	milliliter

CHAPTER I

1.0 INTRODUCTION

1.1 Background

The most of the water bodies in the nearby cities are getting polluted due to the discharge of untreated wastewater that lead to undesirable eutrophication of surface water, which is the most widespread problem to water environment quality around the world, resulting in serious algal blooms, oxygen depletion and bringing about widespread degradation of freshwater ecosystems. The problem is expected to increase due to rapid urbanization if suitable measures are not taken immediately to control and treat effluents. In the developing countries like Nepal, problem is unaddressed as the budget is focused to infrastructure development.

At present, the Bagmati River with its tributaries has been used as a dumping site for all types of wastes. The rich, cultural heritage along the river and the tributaries such as traditional monuments, ghats and temples, is slowly eroding. It is estimated that eighty percent domestic wastewater having BOD of 280 mg/L are discharged into watercourse without any treatment in Kathmandu Valley. The watercourses can take BOD load of 30-80 mg/L (Jha, 2005). This difference indicates that the water bodies in Kathmandu valley are highly contaminated and some parts of the river are biologically dead. The capacity of river to purity itself by means of interaction between biotic and abiotic characteristics (self-purification capacity) of the river has been slowly failing.

Generally in most of the developed countries conventional centralized wastewater treatment system is adopted which are physical, chemical and biological processes that accomplish wastewater treatment. Conventional processes are supported by natural components such as microbial organisms, but in a complex array of energy-intensive mechanical equipment. Financially these plants are very expensive as they require large land area, huge RCC or steel infrastructure, complex electro-mechanical equipment system, huge energy to operate that system and highly skilled manpower. In context of Nepal, it is even difficult to operate continuously in the metropolitan due to lack of continuous supply of electricity. Kathmandu valley consists of five centralized wastewater treatment plants and over twenty decentralized wastewater treatment plants. Out of these, all centralized treatment plants are not in operation due to their design and capacity (Regmi, 2013). Constructed wetlands may become ideal alternative technology, which is simpler, economic and environment friendly. The concept of constructed wetland has been learned from the natural wetlands of our earth.

Constructed wetlands are natural, low cost, environmentally friendly biological wastewater treatment system. The process resembles with natural wetland ecosystem and forms a potential alternative for the treatment of wastewater that can be employed both in developed and developing countries. Constructed wetland system is in operation in various European countries and America from last three decades. In Nepal also, there is growing interest towards it for researchers and small communities.

The constructed wetlands (CWs) for wastewater treatment, also known as treatment wetlands, are engineered systems designed and constructed to utilize natural processes and remove pollutants from contaminated water within a more controlled environment. These systems are robust, have low external energy requirements, and are easy to operate and maintain, which makes them suitable for decentralized wastewater treatment in the areas that do not have public sewage systems or that are economically underdeveloped. At the early stage of CW development, the application of CWs was mainly used for the treatment of traditional tertiary and secondary domestic/municipal wastewater and was often dominated by free-water-surface CWs in North America and horizontal subsurface-flow (HSSF) CWs in Europe and Australia (Wu *et al*., 2014).

Basically there are two types of constructed wetlands: surface flow and subsurface flow. Surface flow wetlands resembles to natural wetlands, where shallow depth wastewater (usually less than 60cm deep) flows over the saturated soil as substrate media. Whereas subsurface flow wetlands mostly use gravel as the main media to support the growth of plants; wastewater flows vertically or horizontally through the substrate where it comes into contact with microorganisms, living on the surfaces of plant roots and substrate, allowing pollutant removal from the bulk liquid (Saeed and Sun, 2012).

Subsurface flow constructed wetlands are further divided into two groups:

(1) Horizontal flow (HF)

In horizontal flow constructed wetland wastewater is fed-in at the inlet and flow slowly through the porous substrate under the surface of the bed in a more or less horizontal path until it reaches the outlet zone as shown in Figure 1.1. During the passage of wastewater through the substrate, the wastewater will be in contact with various oxidation zones like aerobic, anoxic and anaerobic. When wastewater passes through the rhizosphere, it is cleaned by microbiological degradation and by physical and chemical processes (UN-HABITAT, 2008).

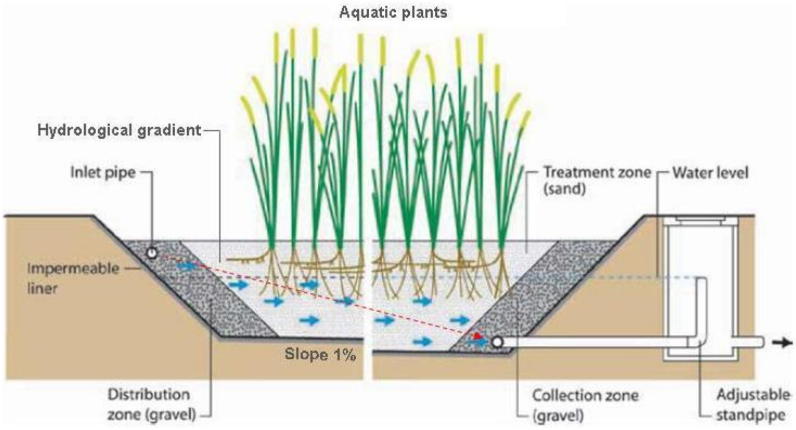

Figure 1.1: Horizontal flow constructed wetland

(2) Vertical flow (VF)

Basically, vertical flow constructed wetland consists of flat bed with sand/ gravel and vegetation. Wastewater is fed intermittently from the top and then gradually percolates down through the bed and is collected by a drainage network at the base as shown in Figure 1.2. Main reason of intermittent loading is good oxygen transfer to the substrate as compared to oxygen transfer through plant. Due to much oxygen transfer capacity, the latest generation of constructed wetlands has been developed as vertical flow system with intermittent loading (UN-HABITAT, 2008).

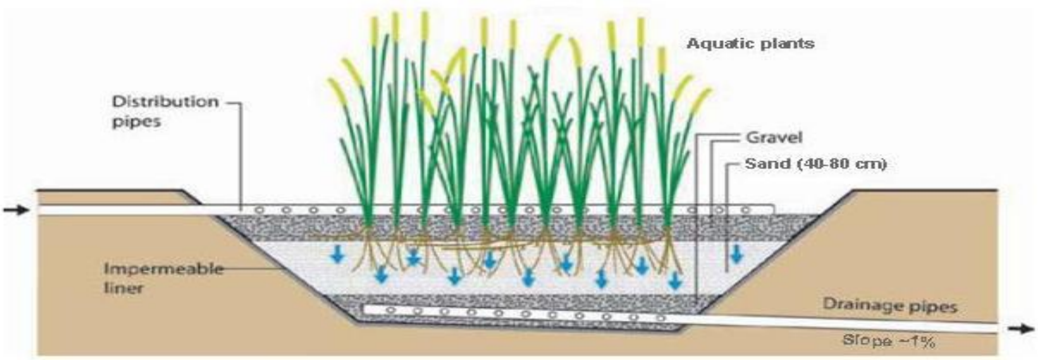

Figure 1.2: Vertical flow constructed wetland

1.2 Pollutant Removal Mechanism in Constructed Wetland

Constructed wetlands are effective for the treatment of BOD, TSS, N and P as well as for reducing metals, organic pollutants and pathogens. In constructed wetland, a pollutant is removed as a result of more than one process. The major pollutant removal process in constructed wetlands is biological as well as physico-chemical. Microbial metabolic activity and plant uptake are major biological processes and sedimentation, adsorption and precipitation at the water-sediment, root-sediment and plant-water interface are major physico-chemical processes. Soluble and colloidal biodegradable organic matter in wastewater is removed as a result of microbial degradation. Biodegradation occurs when dissolved organic matter is carried into the biofilms that attached on submerged plant stems, root systems and surrounding soil or media by diffusion process. Suspended solids are removed by filtration and gravitational settlement (Hua, 2003).

1.3 Wetland Organisms

Constructed wetlands provide a suitable environment for the growth of organisms like bacteria, fungi and algae. As a result of combined action of these organism pollutants of wastewater get break down which is called biodegradation. Among these microorganisms, presence of bacteria is highly significant because bacteria acts as catalysts for pollutant removal in subsurface flow constructed wetland. Unicellular prokaryotic bacteria can be classified according to their metabolic requirements.

Heterotrophic bacteria use organic carbon for the formation of cell tissue whereas autotrophic bacteria use carbon from CO_2. Organisms that use light as their energy source are referred as phototrophic bacteria, and can be either heterotrophic or autotrophic. Organisms that utilize energy from chemical reactions are known as chemotrophs, and can be either heterotrophic or autotrophic. The respiration process of bacteria is carried out in presence or absence of oxygen. Aerobic respiration is the process that utilizes oxygen as the terminal electron acceptor, and carbohydrates are decomposed to CO_2, water, and energy. Anaerobic respiration occurs in absence of oxygen. A wider range of anaerobic bacteria exist in treatment of wastewater in constructed wetlands, promoting different biodegradation routes. Pseudomonas and Bacillus employ NO_3-N as final electron acceptor, producing NO_2-N, N_2O or nitrogen (N_2) gas. Desulfovibrio bacteria utilize sulphate as the final electron acceptor, producing H_2S. Methanobacterium use carbonate to form methane (Saeed & Sun, 2012).

1.4 Rationale of the Study

Pollutant removal by constructed wetland is affected by various factors like HRT, Hydraulic Loading Rate, Filter media, Plant species and atmospheric temperature. All the pollutant removal mechanisms are directly and indirectly dependent on temperature.

BOD: In U.S. and Europe, most of the existing systems were designed as an attached growth biological reactor using a first order plug flow model. USEPA proposed the first order plug flow kinetics in the case of BOD_5 removal as expressed in Eq. 1.1.

$$A_s = \frac{Q[ln \frac{C_O}{C_e}]}{K_T dn} \qquad \text{... Eq.1.1}$$

Where,

A_s	=	bed surface area, m^2
Q	=	average flow through the bed, m^3/d
C_o	=	influent BOD_5, mg/L
C_e	=	effluent BOD_5, mg/L
K_T	=	reaction rate constant at temperature T, d^{-1}
n	=	effective porosity of media % as a decimal
d	=	average depth of liquid in bed, m

Nitrogen Removal: Classical nitrogen removal route in constructed wetland is biological nitrification followed by denitrification. First order kinetics for ammonia removal can be expressed as in Eq.1.2.

$$A_s = \frac{Q[ln \frac{NH_O}{NH_e}]}{K_T dn} \qquad \text{... Eq.1.2}$$

Where,

A_s	=	bed surface area, m^2
Q	=	average flow through the bed, m^3/d
NH_o	=	influent ammonia, mg/L
NH_e	=	effluent ammonia, mg/L
K_T	=	reaction rate constant at temperature T, d^{-1}

n	=	effective porosity of media % as a decimal
d	=	average depth of liquid in bed, m

Though the kinetics of other parameters is not available, temperature affects directly or indirectly on them. Temperature not only affects on microbial activity but also on the growth characteristics of plant. In winter season, number of plant in wetland was not so dense. As summer starts, new plant started to grow. Increase in number of plant also increases the uptake of pollutants.

In Kathmandu, variation of temperature occurs from 0 to 35^{o}C in a year. So, the performance of constructed wetland also changes accordingly with temperature. As a result, the applications of constructed wetlands are restricted in some regions with wide range of temperature change, such as in high altitude. Since temperature exerts a strong influence on the wetland performance, it is important to study the processes of temperature affecting the chemical and biological processes in constructed wetlands.

1.5 Objective of the Study

The main objective of the study was to know the variation pattern of nutrient removal with respect to temperature. Other specific objectives are:

- to determine the removal rate constants of different pollutants like N, P and BOD.
- to compare the efficiency of constructed wetland for the removal of different pollutants.

1.6 Limitations of the Study

Limitations of the study are:

a) Flow was considered to be continuous and constant throughout the study period.
b) Variation of temperature throughout the day is not considered; only average daily temperature was taken.
c) Effect of variation of organic loading rate was not considered.
d) Change in condition of filter media was not considered.

1.7 Organization of the Report

The report is divided into five chapters.

a) Chapter I: Introduction- Introduction includes brief background about constructed wetland and wastewater treatment, rationale of the study, objectives of the study and limitations of the study.
b) Chapter II: Literature Review- This chapter deals with the brief literature review relating to the area of the study.
c) Chapter III: Methodology- This chapter includes the detail about the methodology followed to perform the study.
d) Chapter IV: Results and Discussions- This chapter shows the results obtained during the study period.
e) Chapter V: Conclusions and Recommendations – This chapter contains all conclusions and recommendations regarding the whole study so that it will help for future research and study of same nature.

The Annex contains sampling data, sampling methods, tables, computations and outputs.

CHAPTER II

2.0 LITERATURE REVIEW

2.1 Mechanism of Nutrient Removal in Constructed Wetland

2.1.1 BOD removal mechanism

The physical removal of BOD_5 is believed to occur rapidly through settling and entrapment of particulate matter in the void spaces in the gravel or rock media. Soluble BOD_5 is removed by the microbial growth on the media surfaces and attached to the plant roots and rhizomes penetrating the bed. Some oxygen is believed to be available at microsites on the surfaces of the plant roots, but the remainder of the bed can be expected to be anaerobic (USEPA, 1993).

The major oxygen source for the subsurface components is the oxygen transmitted by the vegetation to the root zone. In most cases the subsurface flow system is designed to maintain flow below the surface of the bed, so there can be very little direct atmospheric re-aeration. The selection of plant species is therefore an important factor. Removal of BOD_5 in subsurface flow systems can be described with first order plug-flow kinetics, as described in Eq. 2.1 (USEPA, 1993):

$$\frac{C_e}{C_o} = \exp(-K_T t) \qquad \text{...Eq.2.1}$$

Where,

C_e = effluent BOD_5, mg/L

C_o = influent BOD_5, mg/L

K_T = reaction rate constant at temperature T, d^{-1}

t = HRT, d

K_T = $K_{20} (1.06)^{(T-20)}$

K_{20} = 1.104 d^{-1}

T = temperature, ^oC

2.1.2 Nitrogen removal mechanism

In wastewater, ammonia nitrogen plays the dominant role over other forms of nitrogen. As in BOD, for subsurface flow constructed wetland, removal of ammonia nitrogen can be described by first order plug-flow reaction as described in Eq. 2.2 (Jing and Lin, 2004).

$$\frac{C_e}{C_o} = \exp(-K_T t) \qquad \text{...Eq.2.2}$$

Where,

C_e	=	effluent ammonia nitrogen concentration, mg/L
C_o	=	influent ammonia nitrogen concentration, mg/L
K_T	=	reaction rate constant at temperature T, d^{-1}
t	=	HRT, d
K_T	=	$K_{T20} \times \theta^{(T-20)}$
K_{T20}	=	volumetric removal rate constant at 20^oC, d^{-1}
T	=	temperature, ^oC

Classic nitrogen removal route

In wastewater, nitrogen can exist as Ammonia Nitrogen (NH_3 and NH_4^+), organic Nitrogen and oxidised Nitrogen (NO_2^- and NO_3^-). Removal of nitrogen in constructed wetland takes place as a result of ammonification, nitrification, denitrification, biomass assimilation, dissimilatory nitrate reduction, plant uptake, ammonia volatilization and adsorption (Saeed and Sun, 2012). The majority of Nitrogen removal route is through either plant uptake or denitrifcation. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system.

Atmospheric oxygen diffuses into the rhizosphere throught the route of leaves, steam, rhizomes and finally to the roots of the plants and create the aerobic zone at root-soil interface. Nitrogen transformation takes place mainly in four locations namely oxidised and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonifcation takes place in both oxidised and reduced layers where organic nitrogen is mineralized to ammonia nitrogen. The oxidised layer and the submerged portions of plants are important sites for nitrifcation in which Ammonia Nitrogen is converted to nitrite N by the Nitrosomonas bacteria and eventually to nitrate N by the Nitrobacter bacteria which is either taken up by the plants or diffuses into the reduced zone where it is converted to N_2 and N_2O by the denitrification process. Detail of the process is presented in Figure 2.1.

Denitrification is the permanent removal nitrogen. The process of denitrification is affected by number of factors like temperature, pH, redox potential, carbon availability and nitrate availability. Actual measurement of denitrification can be done with the help of nitrogen mass balance approach (Hua *et al*., 2003).

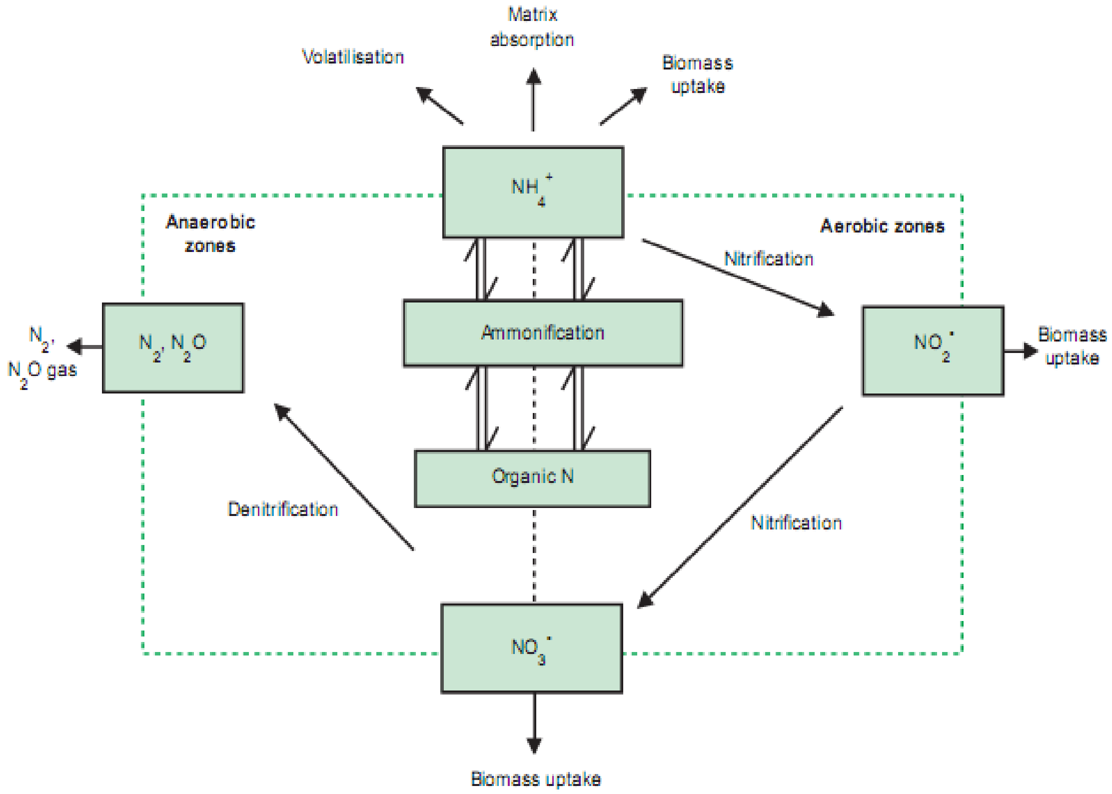

Figure 2.1 Nitrogen transformations in constructed wetland

Modern nitrogen removal routes

New but interesting nitrogen removal routes discovered in wetland systems include partial nitrification-denitrification, anammox, and canon process.

Partial nitrification-denitrification:

Nitrogen removal through partial nitrification-denitrification process includes conversion of NH_4-N to NO_2-N, followed by denitrification of NO_2-N to N_2 gas as in Eq. 2.2 and Eq. 2.3.

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad \text{...Eq.2.2}$$

$$NO_2^- + \frac{1}{2}CH_3OH + H^+ \rightarrow \frac{1}{2}N_2 + \frac{1}{2}CO_2 + 1.5H_2O \quad \text{...Eq.2.3}$$

Anammox:

Amamox is short form of anaerobic ammonium oxidation. It is a newly discovered nitrogen removal process, where ammonium is directly oxidized to nitrogen gas by nitrite in the presence of *planctomycete* bacteria group under anaerobic conditions.

Advantages of Anammox process over conventional process are: (a) no requirement of external carbon sources; (b) lower oxygen demand; and (c) low energy consumption. There are various factors that affect the annamox process. One of the major factors is temperature and optimum temperature is 30-37^{o}C. Figure 2.2 illustrates the classical as well as recently discovered nitrogen removal route.

Canon:

Canon is short form of completely autotrophic nitrite removal over nitrate. The main principle of this process is dependent on the mutual co-existence of aerobic ammonium oxidizers, and anaerobic Anammox bacteria in single reactor. This can be established under oxygen limited conditions to avoid inhibition of Anammox bacteria development, and to achieve appropriate conditions for partial nitrification (Saeed and Sun, 2012).

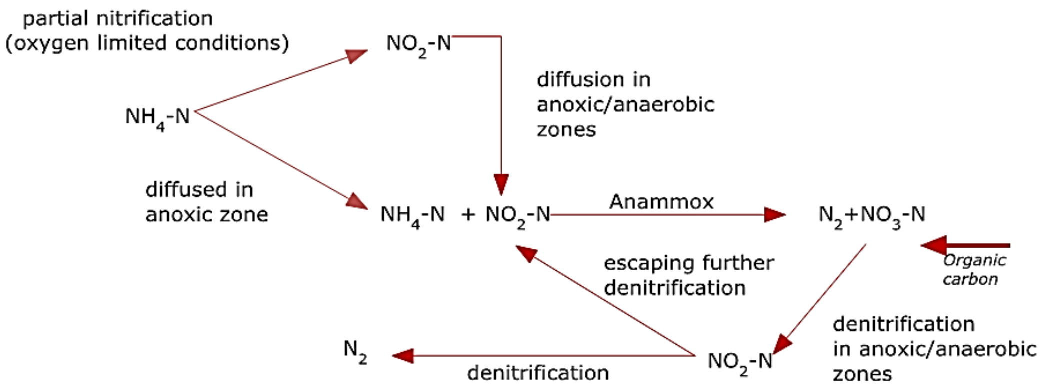

Figure 2.2: Nitrogen removal via anammox and denitrification process

2.1.3 Phosphorus removal mechanism

In wastewater phosphorus is found as Orthophosphate, Dehydrated Orthophosphate (Polyphosphate) and Organic Phosphorus. The conversion of most Phosphorus to the Orthophosphate forms ($H_2PO_4^-$,PO_4^{2-}, PO_4^{3-}) is caused by biological oxidation. Most of the Phosphorus component may fix within the soil media. Phosphate removal is achieved by physical-chemical processes, by adsorption, complexation and precipitation reactions involving Calcium (Ca), Iron (Fe) and Aluminum (Al). The removal of Phosphorus is more dependent on biomass uptake in constructed wetland systems with subsequent harvesting (Hua, 2003).

2.2 Effect of Temperature on Nutrient Removal

Constructed Wetland is a favorable technique for removal of excess nutrients and certain pollutants from wastewater. This technique utilizes natural resources including wetland vegetation, soil, substrate and their associated microbial assemblages to assist in treating wastewater. Various researches have been carried out regarding the effect of temperature on the performance of constructed wetland. Some of the selected literatures related to my study are mentioned below.

Jing and Lin (2004) in the research to measure the variation of ammonia nitrogen in the river water of southern Taiwan found that the concentrations of ammonia nitrogen in the Erh-Ren River varied from less than 1mg N/L to around 26 mg N/L. The concentrations were low in the warm seasons and high in the cold seasons; an apparent opposite relationship between ammonia nitrogen concentrations and water temperature were observed. They found that effluent concentrations of ammonia nitrogen from constructed wetland and control experiment system followed similar trend and cyclic variation with season.

Akratos and Tsihrintzis (2007) also did the similar research to measure the removal efficiency of CW with respect to temperature and other parameters. In the research they found that generally for all pollutants, lower removal efficiencies correspond to lower temperatures and the opposite. For the removal of BOD and COD, dependency of temperature is not so significant in comparison to nitrogen. From their study, they found that the removal of the organic matter is mostly as a result of the microbial activity of aerobic and anaerobic bacteria. Temperature of wastewater inside the porous media during winter season is always higher by 2–3°C than air temperature that allows the continue functioning of microbial activity. Dependency of temperature for the removal of TKN and ammonia is much significant because plant uptake plays a significant role on nitrogen removal and the microorganisms responsible for nitrogen removal function optimally in temperatures above 15°C. Phosphorus removal also shows dependence on temperature.

Atmospheric temperature and nutrient removal are directly proportional to each other. At lower atmospheric temperature, wetland plants become less active and the less ammonia nitrogen and nitrate nitrogen are absorbed. On the other hand, temperature also has great influence on microbial activity. Low temperature is unfavorable for development and metabolism of bacteria. Microbial nitrification is also controlled at low temperature. Huang *et al.* (2013) in their research found that with change in average atmosphere temperature, the rates of reduction in total nitrogen and ammonia nitrogen concentrations in the effluent from the constructed wetlands also changed. During winter and late autumn when the average atmosphere temperature was below 10°C, total nitrogen reduction was below 20% in the unplanted wetlands and 30% in the reed wetlands. When air temperatures were below 5°C during December and January, it was found that removal of total nitrogen and ammonia nitrogen were only about 10% in the unplanted wetlands, and about 20–30% in the reed wetlands. With rise in air temperature after March, removal of total nitrogen and ammonia nitrogen started to increase and reached to peak value in July and August. After September, the nitrogen removal rates fell again in line with falling air temperatures.

Reduction of nutrient concentrations in a wetland is mainly by biotic activity and the most of the biotic activities are temperature-dependent. Therefore, when effectiveness of constructed wetland for the removal of pollutant is to be evaluate, temperature becomes important parameter. In general, the efficiency of treatment in a CW decreases at low temperature primarily because of reduced biotic activity. During the study in eutrophic lake water of China, the nutrient removal rates were found to be fluctuated during one year investigation. Higher ammonia nitrogen and total nitrogen removal effects were found in autumn and summer while in winter the removal remained relatively the lowest in all constructed wetlands (Zhang *et al.*, 2014).

A constructed wetland is a complex assembly of various components. Wastewater, porous media, vegetation and microorganisms are the major components. For the treatment of wastewater, several complex physical, biological and chemical activities have to be undergone. Among them biological activity is predominant in constructed wetland. Biological activity includes microbial activity; mainly bacterial activity and growth of plant. Change in temperature directly affects these biological activities as observed the authors also in their research. In Nepal also variation of temperature found to be high and the study relating to effect of change in temperature in constructed wetland become significant.

CHAPTER III

3.0 METHODOLOGY

Methodology includes laboratory setup, selection of wetland, collection of sample and analysis of sample.

3.1 Experimental Setup

Selection of laboratory and setup:

The study is concerned to find out the effect of temperature on nutrient removal by CW. For the nutrient analysis, laboratory of IOE was used.

Selection of wetland:

For the study, constructed wetland situated inside the premises of IOE was selected. CW of IOE is horizontal bed subsurface flow constructed wetland which treats domestic wastewater of neighboring houses and IOE cafeteria. Major components of CW are shown in Figure 3.1, 3.2 and 3.3. Detail description of wetland is shown in Table 3-1 (Khyoju, 2014).

Table 3-1: Description of constructed wetland

Components	**Dimension (m)**	**Remarks**
Settling Tank	4.20 X 2.55	Brick masonry
Horizontal Bed	42.00 X 7.00 X 0.45	Single bed
Inlet	100mm dia perforated pipe	Continuously flow in inlet
Media: Inlet and outlet zone Filter media	 40mm-80mm size crushed stone 20mm-30mm size crushed stone	150mm compacted clay and PVC geo-membrane sheet is used for lining
Effluent tank	4.90 X 2.20	Brick masonry
Outlet pipe	100mm perforated pipe	
Sampling ports	110mm vertical pipe at 1m interval	

Porosity of media is assumed to be 40% as per standard of USEPA.

3.2 Flow Regulation

Since the wastewater flow throughout time varies significantly, one of the major challenges is to regulate the flow constantly. For this purpose, flow of two weeks was studied continuously. With the help of gate valve connected to inlet pipe, flow was regulated and fixed to 10.80 m^3/day. Detention time in the constructed wetland for the flow is as given by Eq. 3.1.

$$t = \frac{nLWd}{Q} \qquad \text{...Eq.3.1}$$

Where,

n	=	porosity	= 40%
L	=	bed length	= 42 m
W	=	bed width	= 7 m
d	=	depth of flow	= 0.45 m
Q	=	discharge	= 10.80 m^3/d

On putting these values in Eq. 3.1 we get the detention time to be 4.90 day.

3.3 Collection of Sample

Maintenance as well as flow regulation of wetland was done during the first month of the study. After regulating the flow, sample was taken in the regular interval. Generally, sample was taken every Sunday around 10-11 am. Once at a time, two samples were taken; one from inlet and one from outlet. All the samples were kept in refrigerator for future analysis also.

3.4 Analysis of Sample

For the nutrient analysis, standard method was followed. Detail about standard method is explained in ANNEX A to D. Methods used in the analysis are listed in Table 3-2 (Greenberg *et al.*, 1998).

Table 3-2: Methods of analysis

S.N.	**Parameters**	**Methods**
1	BOD	Wrinkle method
2	Nitrate nitrogen	Spectrophotometric method
3	Nitrite nitrogen	Spectrophotometric method
4	Ammonia nitrogen	Phenate method
5	Phosphorus	Ascorbic acid method
6	Temperature	Thermometer

3.4 Description of Wetland

Constructed wetland situated in IOE is horizontal bed subsurface flow constructed wetland planted with common reed plant at 600mm c/c and pebbles as substrate. Wastewater enters through inlet chamber to the settling tank where solid particle gets settle down. To control the flow of water to the wetland, flow control chamber is situated just adjacent to settling tank and finally water enters to the wetland through two pipes as shown in Figure 3.2. Along the center line of wetland, perforated pipe line is laid down to collect the treated water and finally it is connected to the outlet zone as presented in Figure 3.3. For the inspection, 110mm vertical pipes are also placed along the central perforated pipe. Slope of the bed is kept to be 1%.

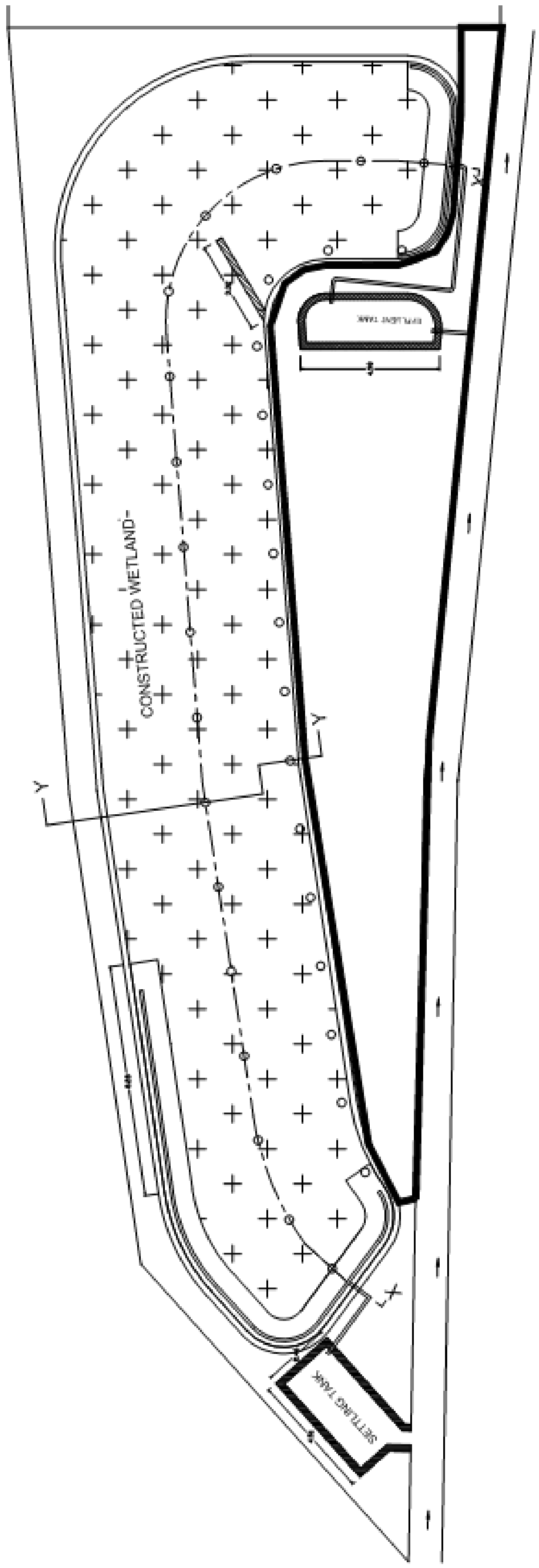

Figure 3.1 Plan of constructed wetland at IOE

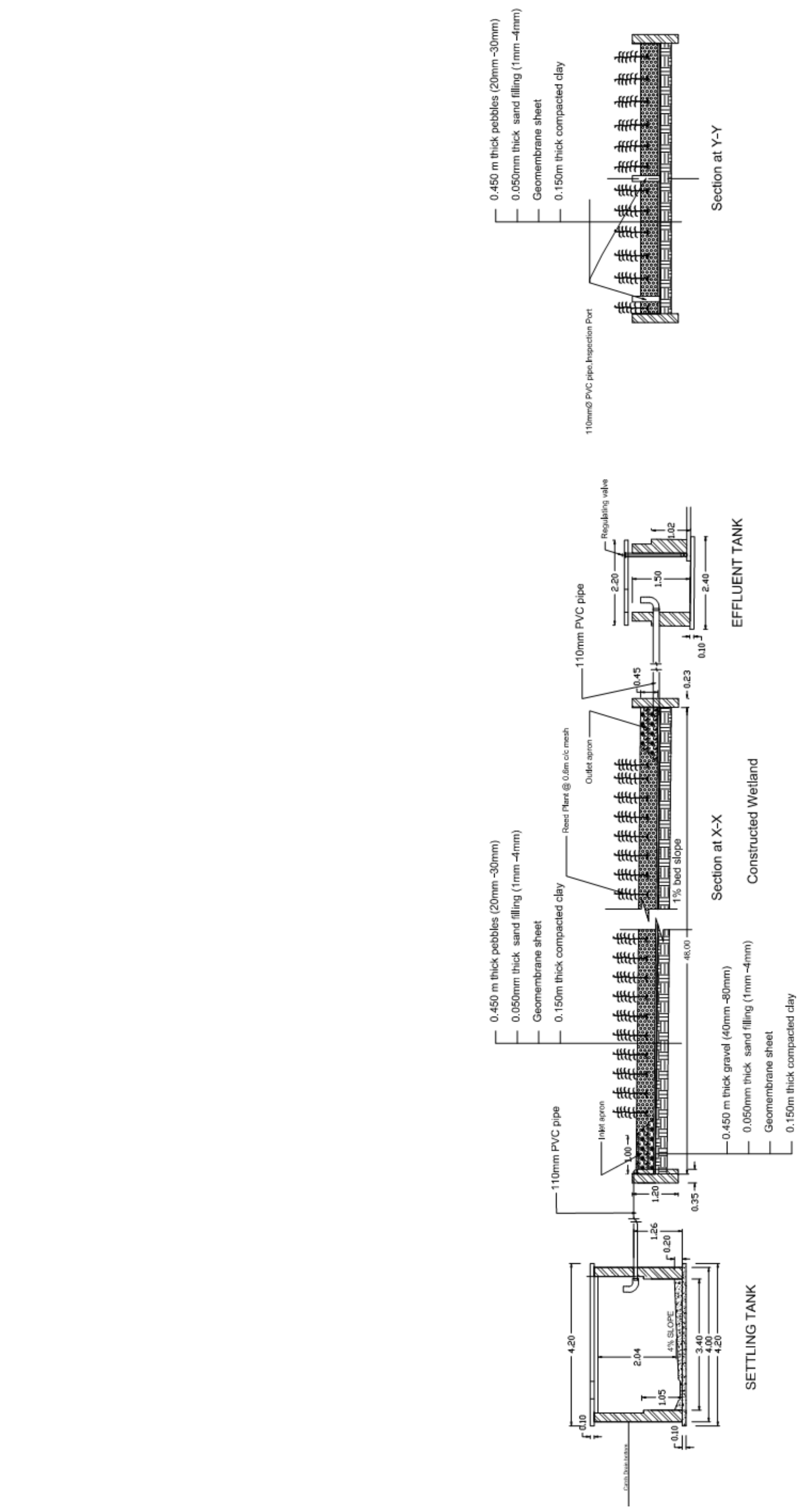

Figure 3.2 Section of constructed wetland at IOE

CHAPTER IV

4.0 RESULTS AND DISCUSSIONS

Among various parameters, our concern was to know the effect on performance of constructed wetland due to variation of ambient temperature. The performance of constructed wetland was measure in terms of NH_4-N, NO_2-N, NO_3-N, PO_4-P and 5 days BOD. Analysis was done on the basis of Standard Method. Detail of calculation is attached in the Annex A to D.

4.1 Performance of Wetland

4.1.1 Ammonia nitrogen removal

During winter season, temperature was very low; minimum temperature was found to be 3^{o}C and during summer maximum temperature was recorded to be 34.5^{o}C. Concentration of ammonia nitrogen throughout the study period was found to be nearly constant which is presented in the Figure 4.1.

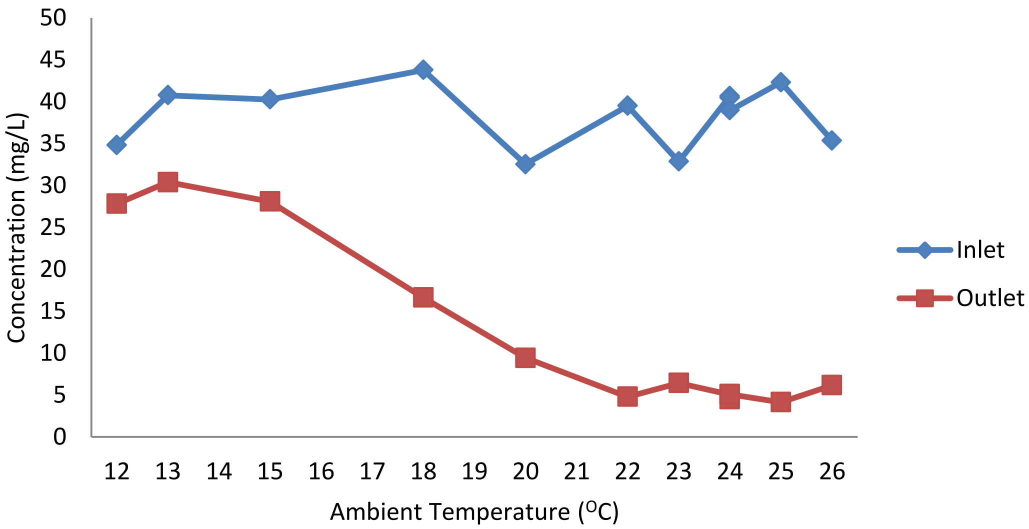

Figure 4.1: Analysis of ammonia nitrogen

At inlet, concentration was 18.65, 34.82, 40.75, 42.83, 33.29, 40.25, 24.46, 45.19, 43.76, 41.57, 32.52, 26.49, 39.50, 32.84, 35.41, 30.61, 23.92, 24.68, 40.65, 23.43, 40.47, 38.96, 42.30, 40.11 and 32.34 mg/L where outlet concentration was 17.39, 27.81, 30.38, 27.26, 25.12, 28.08, 15.42, 27.86, 16.62, 24.63, 9.42, 17.66, 4.78, 6.43, 4.24, 3.83, 3.90, 4.73, 5.05, 3.99, 4.47, 5.09, 4.13 and 5.05 mg/L for the average temperature of 12.05, 12.75, 13.50, 13.65, 13.75, 15.25, 16.80, 16.85, 18.00, 19.80, 20.80, 21.05, 22.85, 23.00, 23.20, 23.50, 24.50, 24.55, 24.70, 24.70, 24.75, 24.85, 25.50, 26.15 and 26.50°C respectively. Concentration of ammonia nitrogen at outlet goes on decreasing with increase in temperature and become constant when average temperature reached to 22°C.

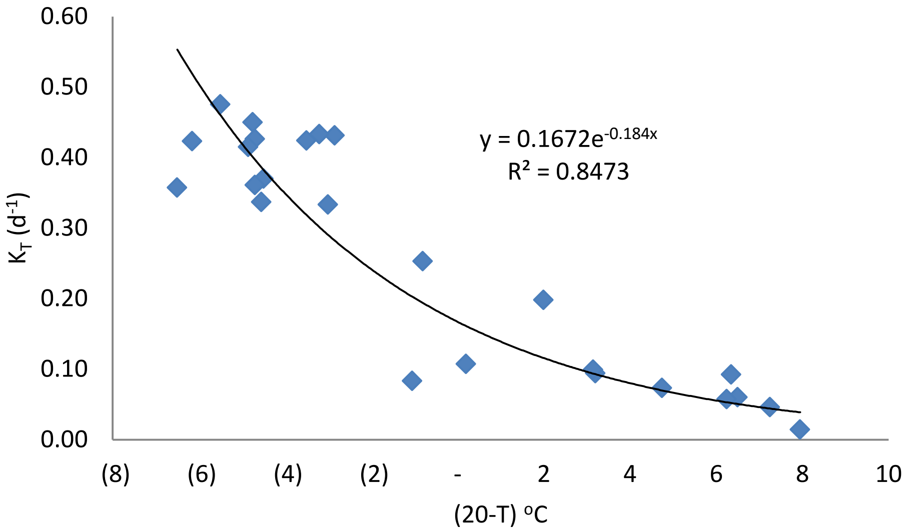

Figure 4.2: Removal kinetics of ammonia nitrogen

From the study, it was found that value of K_T changed exponentially with temperature which is presented in Figure 4.2. The value of K_{T20} was found to be 0.166 d^{-1} and value of θ was found to be 0.83 in average with negligible variation for all temperatures in case of ammonia nitrogen.

4.1.2 Nitrite and nitrate nitrogen removal

Nitrite nitrogen is very unstable in wastewater and it was found in very low concentration. Due to its low concentration and not significantly changed with ambient temperature detail of nitrite nitrogen is only attached in Annex D.

Effect of temperature on the removal of nitrate nitrogen by the constructed wetland is presented in Figure 4.3. Removal was low when temperature was below 21°C and was increased as temperature raise beyond 21°C. The gap between inlet and outlet is nearly similar after 16°C. It can be concluded that change in temperature has not significantly increase the removal efficiency of nitrate nitrogen.

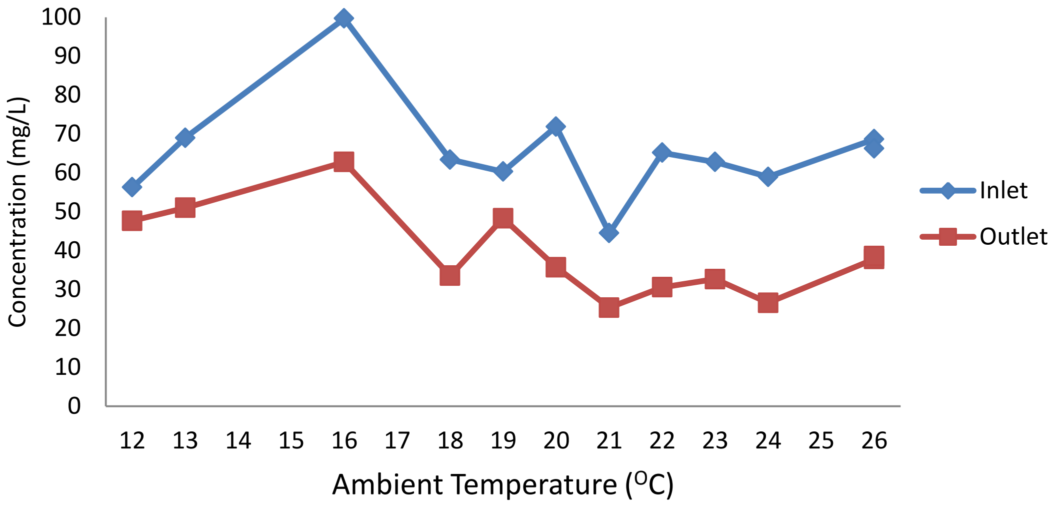

Figure 4.3: Analysis of nitrate nitrogen

For the temperature 12.05, 12.75, 13.50, 13.65, 13.75, 16.80, 18.00, 19.80, 20.80, 21.05, 22.85, 23.00, 23.20, 23.50, 24.50, 24.55, 24.70, 24.70, 24.75, 24.85, 25.50, 26.15 and 26.50°C concentration of nitrate at inlet has been found to be 56.23, 58.20, 68.99, 68.99, 45.68, 99.67, 63.36, 60.27, 71.85, 44.46, 65.15, 62.75, 64.44, 73.45, 64.82, 58.91, 71.43, 61.58, 61.63, 63.93, 95.63, 68.62 and 66.27 mg/L whereas outlet concentration for same temperature was 47.65, 51.50, 50.98, 48.31, 41.60, 62.75, 33.53, 48.31, 35.69, 25.32, 30.53, 32.64, 31.28, 46.06, 29.78, 26.54, 42.30, 30.81, 44.04, 29.12, 57.03, 37.78 and 38.55 mg/L respectively.

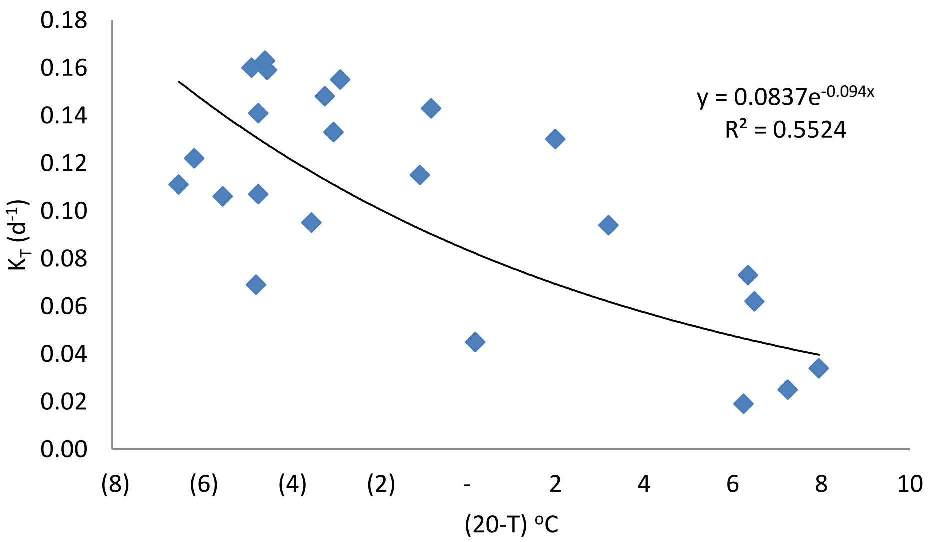

Figure 4.4: Removal kinetics of nitrate nitrogen

From the study of nitrate nitrogen, it was found that value of K_T changed exponentially with temperature which is presented in Figure 4.4. The value of K_{T20} was found to be 0.0646 d^{-1} and value of θ was found to be 0.87 in average (with small variation for some data) for all temperatures.

4.1.3 Phosphorus removal

Phosphorus in wastewater was found to be in very low concentration in comparison to nitrogen. At inlet, concentration was found to be nearly similar. With increase in ambient temperature, removal of phosphorus also increased which is presented in Figure 4.5. Rate of removal of phosphorus was found to be increased up to 20°C and beyond this, rate of removal was found to be constant.

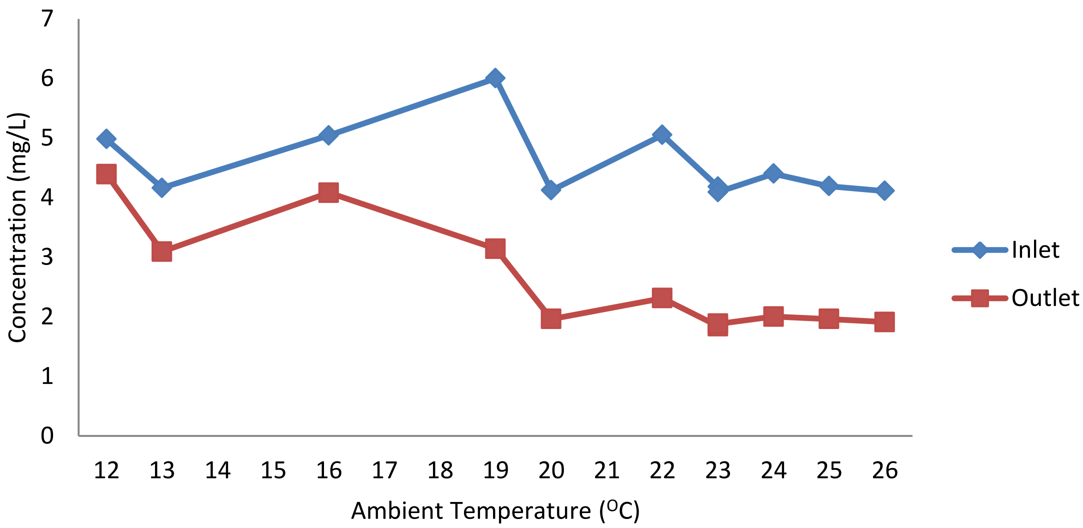

Figure 4.5: Analysis of phosphorus

During the study period, concentration of phosphorus at inlet was found to be 4.98, 8.88, 4.16, 7.10, 5.83, 5.04, 9.53, 6.00, 4.12, 9.02, 5.05, 4.18, 4.09, 3.27, 3.16, 3.06, 4.40, 3.54, 5.93, 3.76, 4.19, 4.83 and 4.11 mg/L whereas for the same sampling date outlet concentration was found to be 4.39, 6.48, 3.09, 4.70, 4.70, 4.08, 4.16, 3.14, 1.96, 5.21, 2.31, 1.84, 1.88, 1.45, 1.48, 1.33, 2.00, 1.86, 2.68, 2.13, 1.96, 2.48 and 1.91 mg/L for the average temperatures 12.05, 12.75, 13.50, 13.65, 13.75, 16.80, 18.00, 19.80, 20.80, 21.05, 22.85, 23.00, 23.20, 23.50, 24.50, 24.55, 24.70, 24.70, 24.75, 24.85, 25.50, 26.15 and 26.50°C respectively. From this result we can conclude that there is low effect of change in temperature on phosphorus removal.

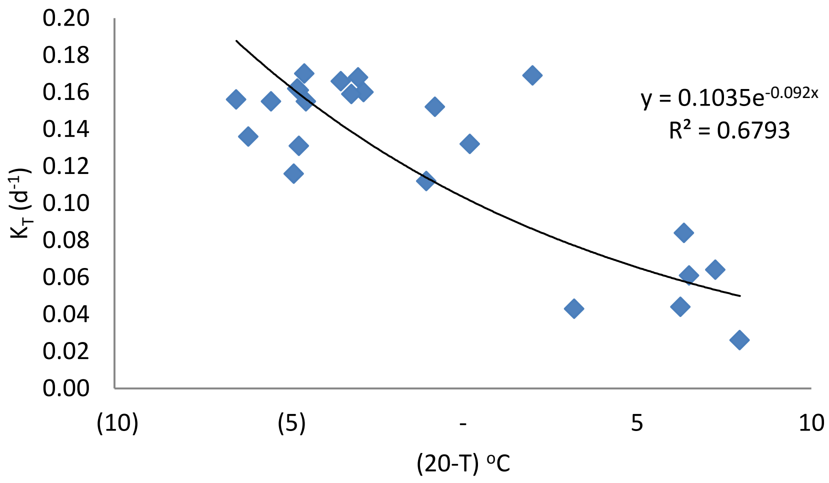

Figure 4.6: Removal kinetics of phosphorus

For phosphorus also, value of K_T changed exponentially with temperature which is presented in Figure 4.6 with R^2 value of 0.6793. The value of K_{T20} was found to be 0.136 d^{-1} and value of θ was found to be 0.93 in average (with small variation for some data) for all temperatures.

4.1.4 Biochemical oxygen demand

BOD is one of the major pollutants of wastewater. Range of concentration at inlet was found to 150 mg/L to 276 mg/L. Effect of change in temperature was also observed in BOD removal. During winter season, concentration of BOD at outlet was found to be 114 mg/L whereas the concentration of BOD during summer season was found to be in the range of 36 mg/L which is presented in Figure 4.7.

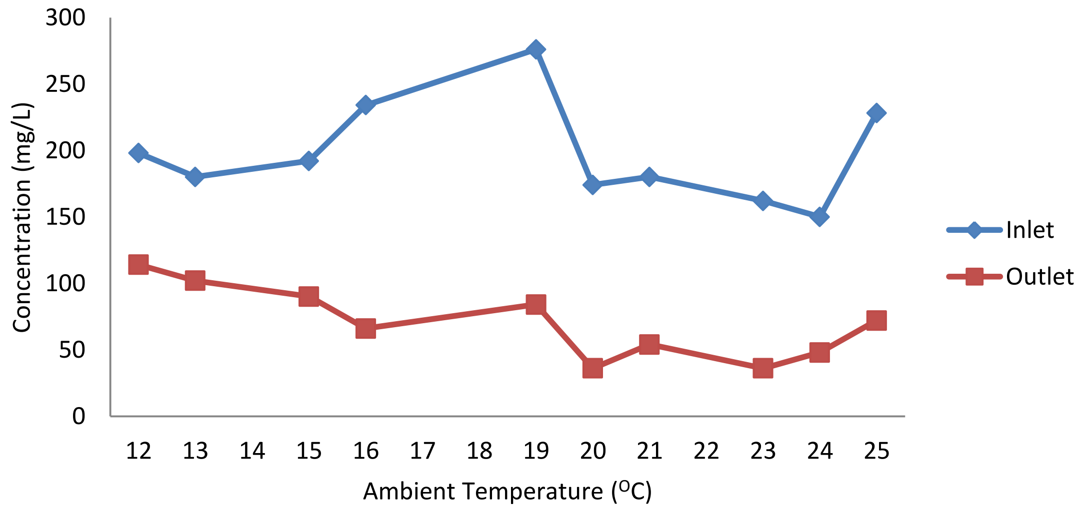

Figure 4.7: Analysis of BOD

From the Figure 4.7, the BOD concentration at inlet was found to be 198, 210, 180, 210, 210, 192, 234, 240, 276, 174, 180, 162, 180, 186, 150, 168 and 228 mg/L. After treatment through wetland, concentration of BOD at outlet was found to be 114, 108, 102, 84, 114, 90, 66, 138, 84, 36, 54, 36, 36, 36, 48, 36 and 72 mg/L for temperatures 12.05, 12.75, 13.50, 13.65, 13.75, 15.25, 16.80, 16.85, 19.80, 20.80, 21.05, 23.00, 23.20, 23.50, 24.55, 24.85 and 25.50°C respectively.

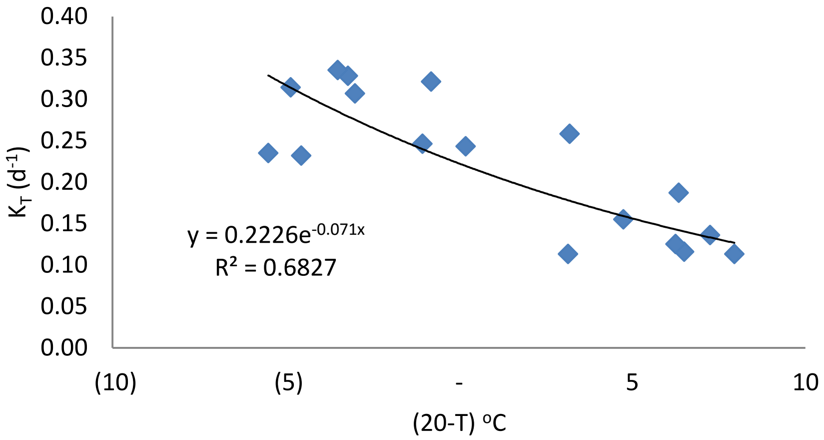

Figure 4.8: Removal kinetics of BOD

In most of the European countries and United States, first order plug flow model has been followed. From the study, in case of BOD also, value of K_T changed exponentially with temperature which is presented in Figure 4.8 with R^2 value of 0.6827. The value of K_{T20} was found to be 0.2586 d^{-1} and value of θ was found to be 0.94 in average (with small variation for some data) for all temperatures.

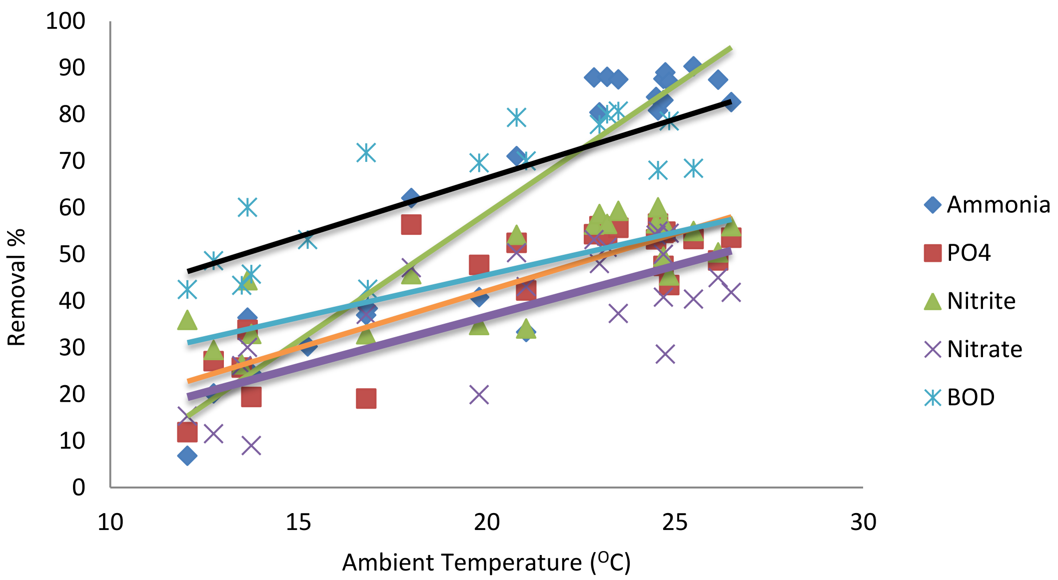

Figure 4.9: Impurities removal by constructed wetland

From the study, it can be said that removal efficiency of constructed wetland for different pollutants was different which is also presented in Figure 4.9. From Figure 4.9, removal of ammonia was found to be highly affected by temperature in comparison to other pollutants. BOD has also high effect of change in temperature whereas nitrate and phosphorus have moderate effect of change in temperature.

In the constructed wetland, plants help to remove the impurities by means of up taking the nutrients for their growth and releases oxygen through photosynthesis. Some amount of oxygen is also released from root zone also which helps to increase the oxygen level in water. Due to increase in temperature, growth of plant rhizomes as well as activity of microorganism increases. Not only the existing rhizomes but also the number of new plants also increases with change in season. Increase in microbiological activity, increase in number of plants and increase in rhizome density help to remove the impurities from wastewater.

CHAPTER V

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Main objective of the research was to know the effect of seasonal variation in temperature on the performance of constructed wetland. Based on the result, following conclusions have been made:

1 Ammonia nitrogen has been found to be varied highly with respect to temperature. The range of removal efficiency has been observed as 20.13 to 90.24%. With the rise in temperature, activity of nitrifying-denitrifying bacteria as well as activity of anammox bacteria has been increased. Value of θ was found to be 0.83 and value of K_{T20} was found to be 0.166 d^{-1}.

2 Removal of nitrate with change in temperature has been found to be in the range of 11.51 to 54.95%. In comparison to ammonia, removal of nitrate is not significantly changed with temperature. But value of θ was found to be 0.87 and value of K_{T20} was found to be 0.0646 d^{-1}.

3 Removal of phosphorus with respect to temperature is slightly in increasing order with temperature. But the concentration of phosphorus is found to be low in wastewater. Whereas value of θ was found to be 0.93 and value of K_{T20} was found to be 0.136 d^{-1}.

4 Removal of BOD has been found to be increased with respect to temperature. At low temperature month like in January, February, March microbial activity has been low than in the month like April to October. It can be concluded that change in temperature has significance in removal of BOD. In case of BOD, θ was found to be fluctuated slightly with average value of 0.94 and value of K_{T20} was found to be 0.6827 d^{-1}.

5 Concentration of nitrite has been found to be very low in wastewater and effect of temperature on removal has been also found to be very low in comparison to other pollutants.

6 Efficiency of constructed wetland was found to be highly affected by temperature for the case of ammonia and BOD, moderately affected for phosphorus and nitrate and very less affected for nitrite removal.

With rise in temperature microbial activity has been increased. Similarly, with rise in ambient temperature, new plants start to grow and rhizome also get expand. As temperature rises all the biological activities were increased which results in removing the pollutants.

5.2 Recommendations

1. It is recommended to study the effect of temperature for different flow rates.
2. It is recommended to study the effect of re-circulation and temperature to increase the effluent quality.
3. It is recommended to study the rate of removal in constructed wetland with respect to flow distance.
4. It is recommended to study the reaction rate for various flows in constructed wetland.
5. It is recommended to study the effect due to density of plants on constructed wetland.

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ANNEXES

ANNEXES

A. Ammonia Analysis

Standard solution of ammonia nitrogen was prepared from ammonium chloride (NH_4Cl) where 1000mg/L of solution was prepared by dissolving 3.82gm NH_4Cl in 1000ml distilled water. (After inauguration of new lab, JICA has provided the various chemicals including standard solutions). Ammonia analysis was done by Phenate Method.

Procedure for preparation of reagents:

- Phenol/Sodium nitroprusside solution (5gm of Phenol and 0.025 gm of Sodium Nitroprusside in 500ml of distilled water) – Solution A.
- Sodium hypochlorite solution (5ml of Sodium Hypochlorite and 7.5gm of Sodium Hydroxide in 500ml of distilled water) – Solution B.
- Using standard stock solution, intermediate standard solution of 5mg/L was prepared and final required standard solutions were prepared as follows using formula $V_1S_1=V_2S_2$

Procedure for preparation of standard solution and measurement of standard solution:

- 4ml of standard solution prepared above was taken into 10ml test tube.
- 2ml of solution A was added in blank as well as all the tubes and shaked gently.
- 2ml of solution B was also added and lid of tube was closed.
- Test tubes were left for an hour at room temperature and after an hour color was developed.
- Similarly same procedure was followed for sample water also.
- Absorbance at 640nm was measured in photometer.
- Standard curve was prepared by plotting absorbance of standard against NH_3-N concentration.
- From the standard curve sample concentration was measured.

Table A-1: Table for ammonia analysis

Required Strength : mg/L	0.1	0.2	0.5	1.0	2.0
Vol. of std. solution A (5mg/L): ml	1	2	5	10	20
Volumetric flask : ml	50	50	50	50	50

Table A-2: Table for ammonia standard curve (Standard solution prepared in Lab)

Concentration mg/L	Absorbance		Average	Remarks
0.0	0.031	0.031	0.031	
0.1	0.067	0.066	0.067	
0.2	0.080	0.084	0.082	
0.5	0.140	0.139	0.140	
1.0	0.238	0.241	0.240	
2.0	0.404	0.399	0.402	

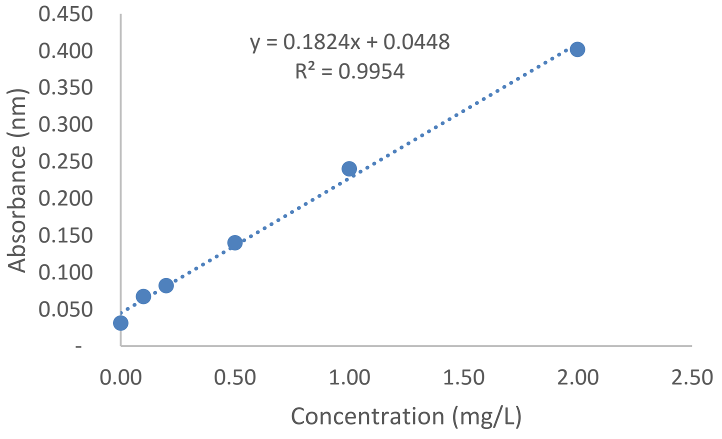

Figure A-1: Ammonia standard curve.

Table A-3: Table for ammonia standard curve (Standard solution provided by Lab)

Concentration mg/L	Absorbance (mn)		Av. Abs. (nm)	Remarks
0.0	0.008	0.001	0.005	
0.1	0.059	0.066	0.063	
0.2	0.142	0.139	0.141	
0.5	0.335	0.345	0.340	
1.0	0.621	0.629	0.625	
2.0	1.115	1.113	1.114	

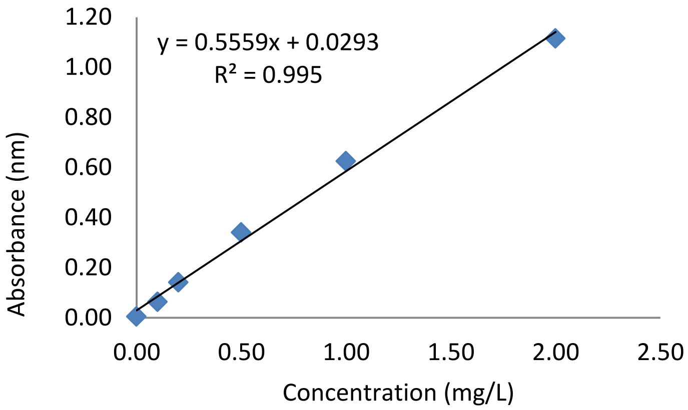

Figure A-2: Ammonia standard curve.

Table A-4: Analysis of water for Ammonia-nitrogen

Sample	Day	Temp (°C)	Absorbance for		Concentration (x10)		Actual Conc. (mg/L)		Removal	Remarks
			Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	%	
1	21-Jan	22.5-3	0.680	0.552	3.482	2.781	34.82	27.81	20.13	y = 0.1824x + 0.0448
2	28-Jan	21.6-2.5	0.385	0.362	1.865	1.739	18.65	17.39	6.76	
3	4-Feb	21.5-6	0.652	0.503	3.329	2.512	33.29	25.12	24.54	
4	11-Feb	22-5	0.788	0.599	4.075	3.038	40.75	30.38	25.45	
5	18-Feb	23-7.5	0.779	0.557	4.025	2.808	40.25	28.08	30.24	
6	22-Feb	25.2-8.5	0.869	0.553	4.519	2.786	45.19	27.86	38.35	
7	1-Mar	16.6-10.7	0.826	0.542	4.283	2.726	42.83	27.26	36.35	
8	15-Mar	22.4-11.2	0.491	0.326	2.446	1.542	24.46	15.42	36.96	
9	22-Mar	28.2-11.4	0.803	0.494	4.157	2.463	41.57	24.63	40.75	
10	29-Mar	27.6-14.5	0.528	0.367	2.649	1.766	26.49	17.66	33.33	
11	5-Apr	27-9	0.843	0.348	4.376	1.662	43.76	16.62	62.02	
12	19-Apr	28.6-13	1.837	0.553	3.252	0.942	32.52	9.42	71.03	y = 0.5559x + 0.0293
13	24-May	32.5-13.5	1.855	0.387	3.284	0.643	32.84	6.43	80.42	
14	7-Jun	34.5-18.5	1.994	0.371	3.534	0.615	35.34	6.15	82.6	
15	21-Jun	31.3-21	2.259	0.31	4.011	0.505	40.11	5.05	87.41	
16	29-Jun	30.4-19	2.289	0.31	4.065	0.505	40.65	5.05	87.58	
17	12-Jul	31-20	2.381	0.259	4.230	0.413	42.30	4.13	90.24	
18	19-Jul	29.5-20	2.279	0.278	4.047	0.447	40.47	4.47	88.95	
19	2-Aug	27.2-18.5	2.225	0.295	3.950	0.478	39.5	4.78	87.90	
20	12-Aug	29.5-20.2	2.195	0.312	3.896	0.509	38.96	5.09	86.94	
21	23-Aug	27-19.4	1.998	0.265	3.541	0.424	35.41	4.24	88.03	
22	6-Sep	30-17	1.731	0.242	3.061	0.383	30.61	3.83	87.49	
23	14-Sep	30-19	1.359	0.246	2.392	0.390	23.92	3.90	83.7	
24	20-Sep	30.4-19	1.332	0.251	2.343	0.399	23.43	3.99	82.97	
25	1-Oct	30.5-18.6	1.401	0.292	2.468	0.473	24.68	4.73	80.83	

Table A-5: Calculation of reaction rate constants K_T and θ for ammonia nitrogen

	ln (Co/Ce)	dxn	KT			20-T	New	Kr	θ	Remarks
Co/Ce			This study	USEPA	Jing and Lin		KT	KT/K20	Kr^(1/(20-T))	
1.072	0.070	0.18	0.014	0.085	0.045	7.95	0.04	0.23	0.83	KT is taken from interpolation between 19.8-20.8 and 0.16-0.19.
1.252	0.225	0.18	0.046	0.086	0.052	7.25	0.04	0.27	0.83	
1.341	0.293	0.18	0.060	0.088	0.060	6.50	0.05	0.30	0.83	
1.571	0.452	0.18	0.092	0.089	0.061	6.35	0.05	0.31	0.83	
1.325	0.281	0.18	0.057	0.089	0.063	6.25	0.05	0.32	0.83	
1.433	0.360	0.18	0.073	0.093	0.083	4.75	0.07	0.42	0.83	
1.586	0.461	0.18	0.094	0.097	0.112	3.20	0.09	0.56	0.83	
1.622	0.484	0.18	0.099	0.097	0.114	3.15	0.09	0.56	0.83	
2.633	0.968	0.18	0.198	0.101	0.142	2.00	0.12	0.70	0.83	
1.688	0.524	0.18	0.107	0.106	0.200	0.20	0.16	0.97	0.86	
3.452	1.239	0.18	0.253	0.110	0.243	(0.80)	0.19	1.17	0.82	
1.500	0.405	0.18	0.083	0.110	0.255	(1.05)	0.20	1.22	0.83	
8.264	2.112	0.18	0.431	0.116	0.360	(2.85)	0.28	1.70	0.83	
5.107	1.631	0.18	0.333	0.117	0.370	(3.00)	0.29	1.75	0.83	
8.351	2.122	0.18	0.433	0.118	0.385	(3.20)	0.30	1.81	0.83	
7.992	2.078	0.18	0.424	0.119	0.408	(3.50)	0.32	1.92	0.83	
6.133	1.814	0.18	0.370	0.122	0.494	(4.50)	0.38	2.31	0.83	
5.218	1.652	0.18	0.337	0.122	0.499	(4.55)	0.39	2.33	0.83	
8.050	2.086	0.18	0.426	0.123	0.513	(4.70)	0.40	2.39	0.83	
5.872	1.770	0.18	0.361	0.123	0.513	(4.70)	0.40	2.39	0.83	
9.054	2.203	0.18	0.450	0.123	0.518	(4.75)	0.40	2.41	0.83	
7.654	2.035	0.18	0.415	0.123	0.529	(4.85)	0.41	2.46	0.83	
10.242	2.326	0.18	0.475	0.126	0.599	(5.50)	0.46	2.77	0.83	
7.943	2.072	0.18	0.423	0.128	0.679	(6.15)	0.52	3.12	0.83	
5.746	1.749	0.18	0.357	0.130	0.726	(6.50)	0.55	3.33	0.83	

B. Phosphorus Analysis

For the analysis of sample (before mid-term), standard solution of phosphorus was prepared from KH_2PO_4. 4.387gm of KH_2PO_4 was dissolved in 1000ml distilled water to make 1000mg/L phosphorus standard solution. (After inauguration of new lab, JICA has provided standard solution having strength 1000mg/L). Ascorbic Acid method was followed for the analysis of Phosphorus.

Procedure for preparation of reagents:

- Sulfuric Acid (To 100ml of water, 50ml of conc sulfuric acid was added) – Solution A.
- Potassium antimonyl tartarate solution (0.24gm of Potassium Antimonyl Tartarate, 6gm Ammonium Molybdate and 120ml of solution A was added in approximate 300ml water and final volume was made to 500ml) – Solution B.
- L- Ascorbic Acid (To 100ml of distilled water, 7.2gm of L-ascorbic acid was added) – Solution C.
- Combined Reagent (Solution B and C were mixed in the ratio of 5:1) – Solution D.
- Using standard stock solution having strength 1000mg/L, intermediate standard solution of 5mg/L was prepared and final required standard solutions were prepared as follows using formula $V_1S_1=V_2S_2$

Procedure for preparation of standard solution and measurement of standard solution:

- 4ml of standard solution prepared above was taken into 10ml test tube.
- 0.4ml of solution D was added in blank as well as all the tubes and shaked gently.
- Lids were closed and leaved the tubes for 15 minutes at room temperature.
- Similarly same procedure was followed for sample water also.
- Absorbance at 880nm was measured in photometer.
- Standard curve was prepared by plotting absorbance of standard against PO_4-P concentration.

Table A-6: Table for orthophosphate analysis

Required Strength : mg/L	0.1	0.2	0.5	1.0	2.0
Vol. of std. solution A (5mg/L): ml	1	2	5	10	20
Volumetric flask : ml	50	50	50	50	50

Table A-7: Table for orthophosphate standard curve (Standard Solution Prepared in Lab)

Concentration mg/L	**Absorbance**		**Average**	**Remarks**
0.0	0.152	0.145	0.149	
0.1	0.204	0.205	0.205	
0.2	0.275	0.263	0.269	
0.5	0.410	0.391	0.401	
1.0	0.573	0.605	0.589	
2.0	0.845	0.883	0.864	

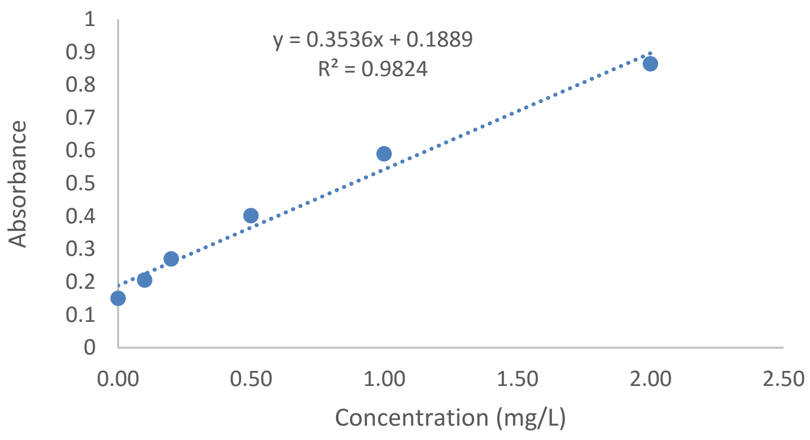

Figure A-3: Phosphorus standard curve.

Table A-8: Table for orthophosphate standard curve (Standard Solution Provided by Lab)

Concentration mg/L	**Absorbance (mn)**		**Av. Abs. (nm)**	**Remarks**
0.0	0.023	0.024	0.024	
0.1	0.168	0.178	0.173	
0.2	0.230	0.261	0.246	
0.5	0.401	0.440	0.421	
1.0	0.710	0.718	0.714	
2.0	1.226	1.253	1.240	

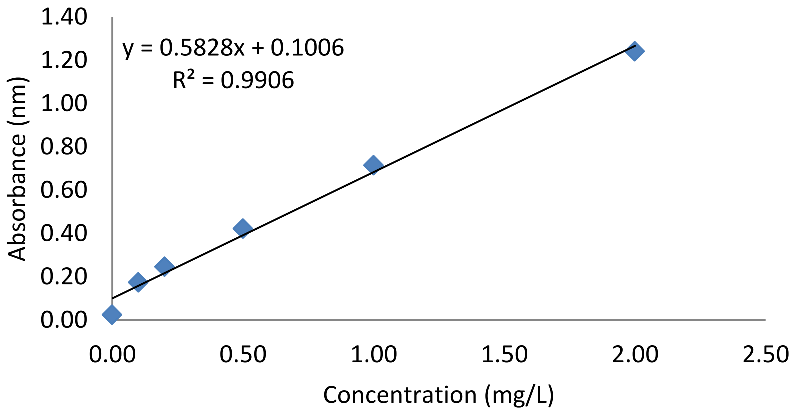

Figure A-4: Phosphorus standard curve.

Table A-9: Analysis of water for Phosphorus

Sample	Day	Temp	Absorbance for		Concentration (x10)		Actual Concentraion		Removal	Remarks
			In	Out	In	Out	Inlet	Outlet	%	
1	21-Jan	22.5-3	0.503	0.418	0.888	0.648	8.88	6.48	27.03	y = 0.3536x + 0.1889
2	28-Jan	21.6-2.5	0.365	0.344	0.498	0.439	4.98	4.39	11.85	
3	4-Feb	21.5-6	0.395	0.355	0.583	0.470	5.83	4.70	19.38	
4	11-Feb	22-5	0.336	0.298	0.416	0.309	4.16	3.09	25.72	
5										
6										
7	1-Mar	16.6-10.7	0.440	0.355	0.710	0.470	7.10	4.70	33.80	
8	15-Mar	22.4-11.2	0.367	0.333	0.504	0.408	5.04	4.08	19.05	
9	22-Mar	28.2-11.4	0.401	0.300	0.600	0.314	6.00	3.14	47.67	
10	29-Mar	27.6-14.5	0.508	0.373	0.902	0.521	9.02	5.21	42.24	
11	5-Apr	27-9	0.526	0.336	0.953	0.416	9.53	4.16	56.35	
12	19-Apr	28.6-13	0.341	0.215	0.412	0.196	4.12	1.96	52.43	y = 0.5828x + 0.1006
13	24-May	32.5-13.5	0.344	0.208	0.418	0.184	4.18	1.84	55.98	
14	7-Jun	34.5-18.5	0.340	0.212	0.411	0.191	4.11	1.91	53.53	
15	21-Jun	31.3-21	0.382	0.245	0.483	0.248	4.83	2.48	48.65	
16	29-Jun	30.4-19	0.357	0.217	0.440	0.200	4.40	2.00	54.55	
17	12-Jul	31-20	0.345	0.215	0.419	0.196	4.19	1.96	53.22	
18	19-Jul	29.5-20	0.446	0.257	0.593	0.268	5.93	2.68	54.81	
19	2-Aug	27.2-18.5	0.395	0.235	0.505	0.231	5.05	2.31	54.26	
20	12-Aug	29.5-20.2	0.320	0.225	0.376	0.213	3.76	2.13	43.35	
21	23-Aug	27-19.4	0.339	0.210	0.409	0.188	4.09	1.88	54.03	
22	6-Sep	30-17	0.291	0.185	0.327	0.145	3.27	1.45	55.66	
23	14-Sep	30-19	0.285	0.187	0.316	0.148	3.16	1.48	53.16	
24	20-Sep	30.4-19	0.307	0.209	0.354	0.186	3.54	1.86	47.46	
25	1-Oct	30.5-18.6	0.279	0.178	0.306	0.133	3.06	1.33	56.54	

Table A-10: Calculation of reaction rate constants K_T and θ for phosphorus

	ln (Co/Ce)	dxn	KT	20-T	New	Kr	θ	Remarks
Co/Ce			This study		KT	KT/K20	Kr^(1/(20-T))	
1.134	0.126	0.18	0.026	7.95	0.05	0.37	0.88	KTis taken from interpolation between 19.8-20.8 and 0.132-0.152.
1.370	0.315	0.18	0.064	7.25	0.05	0.39	0.88	
1.346	0.297	0.18	0.061	6.50	0.06	0.42	0.87	
1.511	0.413	0.18	0.084	6.35	0.06	0.42	0.87	
1.240	0.215	0.18	0.044	6.25	0.06	0.43	0.87	
1.235	0.211	0.18	0.043	3.20	0.08	0.57	0.84	
2.291	0.829	0.18	0.169	2.00	0.09	0.63	0.80	
1.911	0.648	0.18	0.132	0.20	0.10	0.75	0.23	
2.102	0.743	0.18	0.152	(0.80)	0.11	0.82	1.28	
1.731	0.549	0.18	0.112	(1.05)	0.11	0.84	1.18	
2.186	0.782	0.18	0.160	(2.85)	0.13	0.99	1.00	
2.272	0.821	0.18	0.168	(3.00)	0.14	1.00	1.00	
2.176	0.777	0.18	0.159	(3.20)	0.14	1.02	0.99	
2.255	0.813	0.18	0.166	(3.50)	0.14	1.05	0.99	
2.135	0.758	0.18	0.155	(4.50)	0.16	1.15	0.97	
2.301	0.833	0.18	0.170	(4.55)	0.16	1.16	0.97	
2.200	0.788	0.18	0.161	(4.70)	0.16	1.17	0.97	
1.903	0.643	0.18	0.131	(4.70)	0.16	1.17	0.97	
2.213	0.794	0.18	0.162	(4.75)	0.16	1.18	0.97	
1.765	0.568	0.18	0.116	(4.85)	0.16	1.19	0.96	
2.138	0.760	0.18	0.155	(5.50)	0.17	1.26	0.96	
1.948	0.667	0.18	0.136	(6.15)	0.18	1.34	0.95	
2.152	0.766	0.18	0.156	(6.50)	0.19	1.38	0.95	

C. Nitrate Analysis

Nitrate analysis was done by Ultraviolet Spectrophotometric Screening Method. Standard solution for nitrate nitrogen having strength 1000mg/L was provided by JICA (otherwise we can prepare 1000mg/L standard solution by dissolving 7.218gm KNO_3 in distilled water).

Procedure for preparation of reagents:

- Hydrochloric Acid solution, HCl, 1N: (To 110ml of distilled water, 10ml of conc sulfuric acid was added) – Solution A.
- Using standard stock solution having strength 1000mg/L, intermediate standard solution of 5mg/L was prepared and final required standard solutions were prepared as follows using formula $V_1S_1=V_2S_2$

Procedure for preparation of standard solution and measurement of standard solution:

- 10ml of standard solution prepared above was taken into 25ml test tube.
- 0.2ml of solution A (1N HCl) was added in blank as well as all the tubes and mixed thoroughly.
- Similarly same procedure was followed for sample water also.
- Absorbance at 220nm and 275nm was measured in spectrophotometer.
- For samples, blank and standard solutions, two times the absorbance reading at 275nm was deducted from the absorbance reading at 220nm to obtain the absorbance due to nitrate nitrogen.

  $2DS = Abs_{220} - 2XAbs_{275}$

  where:

  2DS = Absorbance due to nitrate nitrogen

  Abs220 = absorbance reading at 220nm

  Abs275 = absorbance reading at 275nm

- Standard curve was obtained by plotting absorbance due to 2DS against concentration of standard solution.

Table A.11: Table for nitrate nitrogen analysis

Required Strength : mg/L	0.1	0.2	0.5	1.0	2.0
Vol. of std. solution A (5mg/L): ml	1	2	5	10	20
Volumetric flask : ml	50	50	50	50	50

Table A.12: Table for nitrate standard curve.

Conc (mg/L)	**Absorbance (220 mn)**		**Av. Abs. (220 nm)**	**Absorbance (275 mn)**		**Av. Abs. (275 nm)**	**2Abs (275)**	**2DS (Abs220-2Abs275)**	**Remarks**
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
0.1	0.033	0.026	0.030	0.000	0.000	0.000	0.000	0.030	
0.2	0.043	0.048	0.046	0.002	0.003	0.003	0.006	0.040	
0.5	0.108	0.110	0.109	0.002	0.003	0.003	0.006	0.103	
1.0	0.227	0.224	0.226	0.012	0.005	0.009	0.018	0.208	
2.0	0.447	0.452	0.450	0.009	0.010	0.010	0.020	0.430	

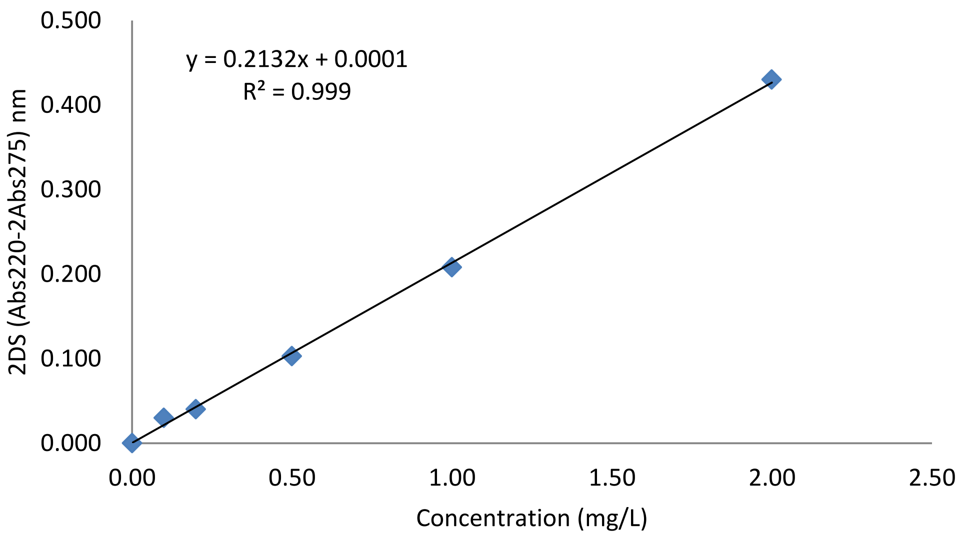

Figure A-5: Nitrate standard curve.

Table A.13: Analysis of water for Nitrate nitrogen

Sample	Day	Temp	Absorbance (220)		Absorbance (275)		2DS (Abs220-2Abs275)		Concentration (x10)		Actual Concentraion		Removal	Remarks
			In	Out	In	Out	In	Out	In	Out	Inlet	Outle	%	
1	21-Jan	22.5-3	1.263	1.136	0.011	0.019	1.241	1.098	5.82	5.15	58.2	51.5	11.51	y = 0.2132x + 0.0001
2	28-Jan	21.6-2.5	1.231	1.05	0.016	0.017	1.199	1.016	5.623	4.765	56.23	47.65	15.26	
3	4-Feb	21.5-6	1.012	0.911	0.019	0.012	0.974	0.887	4.568	4.16	45.68	41.6	8.93	
4	11-Feb	22-5	1.503	1.113	0.016	0.013	1.471	1.087	6.899	5.098	68.99	50.98	26.11	
5														
6														
7	1-Mar	16.6-10.7	1.493	1.062	0.011	0.016	1.471	1.03	6.899	4.831	68.99	48.31	29.98	
8	15-Mar	22.4-11.2	2.189	1.372	0.032	0.017	2.125	1.338	9.967	6.275	99.67	62.75	37.04	
9	22-Mar	28.2-11.4	1.311	1.054	0.013	0.012	1.285	1.03	6.027	4.831	60.27	48.31	19.84	
10	29-Mar	27.6-14.5	0.984	0.582	0.018	0.021	0.948	0.54	4.446	2.532	44.46	25.32	43.05	
11	5-Apr	27-9	1.401	0.747	0.025	0.016	1.351	0.715	6.336	3.353	63.36	33.53	47.08	
12	19-Apr	28.6-13	1.568	0.801	0.018	0.02	1.532	0.761	7.185	3.569	71.85	35.69	50.33	
13	24-May	32.5-13.5	1.382	0.752	0.022	0.028	1.338	0.696	6.275	3.264	62.75	32.64	47.98	
14	7-Jun	34.5-18.5	1.447	0.872	0.017	0.025	1.413	0.822	6.627	3.855	66.27	38.55	41.83	
15	21-Jun	31.3-21	1.485	0.836	0.011	0.0152	1.463	0.8056	6.862	3.778	68.62	37.78	44.94	
16	29-Jun	30.4-19	1.553	0.932	0.015	0.015	1.523	0.902	7.143	4.23	71.43	42.3	40.78	
17	12-Jul	31-20	2.087	1.252	0.024	0.018	2.039	1.216	9.563	5.703	95.63	57.03	40.36	
18	19-Jul	29.5-20	1.336	0.975	0.011	0.018	1.314	0.939	6.163	4.404	61.63	44.04	28.54	
19	2-Aug	27.2-18.5	1.425	0.675	0.018	0.012	1.389	0.651	6.515	3.053	65.15	30.53	53.14	
20	12-Aug	29.5-20.2	1.393	0.655	0.015	0.017	1.363	0.621	6.393	2.912	63.93	29.12	54.45	
21	23-Aug	27-19.4	1.4	0.689	0.013	0.011	1.374	0.667	6.444	3.128	64.44	31.28	51.46	
22	6-Sep	30-17	1.586	1.01	0.01	0.014	1.566	0.982	7.345	4.606	73.45	46.06	37.29	
23	14-Sep	30-19	1.424	0.669	0.021	0.017	1.382	0.635	6.482	2.978	64.82	29.78	54.06	
24	20-Sep	30.4-19	1.335	0.683	0.011	0.013	1.313	0.657	6.158	3.081	61.58	30.81	49.97	
25	1-Oct	30.5-18.6	1.292	0.598	0.018	0.016	1.256	0.566	5.891	2.654	58.91	26.54	54.95	

Table A-14: Calculation of reaction rate constants K_T and θ for nitrate nitrogen

Co/Ce	ln (Co/Ce)	dxn	KT This study	20-T	New KT	Kr KT/K20	θ Kr^(1/(20-T))	Remarks
1.180	0.166	0.18	0.034	7.95	0.04	0.59	0.94	KT is taken from interpolation between 19.8-20.8 and 0.045-0.143.
1.130	0.122	0.18	0.025	7.25	0.04	0.64	0.94	
1.353	0.302	0.18	0.062	6.50	0.04	0.69	0.94	
1.428	0.356	0.18	0.073	6.35	0.04	0.70	0.94	
1.098	0.093	0.18	0.019	6.25	0.05	0.70	0.95	
1.588	0.462	0.18	0.094	3.20	0.06	0.95	0.98	
1.890	0.637	0.18	0.130	2.00	0.07	1.07	1.03	
1.248	0.222	0.18	0.045	0.20	0.08	1.27	3.31	
2.013	0.700	0.18	0.143	(0.80)	0.09	1.40	0.66	
1.756	0.563	0.18	0.115	(1.05)	0.09	1.44	0.71	
2.134	0.758	0.18	0.155	(2.85)	0.11	1.71	0.83	
1.922	0.653	0.18	0.133	(3.00)	0.11	1.74	0.83	
2.060	0.723	0.18	0.148	(3.20)	0.11	1.77	0.84	
1.595	0.467	0.18	0.095	(3.50)	0.12	1.83	0.84	
2.177	0.778	0.18	0.159	(4.50)	0.13	2.01	0.86	
2.220	0.798	0.18	0.163	(4.55)	0.13	2.02	0.86	
1.689	0.524	0.18	0.107	(4.70)	0.13	2.05	0.86	
1.999	0.693	0.18	0.141	(4.70)	0.13	2.05	0.86	
1.399	0.336	0.18	0.069	(4.75)	0.13	2.06	0.86	
2.195	0.786	0.18	0.160	(4.85)	0.13	2.08	0.86	
1.677	0.517	0.18	0.106	(5.50)	0.14	2.22	0.86	
1.816	0.597	0.18	0.122	(6.15)	0.15	2.37	0.87	
1.719	0.542	0.18	0.111	(6.50)	0.16	2.45	0.87	

D. Nitrite Analysis

Nitrate analysis was done by Colorimetric Method. Standard solution for nitrate nitrogen having strength 1000mg/L was provided by JICA.

Procedure for preparation of reagents:

- To approximately 80ml of distilled water, 10ml of phosphoric acid (85%), 0.1gm N-(1-Naphthyl) ethylenediamine dihydrochloride and 1gm sulfanilamide was added and final volume was made to 100ml.
- Using standard stock solution having strength 1000mg/L, intermediate standard solution of 5mg/L was prepared and final required standard solutions were prepared as follows using formula $V_1S_1=V_2S_2$

Procedure for preparation of standard solution and measurement of standard solution:

- 10ml of standard solution prepared above was taken into 25ml test tube.
- 0.4ml of color reagent was added in blank as well as all the tubes and mixed thoroughly.
- After closing the lead, tubes were left for 20 minutes in room temperature.
- Similarly same procedure was followed for sample water also.
- After 20 minutes, absorbance at 543 was taken.
- Standard curve was obtained by plotting absorbance due to nitrite nitrogen against concentration of standard solution.

Table A.15: Table for nitrite nitrogen analysis

Required Strength : mg/L	0.1	0.2	0.5	1.0	2.0
Vol. of std. solution A (5mg/L): ml	1	2	5	10	20
Volumetric flask : ml	50	50	50	50	50

Table A. 16: Table for standard curve for nitrite nitrogen.

Concentration mg/L	**Absorbance (mn)**		**Av. Abs. (nm)**	**Remarks**
0.0	0.004	0.004	0.004	
0.1	0.264	0.266	0.265	
0.2	0.565	0.569	0.567	
0.5	1.421	1.430	1.426	
1.0	2.077	2.109	2.093	

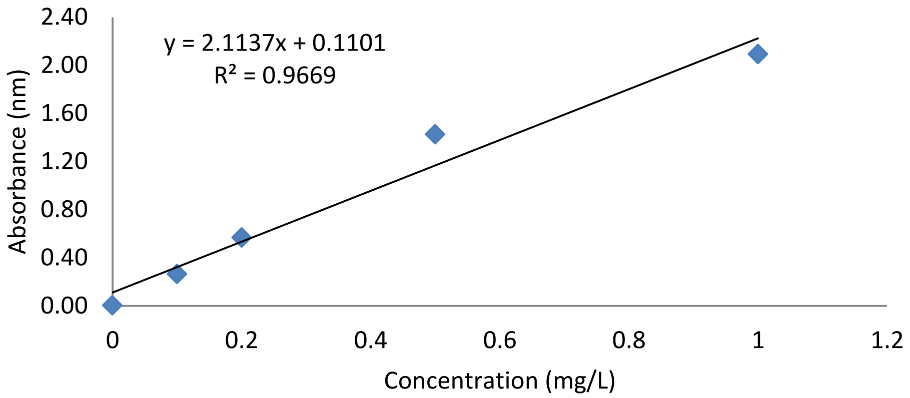

Figure A-6: Nitrite standard curve

Table A.17: Analysis of water for nitrite nitrogen.

Sample	Day	Temp	Absorbance for		Concentration (x10)		Actual Concentraion		Removal %	Remarks
			In	Out	In	Out	Inlet	Outlet		
1	21-Jan	22.5-3	0.583	0.445	0.224	0.158	2.24	1.58	29.46	
2	28-Jan	21.6-2.5	0.462	0.336	0.167	0.107	1.67	1.07	35.93	
3	4-Feb	21.5-6	0.425	0.322	0.149	0.100	1.49	1.00	32.89	
4	11-Feb	22-5	0.382	0.311	0.129	0.095	1.29	0.95	26.36	
5										
6										
7	1-Mar	16.6-10.7	0.448	0.298	0.160	0.089	1.60	0.89	44.38	
8	15-Mar	22.4-11.2	0.523	0.387	0.195	0.131	1.95	1.31	32.82	
9	22-Mar	28.2-11.4	0.401	0.300	0.138	0.090	1.38	0.90	34.78	
10	29-Mar	27.6-14.5	0.508	0.373	0.188	0.124	1.88	1.24	34.04	
11	5-Apr	27-9	0.526	0.336	0.197	0.107	1.97	1.07	45.69	
12	19-Apr	28.6-13	0.341	0.215	0.109	0.050	1.09	0.50	54.13	
13	24-May	32.5-13.5	0.344	0.208	0.111	0.046	1.11	0.46	58.56	y = 2.1137x + 0.1101
14	7-Jun	34.5-18.5	0.340	0.212	0.109	0.048	1.09	0.48	55.96	
15	21-Jun	31.3-21	0.382	0.245	0.129	0.064	1.29	0.64	50.39	
16	29-Jun	30.4-19	0.357	0.217	0.117	0.051	1.17	0.51	56.41	
17	12-Jul	31-20	0.345	0.215	0.111	0.050	1.11	0.50	54.95	
18	19-Jul	29.5-20	0.446	0.257	0.159	0.070	1.59	0.70	55.97	
19	2-Aug	27.2-18.5	0.395	0.235	0.135	0.059	1.35	0.59	56.30	
20	12-Aug	29.5-20.2	0.320	0.225	0.099	0.054	0.99	0.54	45.45	
21	23-Aug	27-19.4	0.339	0.210	0.108	0.047	1.08	0.47	56.48	
22	6-Sep	30-17	0.291	0.185	0.086	0.035	0.86	0.35	59.30	
23	14-Sep	30-19	0.285	0.187	0.083	0.036	0.83	0.36	56.63	
24	20-Sep	30.4-19	0.307	0.209	0.093	0.047	0.93	0.47	49.46	
25	1-Oct	30.5-18.6	0.279	0.178	0.080	0.032	0.80	0.32	60.00	

Table A-18: Calculation of reaction rate constants K_T and θ for nitrite nitrogen

	ln (Co/Ce)	dxn	KT	20-T	New	Kr	θ	Remarks
Co/Ce			This study		KT	KT/K20	Kr^(1/(20-T))	
1.561	0.445	0.18	0.091	7.95	0.08	0.77	0.97	KTis taken from interpolation between 19.8-20.8 and 0.087-0.159.
1.418	0.349	0.18	0.071	7.25	0.08	0.80	0.97	
1.358	0.306	0.18	0.062	6.50	0.08	0.83	0.97	
1.798	0.587	0.18	0.120	6.35	0.08	0.84	0.97	
1.490	0.399	0.18	0.081	6.25	0.08	0.84	0.97	
1.489	0.398	0.18	0.081	3.20	0.10	1.01	1.00	
1.841	0.610	0.18	0.124	2.00	0.11	1.08	1.04	
1.533	0.427	0.18	0.087	0.20	0.12	1.20	2.49	
2.180	0.779	0.18	0.159	(0.80)	0.13	1.27	0.74	
1.516	0.416	0.18	0.085	(1.05)	0.13	1.29	0.78	
2.288	0.828	0.18	0.169	(2.85)	0.14	1.43	0.88	
2.413	0.881	0.18	0.180	(3.00)	0.14	1.44	0.88	
2.298	0.832	0.18	0.170	(3.20)	0.15	1.46	0.89	
2.457	0.899	0.18	0.183	(3.50)	0.15	1.49	0.89	
2.306	0.836	0.18	0.171	(4.50)	0.16	1.58	0.90	
2.500	0.916	0.18	0.187	(4.55)	0.16	1.58	0.90	
2.294	0.830	0.18	0.169	(4.70)	0.16	1.59	0.91	
1.979	0.683	0.18	0.139	(4.70)	0.16	1.59	0.91	
2.271	0.820	0.18	0.167	(4.75)	0.16	1.60	0.91	
1.833	0.606	0.18	0.124	(4.85)	0.16	1.61	0.91	
2.220	0.798	0.18	0.163	(5.50)	0.17	1.67	0.91	
2.016	0.701	0.18	0.143	(6.15)	0.17	1.73	0.91	
2.271	0.820	0.18	0.167	(6.50)	0.18	1.77	0.92	

E- BOD analysis

To determine the value of reaction rate constant, following table is developed. Value is compared with that of USEPA.

Table A-19: Calculation of reaction rate constants K_T and θ for BOD

	ln (Co/Ce)	dxn	KT	20-T	New	Kr	Remarks
Co/Ce			This study		KT	KT/K20	
1.737	0.552	0.18	0.113	7.95	0.13	0.49	KT is taken from interpolation between 19.8-20.8 and 0.243-0.321.
1.944	0.665	0.18	0.136	7.25	0.13	0.51	
1.765	0.568	0.18	0.116	6.50	0.14	0.54	
2.500	0.916	0.18	0.187	6.35	0.14	0.55	
1.842	0.611	0.18	0.125	6.25	0.14	0.55	
2.133	0.758	0.18	0.155	4.75	0.16	0.61	
3.545	1.266	0.18	0.258	3.20	0.18	0.68	
1.739	0.553	0.18	0.113	3.15	0.18	0.69	
3.286	1.190	0.18	0.243	0.20	0.22	0.85	
4.833	1.575	0.18	0.321	(0.80)	0.23	0.91	
3.333	1.204	0.18	0.246	(1.05)	0.24	0.92	
4.500	1.504	0.18	0.307	(3.00)	0.27	1.06	
5.000	1.609	0.18	0.328	(3.20)	0.28	1.08	
5.167	1.642	0.18	0.335	(3.50)	0.28	1.10	
3.125	1.139	0.18	0.232	(4.55)	0.31	1.19	
4.667	1.541	0.18	0.314	(4.85)	0.31	1.21	
3.167	1.153	0.18	0.235	(5.50)	0.33	1.27	

F. Summary

Table A-20: Removal of pollutants for different months.

Ammonia nitrogen					Orthophosphate				
Month	Av. Temp	Inlet	Outlet	% Removal	Month	Av. Temp	Inlet	Outlet	% Removal
Jan	12.40	26.73	22.60	18.27	Jan	12.40	6.93	5.44	21.57
Feb	14.83	39.87	27.86	30.12	Feb	14.83	5.00	3.90	22.02
Mar	17.82	33.83	21.24	37.22	Mar	17.82	6.79	4.28	36.93
Apr	19.40	38.14	13.02	65.86	Apr	19.40	6.83	3.06	55.16
May	23.00	32.84	6.43	80.42	May	23.00	4.18	1.84	55.98
Jun	25.78	38.70	5.41	86.02	Jun	25.78	4.45	2.13	52.10
Jul	25.12	41.38	4.30	89.61	Jul	25.12	5.06	2.32	54.15
Aug	23.63	37.95	4.70	87.62	Aug	23.63	4.30	2.11	51.01
Sep	24.23	25.98	3.90	84.99	Sep	24.23	3.32	1.60	51.96
Oct	24.55	24.68	4.73	80.83	Oct	24.55	3.06	1.33	56.54

Nitrite nitrogen					Nitrate nitrogen				
Month	Av. Temp	Inlet	Outlet	% Removal	Month	Av. Temp	Inlet	Outlet	% Removal
Jan	12.40	1.96	1.33	32.23	Jan	12.40	57.22	49.58	13.35
Feb	14.83	1.39	0.98	29.86	Feb	14.83	57.34	46.29	19.26
Mar	17.82	1.70	1.09	36.27	Mar	17.82	68.35	46.17	32.44
Apr	19.40	1.53	0.79	48.69	Apr	19.40	67.61	34.61	48.81
May	23.00	1.11	0.46	58.56	May	23.00	62.75	32.64	47.98
Jun	25.78	1.18	0.54	54.08	Jun	25.78	68.77	39.54	42.50
Jul	25.12	1.35	0.60	55.56	Jul	25.12	78.63	50.54	35.73
Aug	23.63	1.14	0.53	53.22	Aug	23.63	64.51	30.31	53.01
Sep	24.23	0.87	0.39	54.96	Sep	24.23	66.62	35.55	46.63
Oct	24.55	0.80	0.32	60.00	Oct	24.55	58.91	26.54	54.95

BOD				
Month	Av. Temp	Inlet	Outlet	% Removal
Jan	12.40	204.0	111.0	45.59
Feb	14.84	205.5	111.0	45.99
Mar	17.83	225.0	72.0	68.00
Apr	20.80	174.0	36.0	79.31
May	23.00	162.0	36.0	77.78
Jul	25.50	228.0	72.0	68.42
Aug	24.03	174.0	36.0	79.31
Sep	23.50	186.0	36.0	80.65

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