# STUDY ON THE PERFORMANCE OF VERTICAL SUBSURFACE DOWN FLOW CONSTRUCTED WETLAND SYSTEM FOR TREATMENT OF MUNICIPAL SEWAGE FLOWING THROUGH OPEN OUTFALL DRAIN

*A thesis submitted towards partial fulfilment of the requirements for the degree of*

**Master of Engineering in**
**Water Resources and Hydraulic Engineering**
Course affiliated to Faculty of Engineering & Technology
Jadavpur University

*Submitted by*


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## CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**STUDY ON THE PERFORMANCE OF VERTICAL SUBSURFACE DOWN FLOW CONSTRUCTED WETLAND SYSTEM FOR TREATMENT OF MUNICIPAL SEWAGE FLOWING THROUGH OPEN OUTFALL DRAIN**" is bonafide work carried out by **ANINDYA ROY PRADHAN** under our supervision and guidance for partial fulfilment of the requirement for Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2018-2019.

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# CERTIFICATE OF APPROVAL **

**This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.**

Committee

Final Examination
for the evaluation of the thesis

**** Only in case the thesis is approved.**

**DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS**

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as a part of my Master of Water Resources & Hydraulic Engineering degree during academic session 2018-2019.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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# ABSTRACT

The East Calcutta Wetlands are a complex of natural and human-made wetlands lying east of the city of Calcutta (Kolkata), of West Bengal in India. The wetlands cover 125 square kilometers, and include salt marshes and salt meadows, as well as sewage farms and settling ponds. The wetlands are used to treat Kolkata's sewage, and the nutrients contained in the waste water sustaining fish farms and agriculture. The East Calcutta Wetlands were designated a "wetland of international importance" under the Ramsar Convention on 19 August 2002. Recently illegal landfills are on the rise and the wetlands are being slowly assimilated in the stream city. This unprecedented land development and urbanization are creating concerns about the impact on the environment. This is because the wetlands serve as a natural sponge absorbing excess rainfall and doing its bit to reduce pollution. Wetlands are under threat due to exponential expansion of real-estate projects in eastern Kolkata especially in the Salt Lake and Rajarhat sectors. This has resulted in the urgent need for the development and implementation of innovative systems to resolve the wastewater treatment constraints. Constructed wetland systems are a good such alternative technologies which have the potential to meet the required influent treatment standards as compared to conventional methods. The plants, microorganisms and substrates together act as a filter and purification system. First, water is slowed as it enters the wetland, allowing for the sedimentation of solids. Through the process of water flow through the constructed wetland, plant roots and the substrate remove the larger particles present in the wastewater. Pollutants and nutrients present in the wastewater are then naturally broken down and taken up by the bacteria and plants, thereby removing them from the water. The retention time in the wetland, which varies depending on the design and desired quality level, along with UV radiation and plant secretion of antibiotics will also kill the pathogens present in wastewater. After treatment in a constructed wetland, water can be safely released into surface waters or used various purposes.

To develop a energy efficient constructed wetland technology for in-situ treatment of domestic waste water flowing through outfall drain and to study different criteria and variables of the treatment unit for arriving at the design guideline a bench scale study on performance of constructed wetland was conducted. From the bench scale model study analysis of vertical Flow Constructed Wetland, it was found that the removal efficiency of Turbidity, TSS, COD, BOD, Phosphorus, TKN, TC and FC were varying from 73% - 90.6%, 52.6% - 78.2%, 26.8% - 56.2%, 33.3% - 91.6%, 83.9% - 92.9%, 76.9% - 96.8%, 35.9% - 99.8% and 15.3% - 99.8% respectively.

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# INTRODUCTION

## 1.1 GENERAL

Water is the most essential commodity for the sustenance of life. Water makes everything grow but, there is a saying "Water water everywhere but not a drop to drink" .It emphasizes the importance of potable water. Water for human consumption ought to be pure and wholesome. Water plays an important role in making human life not only survive but comfortable and luxurious. Water is used for drinking, cooking, bathing, air-conditioning, flushing of sewers, firefighting, entertainment, industrial processes, power generation etc.

Water is and has been used for human consumption, since ages. Even in ancient cities there used to be a network of water supply and its proper disposal. Water then was carried through earthen and stone channels and was usually untreated but now a day's importance of treated water is well understood and it is treated before supplying it to community. With the advancement in technology new methods of treatment device have been evolved and are being adopted.

## 1.2 WORLD WATER SCENARIO

Over 28 countries as on 1990, experienced water stress or scarcity. With world population growing by 1.6 percent a year, it is predicted that by 2025, about 46 to 52 countries will fall into these categories. Besides, human being, coastal and marine ecosystem will be facing major threats from water. It will also lead to the increase in international conflicts particularly among the water-dependent countries. An approach toconservation and sustainable use of water for safe future should be the guiding policy for solving the ever-growing water problem.

Freshwater resources are being depleted very fast. The available freshwater resources are unevenly distributed, with much of the water located far from human population. There arean estimated 263 major international river basins in the world, covering about 45% of theearth's land surface area. Among the available freshwater, 90% is available through groundwater resources serving the drinking water requirement of about 1.5 billion people. Agriculture sector is the largest consumer of the available water accounting to 75% of the available global water followed by industrial activities to 20% and remaining 5% is for domestic sector.

## 1.3 INDIAN SCENARIO

With a diverse population that is three times the size of the United States but one-third the physical size, India has the second largest population in the world. According to the World Bank, India has taken significant steps to reduce poverty but the number of people who live in poverty is still highly disproportionate to the number of people who are middle-income, with a combined rate of over 52% of both rural and urban poor.

Although India has made improvements over the past decades to both the availability and quality of municipal drinking water systems, its large population has stressed planned water resources and rural areas are left out. In addition, rapid growth in India's urban areas has stretched government solutions, which have been compromised by over-privatization.

Regardless of improvements to drinking water, many other water sources are contaminated with both bio and chemical pollutants, and over 21% of the country's diseases are water-related. Furthermore, only 33% of the country has access to traditional sanitation.

One concern is that India may lack overall long-term availability of replenishable water resources. While India's aquifers are currently associated with replenishing sources, the country is also a major grain producer with a great need for water to support the commodity. As with all countries with large agricultural output, excess water consumption for food production depletes the overall water table.

Many rural communities in India who are situated on the outskirts of urban sprawl also have little choice but to drill wells to access groundwater sources. However, any water system adds to the overall depletion of water. There is no easy answer for India which must tap into water sources for food and human sustenance, but India's overall water availability is running dry.

India's water crisis is often attributed to lack of government planning, increased corporate privatization, industrial and human waste and government corruption. In addition, water scarcity in India is expected to worsen as the overall population is expected to increase to 1.6 billion by year 2050. To that end, global water scarcity is expected to become a leading cause of national political conflict in the future, and the prognosis for India is no different.

On a positive note, some areas of India are fortunate to have a relatively wet climate, even in the most arid regions. However, with no rain catchment programs in place, most of the water is displaced or dried up instead of used. In these areas, rain harvesting could be one solution for water collection.

### 1.4 MUNICIPAL WASTEWATER GENERATION AND TREATMENT IN INDIA

Water, food and energy securities are emerging as increasingly important and vital issues for India and the world. Most of the river basins in India and elsewhere are closing or closed and experiencing moderate to severe water shortages, brought on by the simultaneous effects of agricultural growth, industrialization and urbanization. Current and future fresh water demand could be met by enhancing water use efficiency and demand management. Thus, wastewater/low quality water is emerging as potential source for demand management after essential treatment. An estimated 38354 million litres per day (MLD) sewage is generated in major cities of India, but the sewage treatment capacity is only of 11786 MLD. Similarly, only 60% of industrial waste water, mostly large scale industries, is treated. Performance of state owned sewage treatment plants, for treating municipal waste water, and common effluent treatment plants, for treating effluent from small scale industries, is also not complying with prescribed standards. Thus, effluent from the treatment plants, often, not suitable for household purpose and reuse of the waste water is mostly restricted to agricultural and industrial purposes. Wastewater- irrigated fields generate great employment opportunity for female and male agricultural laborers to cultivate crops, vegetables, flowers, fodders that can be sold in nearby markets or for use by their livestock. However, there are higher risk associated to human health and the environment on use of wastewater especially in developing countries, where rarely the wastewater is treated and large volumes of untreated wastewater are being used in agriculture (*Water* Technology Centre, Indian Agricultural Research Institute, New Delhi)

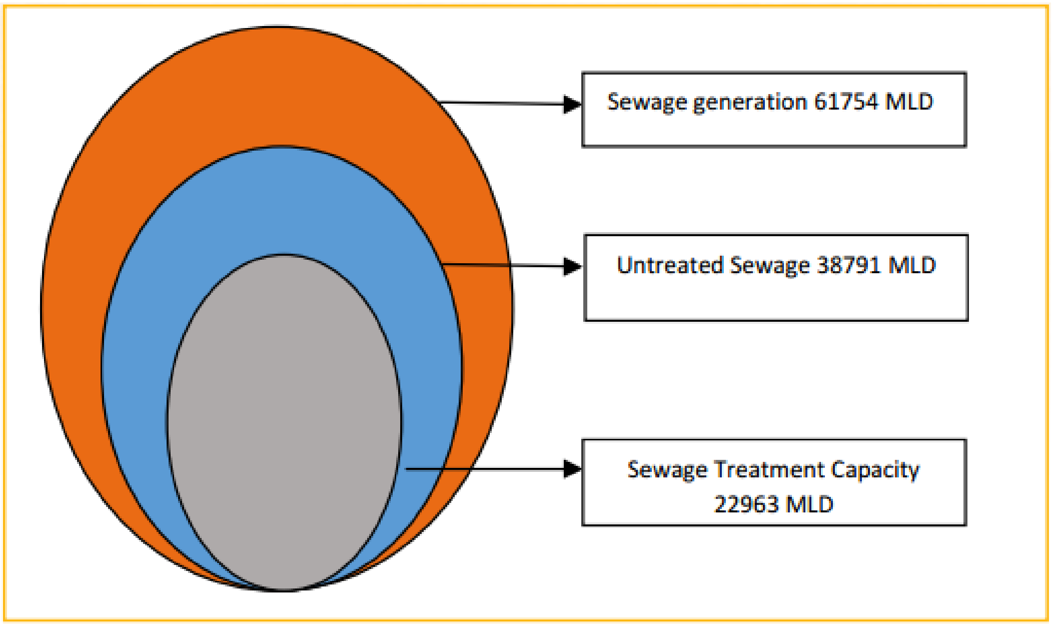


Fig 1.1: India’s Sewage generation and treatment 2019

### 1.4.1 STATUS IN METROPOLITAN CITIES IN INDIA


Fig 1.2 : status of water supply, wastewater generation & treatment in class-I cities

With rapid expansion of cities and domestic water supply, quantity of gray/wastewater is increasing in the same proportion. As per CPHEEO estimates about 70-80% of total water supplied for domestic use gets generated as wastewater. The per capita wastewater generation by the class-I cities and class-II towns, representing 72% of urban population in India, has been estimated to be around 98 lpcd while that from the National Capital Territory-Delhi alone (discharging 3,663 mld of wastewaters, 61% of which is treated) is over 220 lpcd (CPCB, 1999). As per CPCB estimates, the total wastewater generation from Class I cities (498) and Class II (410) towns in the country is around 35,558 and 2,696 MLD respectively. While, the installed sewage treatment capacity is just 11,553 and 233 MLD, respectively (Figure 2) thereby leading to a gap of 26,468 MLD in sewage treatment capacity. Maharashtra, Delhi, Uttar Pradesh, West Bengal and Gujarat are the major contributors of wastewater (63%; CPCB, 2007a). Further, as per the UNESCO and WWAP (2006) estimates (Van-Rooijen et al., 2008), the industrial water use productivity of India (IWP, in billion constant 1995 US$ per m 3 ) is the lowest (i.e. just 3.42) and about 1/30th of that for Japan and Republic of Korea. It is projected that by 2050, about 48.2 BCM (132 billion litres per day) of wastewaters (with a potential to meet 4.5% of the total irrigation water demand) would be generated thereby further widening this gap.

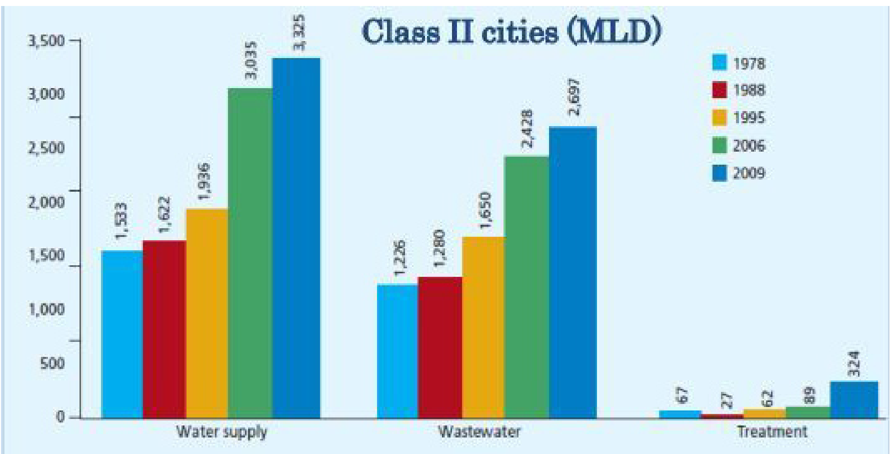


Fig 1.3 : status of water supply, wastewater generation & treatment in class-II cities

In India, there are 234-Sewage Water Treatment plants (STPs). Most of these were developed under various river action plans (from 1978-79 onwards) and are located in (just 5% of) cities/ towns along the banks of major rivers (CPCB, 2005a). In class-I cities, oxidation pond or Activated sludge process is the most commonly employed technology, covering 59.5% of total installed capacity. This is followed by Up-flow Anaerobic Sludge Blanket technology, covering 26% of total installed capacity. Series of Waste Stabilization Ponds technology is also employed in 28% of the plants, though its combined capacity is only 5.6%. A recent World Bank Report (Shuval et al. 1986) came out strongly in favour of stabilization ponds as the most suitable wastewater treatment system in developing countries, where land is often available at reasonable opportunity cost and skilled labour is in short supply.

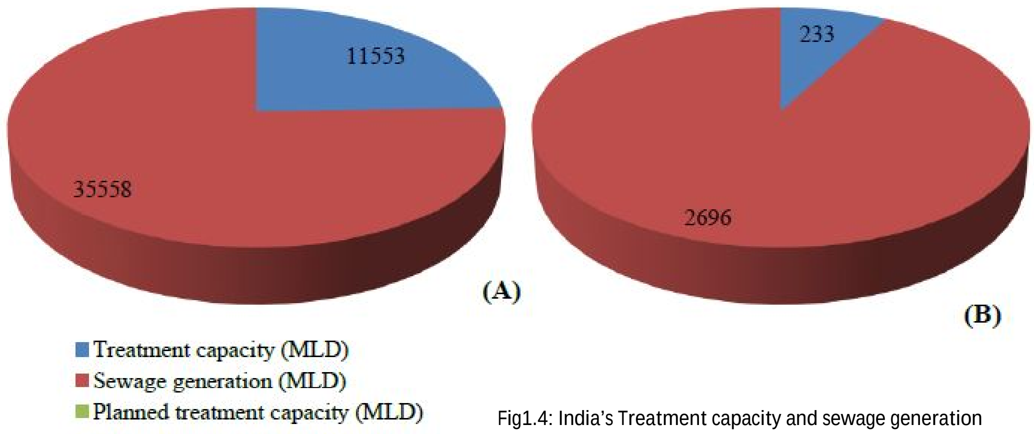


Fig1.4: India's Treatment capacity and sewage generation

Apart from domestic sewage, about 13468 MLD of wastewater is generated by industries of which only 60% is treated. In case of small scale industries that may not afford cost of waste water treatment plant, Common Effluent Treatment Plants (CETP) has been set-up for cluster of small scale industries (CPCB, 2005b). The treatment methods adapted in these plants are dissolved air floatation, dual media filter, activated carbon filter, sand filtration and tank stabilization, flash mixer, clariflocculator, secondary clarifiers and Sludge drying beds, etc. Coarse material and settable solids are removed during primary treatments by screening, grit removal and sedimentation. Treated industrial waste water from CETPs mixed disposed in rivers. For example, 10 CETPs from Delhi with capacity of 133 MLD dispose their effluent in Yamuna River.

### 1.4.2 STATUS OF SEWAGE GENERATION AND TREATMENT CAPACITY IN CITIES

| S. No. | Name of the city | Sewage generation (in MLD) | Sewage Treatment Capacity (in MLD) | Percent of treatment capacity |
|---|---|---|---|---|
| 1 | Hyderabad | 426.21 | 593 | 100 |
| 2 | Vishakhapatnam | 134.99 | - | - |
| 3 | Vijayawada | 128.39 | - | - |
| 4 | Patna | 279.14 | 105 | 37 |
| 5 | Delhi | 3800 | 2330 | 61 |
| 6 | Ahmadabad | 472 | 488 | 96 |
| 7 | Surat | 432 | 202 | 46 |
| 8 | Rajkot | 108.8 | 44.5 | 40 |
| 9 | Vadodara | 180 | 206 | 100 |
| 10 | Bangalore | 771.75 | - | - |
| 11 | Indore | 204 | 78 | 38 |
| 12 | Bhopal | 334.75 | 22 | 6 |
| 13 | Jabalpur | 143.34 | - | - |
| 14 | Mumbai | 2671 | 2130 | 80 |
| 15 | Pune | 474 | 305 | 64 |
| 16 | Nagpur | 380 | 100 | 26 |
| 17 | Nasik | 227.84 | 107.5 | 47 |
| 18 | Ludhiana | 235.2 | 311 | 100 |
| 19 | Amritsar | 192 | - | - |
| 20 | Jaipur | 451.71 | 54 | 11 |
| 21 | Chennai | 158 | 264 | 100 |
| 22 | Kanpur | 417.35 | 171 | 41 |
| 23 | Lucknow | 363.81 | 42 | 11 |
| 24 | Agra | 260.36 | 88 | 33 |
| 25 | Kolkata | 705.86 | 172 | 24 |
| 26 | Faridabad | 164 | 65 | 39 |
| 27 | Jamshedpur | 199.43 | - | - |
| 28 | Asansol | 147 | - | - |
| 29 | Coimbatore | 120 | - | - |
| 30 | Madurai | 97.93 | - | - |
| 31 | Meerut | 177.05 | - | - |
| 32 | Varanasi | 230.17 | 102 | 44 |
| 33 | Allahabad | 176 | 60 | 34 |
| 34 | Kochi | 188.4 | - | - |
| 35 | Dhanbad | 192 | - | - |
| | **Total** | **15644** | **8040** | **51** |

Table 1.1: India's sewage generation and treatment capacity

There are 35 metropolitan cities (more than 10 Lac Population) in India; 15644MLD of sewage is generated from these metropolitan cities. The treatment capacity exists for 8040MLD. Among the metropolitan cities, Delhi has the maximum treatment capacity that is 2330MLD. Next to Delhi, Mumbai has the capacity of 2130MLD which is 26% of total capacity in metropolitan cities. Delhi and Mumbai therefore in combination have 55% of treatment capacity of the metropolitan cities. Some cities such as Hyderabad, Vadodara, Chennai, Ludhiana and Ahmadabad treatment capacity meets the volume of generation. Cities like delhi, dhanbad have more than 50% rest of the cities have the capacity less than 50%

### 1.4.3 STATUS OF MUNICIPAL WASTEWATER GENERATION GENERATION CLASS-I & II CITIES

There are projected 498 Class-I Cities (having more than 1 Lac Population) in India. Nearly 52% cities (260 out of 498) cities are located in Andhra Pradesh, Maharashtra, Tamilnadu, Uttar Pradesh and West Bengal. The sewage generated in class-I cities estimated 35558.12 MLD. 93% of total wastewater is generated in Class-I cities only. Total Sewage treatment capacity of class-I cities is reported 11553.68 MLD, which is 32% of the sewage generation. Out of 11553.69 MLD sewage treatment capacity 8040 MLD is treated in 35 metropolitan cities. This indicates that other than metropolitan cities, the capacity of 462 Class-I cities is only 31%. Actual sewage treatment due to inadequacy of the sewage collection system shall be low compare to capacity. The class-II cities are mostly located in Andhra Pradesh, Maharashtra, Tamilnadu, Uttar Pradesh and Gujarat (total 225, nearly 50%). The total wastewater generated in class-II towns is 233.7, which is 8% of the total sewage generated.

| S. No. | State/Union Territory | Sewage generation in class -1 Cities (in MLD) | Sewage generation in class -1 towns (in MLD) | Total (in MLD) |
|---|---|---|---|---|
| 1 | Andaman & Nicobar | 12.00 | - | 12.0064 |
| 2 | Andhra Pradesh | 1760.60 | 217.59 | 1978.1996 |
| 3 | Assam | 380.14 | 6.46 | 386.6 |
| 4 | Bihar | 1009.7 | 107.42 | 1117.12 |
| 5 | Chandigarh | 429.76 | - | 58.2936 |
| 6 | Chhattisgarh | 350.47 | 40.82 | 391.29 |
| 7 | Delhi | 3800 | - | 3800 |
| 8 | Goa | 9.79 | 13.89 | 23.62 |
| 9 | Gujarat | 1680.92 | 227.55 | 1908.47 |
| 10 | Haryana | 626.69 | 43.52 | 670.212 |
| 11 | Himachal Pradesh | 28.94 | - | 28.94 |
| 12 | Jammu & Kashmir | 213.93 | 27.86 | 27.86 |
| 13 | Jharkhand | 830.47 | 78.21 | 908.68 |
| 14 | Karnataka | 1790.40 | 233.37 | 2023.778 |
| 15 | Kerala | 575.17 | 231.32 | 806.49 |
| 16 | Madhya Pradesh | 1248.72 | 130.9 | 1379.626 |
| 17 | Maharashtra | 9986.29 | 213.73 | 10200.02 |
| 18 | Manipur | 26.74 | - | 26.74 |
| 19 | Meghalaya | 20.84 | 11.25 | 32.09 |
| 20 | Mizoram | 5.712 | - | 5.712 |
| 21 | Nagaland | 13.62 | 1.36 | 14.984 |
| 22 | Orissa | 660.73 | 78.42 | 739.15 |
| 23 | Pondicherry | 56.46 | 7.984 | 64.444 |
| 24 | Punjab | 1528.26 | 157.40 | 1685.664 |
| 25 | Rajasthan | 1382.37 | 147.79 | 1530.16 |
| 26 | Tamilnadu | 1077.21 | 184.67 | 1261.88 |
| 27 | Tripura | 24 | - | 24 |
| 28 | Uttar Pradesh | 3506.01 | 345.70 | 3851.71 |
| 29 | Uttrakhand | 176.97 | 9.07 | 188.31 |
| 30 | West Bengal | 2345.21 | 180.42 | 2525.63 |
| | **Total** | **35558.12** | **2696.70** | **38254.82** |

Table 1.2: Sewage generation treatment capacity in indian cities

## 1.5 FUTURE SCENARIO OF SEWAGE GENERATION IN INDIA

It is estimated that the projected wastewater from urban centres may cross 120,000 mld by 2051 and that rural India will also generate not less than 50,000 mld in view of water supply designs for community supplies in rural areas. However, wastewater management plans do not address this increasing pace of wastewater generation. In view of the population increase, demand of freshwater for all uses will become unmanageable.

| *Year* | *Urban population (million)* | *Wastewater generation lpcd* | *Gross wastewater generation (mld)* |
|---|---|---|---|
| 1977–8 | 72.8 | 116 | 7007 |
| 1989–90 | 122.7 | 119 | 12145 |
| 1994–5 | 151.6 | 130 | 16662 |
| 2003–4 | 243.5 | 121 | 26254 |
| 2009 | 316.15 | 121 | 38254 |
| 2051 | 1000 (Projected) | 121 (Assumed) | 120000 (Projected) |

Table 1.3: year wise waste water generation in india

## 1.6 STATUS OF SEWAGE GENERATION AND TREATMENT IN WESTBENGAL

● It was estimated that about 527 million litres of waste water fall into the river Ganges from the 15 class I cities located along its bank. The KMDA under the Department of Urban Development, Government of West Bengal was designated as the supreme organization for implementation of the GAP Phase I schemes with the help of KMWSA and the Public Health Engineering Department.

● Different conventional sewage treatment technology was adopted at various location. Low cost treatment methods were used in some places where land were available and were found to be most suitable to reduce the bacterial load.

● Performance of individual sewage treatment plant is satisfactory but the influent sewage strength in items of each organic matter content (BOD value) in most location was found to be low in comparison to the prior assumption. Thus the STPs are mostly operated at under load condition.

● It is observed that there are gaps in sewer lines and thus the sewage is not reaching to the treatment plant. The sewer lines are also silted and thus the sewage cannot flow smoothly towards treatment plant.

● Algae and water hyacinth growth was observed in low cost treatment plant.
● Sewage treatment plant at behrampur is non functional due to absence of sewage. A stretch of 150m of sewer line leading to main pumping station could not be laid properly due to some construction difficulties. Some alternative arrangements are required to be formulated to make the system operational.
● Although all the STPs are required to take consent to operate under the water at 1974, it was observed that none of them have taken consent from the westbengal pollution control board.
● The STPs were not provided with standby power arrangement. However the power supply was reasonably stable at the ASPs and trickling filter.

## 1.7 SEWAGE CHARACTERISTICS

**●Temperature**

The observations of temperature of sewage are useful in indicating solubility of oxygen, which affects transfer capacity of aeration equipment in aerobic systems, and rate of biological activity. Extremely low temperature affects adversely on the efficiency of biological treatment systems and on efficiency of sedimentation. In general, under Indian conditions the temperature of the raw sewage is observed to be between 15 and 35 0 C at various places in different seasons.

**●pH**

The hydrogen ion concentration expressed as pH, is a valuable parameter in the operation of biological units. The pH of the fresh sewage is slightly more than the water supplied to the community. However, decomposition of organic matter may lower the pH, while the presence of industrial wastewater may produce extreme fluctuations. Generally the pH of raw sewage is in the range 5.5 to 8.0.

**●Colour and Odour**

Fresh domestic sewage has a slightly soapy and cloudy appearance depending upon its concentration. As time passes the sewage becomes stale, darkening in colour with a pronounced smell due to microbial activity.

**●Solids**

Though sewage generally contains less than 0.5 percent solids, the rest being water, still the nuisance caused by the solids cannot be overlooked, as these solids are highly degradable and therefore need proper disposal. The sewage solids may be classified into dissolved solids, suspended solids and volatile suspended solids. Knowledge of the volatile or organic fraction of solid, which decomposes, becomes necessary, as this constitutes the load on biological treatment units or oxygen resources of a stream when sewage is disposed off by dilution. The estimation of suspended solids, both organic and inorganic, gives a general picture of the load on sedimentation and grit removal system during sewage treatment. Dissolved inorganic fraction is to be considered when sewage is used for land irrigation or any other reuse is planned.

**●Nitrogen and Phosphorus**

The principal nitrogen compounds in domestic sewage are proteins, amines, amino acids, and urea. Ammonia nitrogen in sewage results from the bacterial decomposition of these organic constituents. Nitrogen being an essential component of biological protoplasm, its concentration is important for proper functioning of biological treatment systems and disposal on land. Generally, the domestic sewage contains sufficient nitrogen, to take care of the needs of the biological treatment. For industrial wastewater if sufficient nitrogen is not present it is required to be added externally. Generally nitrogen content in the untreated sewage is observed to be in the range of 20 to 50 mg/L measured as TKN. Phosphorus is contributing to domestic sewage from food residues containing phosphorus and their breakdown products. The use of increased quantities of synthetic detergents adds substantially to the phosphorus content of sewage. Phosphorus is also an essential nutrient for the biological processes. The concentration of phosphorus in domestic sewage is generally adequate to support aerobic biological wastewater treatment. However, it will be matter of concerned when the treated effluent is to be reused. The concentration of PO4 in raw sewage is generally observed in the range of 5 to 10 mg/L.

**●Chlorides**

Concentration of chlorides in sewage is greater than the normal chloride content of water supply. The chloride concentration in excess than the water supplied can be used as an index of the strength of the sewage. The daily contribution of chloride averages to about 8 gm per person. Based on an average sewage flow of 150 LPCD, this would result in the chloride content of sewage being 50 mg/L higher than that of the water supplied. Any abnormal increase should indicate discharge of chloride bearing wastes or saline groundwater infiltration, the latter adding to the sulphates as well, which may lead to excessive generation of hydrogen sulphide.

**●Organic Material**

Organic compounds present in sewage are of particular interest for environmental engineering. A large variety of microorganisms (that may be present in the sewage or in the receiving water body) interact with the organic material by using it as an energy or material source. The utilization of the organic material by microorganisms is called metabolism. The conversion of organic material by microorganism to obtain energy is called catabolism and the incorporation of organic material in the cellular material is called anabolism. To describe the metabolism of microorganisms and oxidation of organic material, it is necessary to characterize quantitatively concentration of organic matter in different forms. In view of the enormous variety of organic compounds in sewage it is totally unpractical to determine these individually. Thus a parameter

must be used that characterizes a property that all these have in common. In practice two properties of almost all organic compounds can be used:
(1) organic compound can be oxidized; and
(2) organic compounds contain organic carbon.
In environmental engineering there are two standard tests based on the oxidation of organic material: 1) the Biochemical Oxygen Demand (BOD) and 2) the Chemical Oxygen Demand (COD) tests. In both tests, the organic material concentration is measured during the test. The essential differences between the COD and the BOD tests are in the oxidant utilized and the operational conditions imposed during the test such as biochemical oxidation and chemical oxidation. The other method for measuring organic material is the development of the Total Organic Carbon (TOC) test as an alternative to quantify the concentration of the organic material.

**Biochemical Oxygen Demand (BOD):** The BOD of the sewage is the amount of oxygen required for the biochemical decomposition of biodegradable organic matter under aerobic conditions. The oxygen consumed in the process is related to the amount of decomposable organic matter. The general range of BOD observed for raw sewage is 100 to 400 mg/L. Values in the lower range are being common under average Indian cities.

**Chemical Oxygen Demand (COD):** The COD gives the measure of the oxygen required for chemical oxidation. It does not differentiate between biological oxidisable and nonoxidisable material. However, the ratio of the COD to BOD does not change significantly for particular waste and hence this test could be used conveniently for interpreting performance efficiencies of the treatment units. In general, the COD of raw sewage at various places is reported to be in the range 200 to 700 mg/L. In COD test, the oxidation of organic matter is essentially complete within two hours, whereas, biochemical oxidation of organic matter takes several weeks. In case of wastewaters with a large range of organic compounds, an extra difficulty in using BOD as a quantitative parameter is that the rate of oxidation of organic compounds depends on the nature and size of its molecules. Smaller molecules are readily available for use by bacteria, but large molecules and colloidal and suspended matters can only be metabolized after preparatory steps of hydrolysis. It is therefore not possible to establish a general relationship between the experimental five-day BOD and the ultimate BOD of a sample, i.e., the oxygen consumption after several weeks. For sewage (with k=0.23 d-1 at 20o C) the BOD5 is 0.68 times of ultimate BOD, and ultimate BOD is 87% of the COD. Hence, the COD /BOD ratio for the sewage is around 1.7.

**● Toxic Metals and Compounds**

Some heavy metals and compounds such as chromium, copper, cyanide, which are toxic may find their way into municipal sewage through industrial discharges. The concentration of these compounds is important if the sewage is to treat by biological treatment methods or disposed off in stream or on land. In general these compounds are within toxic limits in sanitary sewage; however, with receipt of industrial discharges they may cross the limits in municipal wastewaters. Effect of Industrial Wastes Wastewaters from industries can form important component of sewage in both volume and composition. It is therefore necessary that details about nature of industries, the quantity and characteristics of the wastewater and their variations, which may affect the sewerage system and sewage treatment process, should be collected.

### 1.8 EFFECT OF UNTREATED SEWAGE ON SURFACE WATER BODIES

- Effect of organic pollution
- Effect of nutrients
- Effect of high dissolved solids (TDS)
- Effect of toxic pollutants on water quality
- Effect of ecological balance

### 1.9 EFFECTS OF UNTREATED SEWAGE ON HUMAN HEALTH

Some 60% of all infant mortality is linked to infectious and parasitic diseases, most of them water related.

- Water borne diseases – Typhoid, cholera, jaundice, diarrhea etc.
- Water based diseases – Schistosomiasis, guinea worm etc.
- Water related vector diseases – sleeping sickness, malaria etc.
- Water waste diseases – scabis, trachoma etc.

# CONSTRUCTED WETLAND SYSTEM

## 2.1 NATURAL TECHNOLOGIES FOR WASTE WATER TREATMENT

Natural technologies for waste water treatment use natural, commonly occurring self treatment processes that take place in soil, water and wetland environments. Soil and vegetation are directly involved in the processes, mainly through the formation of favorable condition for the development of microorganisms taking part in the treatment process. These technologies are defined in terms of the presence of natural components or complete systems in the waste water treatment. These systems can use unique natural components or more complex system with various components or inter ecosystems. The process involved in these technologies in order to eliminate waste water pollutants tend to be similar to those used in conventional systems which are combined with other naturally occurring process of the ecosystems. The main difference between conventional and natural technologies is that the former tends to occur in energy - accelerated velocity reactors, while in the extensive systems , the process occur at natural speeds.

| **CONVENTIONAL** | **NATURAL** |
|---|---|
| High energy expenditure: electrical energy for oxidation and mixing in reactors | Little or no energy expenditure: Natural energy (sunlight and wind energy) |
| Advanced technological equipment | Little or no advanced technological equipment |
| Proportionally lower surface area | Require considerable surface area |
| Short hydraulic retention time | Long hydraulic retention time |
| Process may be rapidly modified | Treatment mechanism have considerable inertia |
| Complex maintenance and exploitation | Simple maintenance and exploitation |
| Specialized labour supply required | Management should know the process and be able to prevent problems |
| Technological appearance | Good integration in landscape |
| Artificial process (very accelerated system) | Natural process at natural speed |

Table2.1: Comparison of Conventional and Natural Technologies

### 2.1.1 CLASSIFICATION OF NATURAL TECHNOLOGIES

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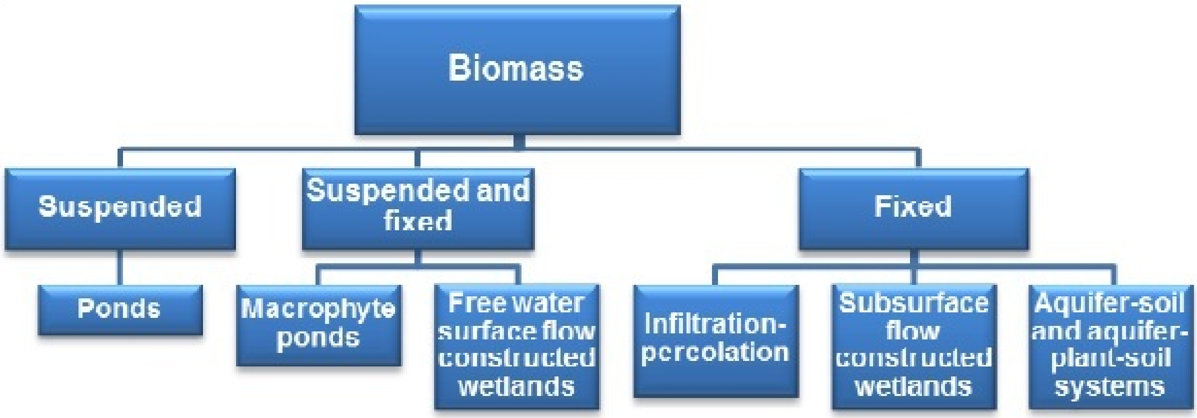



## 2.2CONSTRUCTED WETLAND AN ECO-TECHNOLOGICAL ADVANCEMENT

A constructed wetland (CW) is an artificial wetland to treat municipal or industrial wastewater, greywater or stormwater runoff. It may also be designed for land reclamation after mining or as a mitigation step for natural areas lost to land development.Constructed wetlands are engineered systems that use natural functions vegetation, soil, and organisms to treat wastewater. Depending on the type of wastewater the design of the constructed wetland has to be adjusted accordingly. Constructed wetlands have been used to treat both centralized and on-site wastewater. Primary treatment is recommended when there is a large amount of suspended solids or soluble organic matter (measured as BOD and COD). Similarly to natural wetlands, constructed wetlands also act as a biofilter and/or can remove a range of pollutants (such as organic matter, nutrients, pathogens, heavy metals) from the water. Constructed wetlands are a sanitation technology that have not been designed specifically for pathogen removal, but instead have been designed to remove other water quality constituents such as suspended solids, organic matter and nutrients (nitrogen and phosphorus).[1] All types of pathogens (i.e., bacteria, viruses, protozoan and helminths) are expected to be removed to some extent in a constructed wetland. Subsurface wetlands provide greater pathogen removal than surface wetlands.

## 2.3 HISTORY OF CONSTRUCTED WETLANDS

The scientific studies on the use of CWs for wastewater treatment began in themiddle of the last century. The first experiments were undertaken by Käthe Seidel inGermany in the early 1950s at the Max Planck Institute in Plön (Seidel, 1955). In herreport, she discussed the possibility “of lessening the overfertilization, pollution andsilting up of inland waters through appropriate plants, thereby allowing the contaminatedwaters to support life once more” (Seidel, Happel, &Graue, 1978, p. 2). She opines thatmacrophytes (e.g.,*Schoenoplectuslacustris*) are capable of removing large quantities oforganic and inorganic substances from polluted water. Moreover, *Schoenoplectus*spp.(bulrush) not only enriches the soil on which it grows in bacteria and humus butapparently exudes antibiotics. Bacteria and heavy metals in the polluted water areeliminated and removed by passing through the macrophytes.Seidel's discoveries gave birth to modern CWs and stimulated the followingresearch and applications of engineered treatment wetlands in the Western world.However, most of her studies focused on the subsurface flow (SSF) CW. The first fullscaleCW was built with a FWS system in the Netherlands in 1967 (De Jong, 1976). Thistreatment facility was designed to clean the wastewater from a camping site with 6000summer visitors per day.In North American, the experimentation with FWS wetlands started with theobservation of assimilative capacity in natural wetlands at the end of the 1960s andbeginning of 1970s (Spangler, Sloey, & Fetter, 1976; Wolverton, 1987). Between 1967and 1972, researchers in Chapel Hill, North Carolina began a five year study using acombination of constructed coastal ponds and natural salt marshes for the recycling andreuse of municipal wastewater (Odum, Ewel, Mitsch, & Ordway, 1977). In 1973, the firstfully CW consisting of a series of constructed marshes, ponds and meadows was built inBrookhaven, New York (Kadlec& Knight, 1996). About the same time, aninterdisciplinary research team at the University of Michigan began the Houghton Lakeproject. This is the first application of a treatment wetland in a cold climate area (Kadlec,Richardson, &Kadlec, 1975; Kadlec& Tilton, 1979). Since then, FWS CWs have beenbroadly used in the United States for various types of wastewater treatment.

## 2.4 TYPES OF CONSTRUCTED WETLAND

| | Constructed Wetlands | | | | | | |
|---|---|---|---|---|---|---|---|
| Water Level | FWS | | | | SSF | | |
| Plants | Free-floating | Floating-leaved | Submerged | Emergent | Emergent | | |
| Flow | Horizontal | | | | Horizontal | Vertical | |
| Direction | | | | | | Down flow | Up flow |

Table 2.2 : Constructed wetland classification

There are several types of constructed wetlands. Constructed wetland systems can also be combined with conventional treatment technologies. According to the life form of the dominating macrophytes, CWs for wastewater treatment may be classified into three types (Brix, 1994): (a) free-floating macrophyte-based systems, (b) submerged macrophytebased systems, and (c) rooted emergent macrophyte-based systems. Another classification of wetlands based upon the water flow regime of different rooted emergent systems distinguishes CWs into (a) surface flow systems, (b) horizontal subsurface flow systems, (c)vertical subsurface flow systems, and (d) hybrid systems. Surface flow wetlands (SF) are densely vegetated by a variety of plant species and typically have water depths less than 0.4 m. subsurface flow wetlands (SSF) use a bed of soil or gravel as a substrate for the growth of rooted emergent wetland plants. Mechanically pretreated wastewater flows by gravity, through the bed substrate, where it contacts a mixture of facultative microorganisms living in association with the substrate and plant roots (Haberl et al., 2003). Depending on the direction of flow of the wastewater, SSF wetlands can be either horizontal flow type or vertical flow type. In horizontal SSF systems, the substrate is maintained water saturated through continuous application of wastewater.

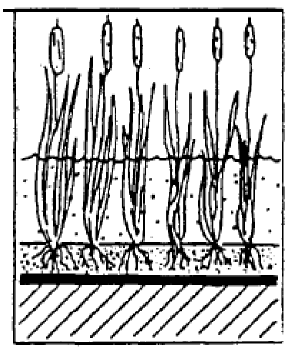



Fig 2.1(a): Surface Flow Wetland

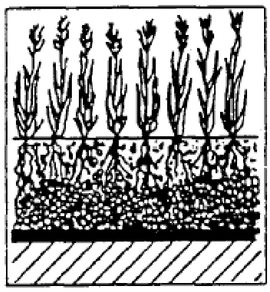



Fig 2.1(b): Subsurface Flow Wetland

### 2.4.1 SURFACE FLOW CONSTRUCTED WETLANDS

A surface flow (SF) constructed wetland consists of a shallow basin, soil or other medium to support the roots of vegetation, and a water control structure that maintains a shallow depth of water. The water surface is above the substrate. SFCW look much like natural marshes and can provide wildlife habitat and aesthetic benefits as well as water treatment. In SFCW, the nearsurface layer is aerobic while the deeper waters and substrate are usually anaerobic. Stormwater wetlands and wetlands built to treat mine drainage and agricultural runoff are usually SF wetlands. SF wetlands are sometimes called free water surface wetlands or, if they are for mine drainage, aerobic wetlands. The advantages of SF wetlands are that their capital and operating costs are low, and that their construction, operation, and maintenance are straightforward. The main disadvantage of SF systems is that they generally require a larger land area than other systems.

The channel or basin is lined with an impermeable barrier (clay or geo-textile) covered with rocks, gravel and soil and planted with native vegetation (e.g., cattails, reeds and/or rushes). The wetland is flooded with wastewater to a depth of 10 to 45 cm above ground level. The wetland is compartmentalized into at least two independent flow paths. The number of compartments in series depends on the treatment target. The efficiency of the free-water surface constructed wetland also depends on how well the water is distributed at the inlet. Wastewater can be fed into the wetland, using weirs or by drilling holes in a distribution pipe, to allow it to enter at evenly spaced intervals

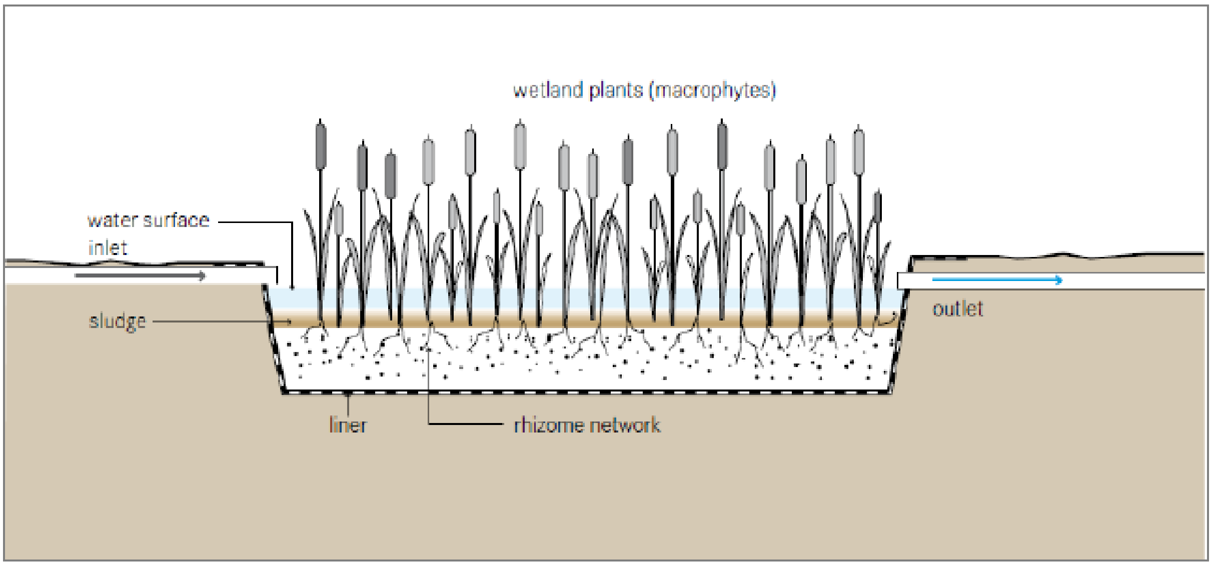



Fig 2.2: Surface Flow Constructed Wetlands

### 2.4.2 SUBSURFACE FLOW CONSTRUCTED WETLANDS

A subsurface flow (SSF) wetland consists of a sealed basin with a porous substrate of rock or gravel. The water level is designed to remain below the top of the substrate. In most of the systems in the United States, the flow path is horizontal, although some European systems use vertical flow paths. SSF systems are called by several names. Including vegetated submerged bed, root zone method, microbial rock reed filter, and plant-rock filter systems. Because of the hydraulic constraints imposed by the substrate, SSF wetlands are best suited to wastewaters with relatively low solids concentrations and under relatively uniform flow conditions. SSF wetlands have most frequently been used to reduce 5-day biochemical oxygen demand (BOD5) from domestic wastewaters. The advantages cited for SSF wetlands are greater cold tolerance, minimization of pest and odor problems, and, possibly, greater assimilation potential per unit of land area than in SF systems.

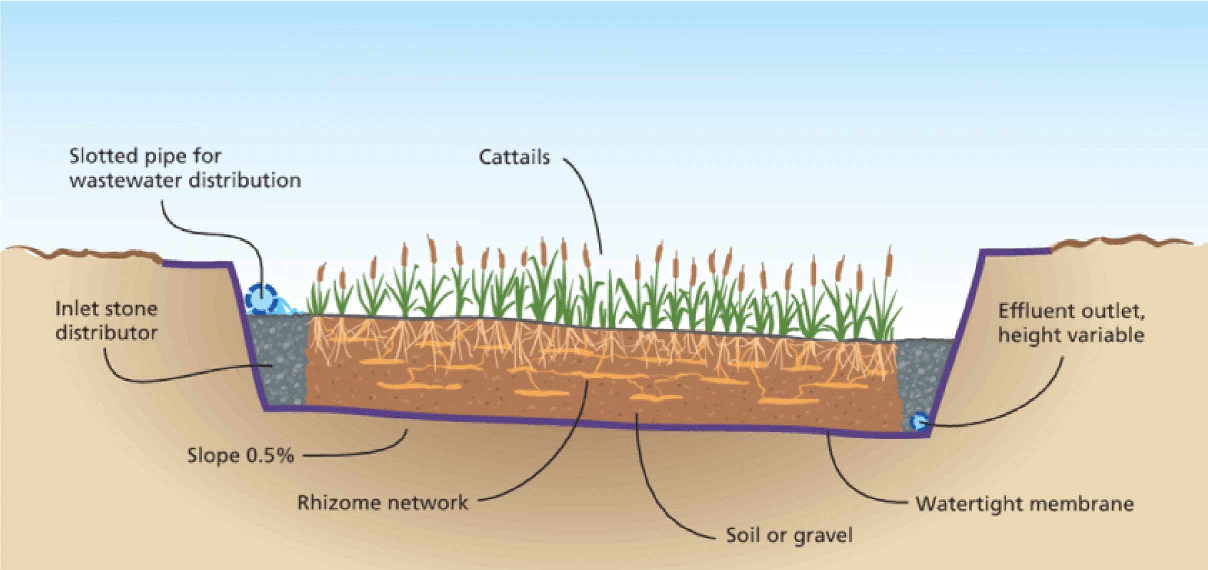



Fig 2.3: Subsurface Flow Constructed Wetlands

### 2.4.3 HORIZONTAL FLOW CONSTRUCTED WETLAND SYSTEM

The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics as well. The plant roots play an important role in maintaining the permeability of the filter. The design of a horizontal subsurface flow constructed wetland depends on the treatment target and the amount and quality of the influent. It includes decisions about the amount of parallel flow paths and compartmentation. The removal efficiency of the wetland is a function of the surface area (length multiplied by width), while the cross-sectional area (width multiplied by depth) determines the maximum possible flow. Generally, a surface area of about 5 to 10 $m^2$ per person equivalent is required.

Pre- and primary treatment is essential to prevent clogging and ensure efficient treatment. The influent can be aerated by an inlet cascade to support oxygen-dependent processes, such as BOD reduction and nitrification. The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. It should be wide and shallow so that the flow path of the water in contact with vegetation roots is maximized. A wide inlet zone should be used to evenly distribute the flow. A well-designed inlet that allows for even distribution is important to prevent short-circuiting. The outlet should be variable so that the water surface can be adjusted to optimize treatment performance.

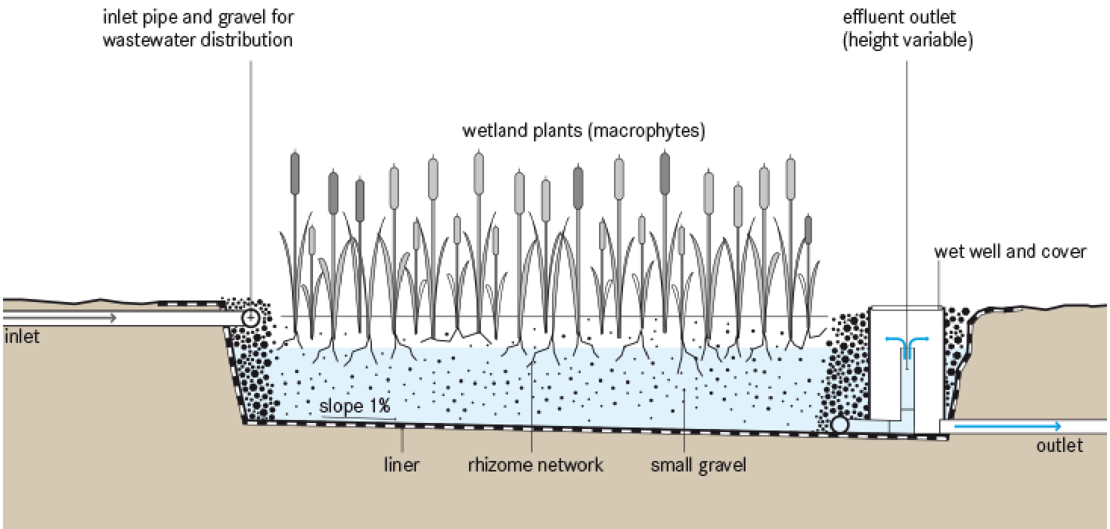



Fig 2.4: HorizontalFlow Constructed Wetlands

### 2.4.4 VERTICAL FLOW CONSTRUCTED WETLAND SYSTEM

A vertical flow constructed wetland is a planted filter bed that is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The important difference between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions.

The vertical flow constructed wetland can be designed as a shallow excavation or as an above ground construction. Clogging is a common problem. Therefore, the influent should be well settled in a primary treatment stage before flowing into the wetland. The design and size of the wetland is dependent on hydraulic and organic loads. Generally, a surface area of about 1 to 3 m2 per person equivalent is required. Each filter should have an impermeable liner and an effluent collection system. A ventilation pipe connected to the drainage system can contribute to aerobic conditions in the filter. Structurally, there is a layer of gravel for drainage (a minimum of 20 cm), followed by layers of sand and gravel. Depending on the climate, Phragmitesaustralis (reed), Typha sp. (cattails) or Echinochloapyramidalis are common plant options. Testing may be required to determine the suitability of locally available plants with the specific wastewater. Due to good oxygen transfer, vertical flow wetlands have the ability to nitrify, but denitrification is limited. In order to create a nitrification-denitrification treatment train, this technology can be combined with a Free-Water Surface or Horizontal Flow Wetland.

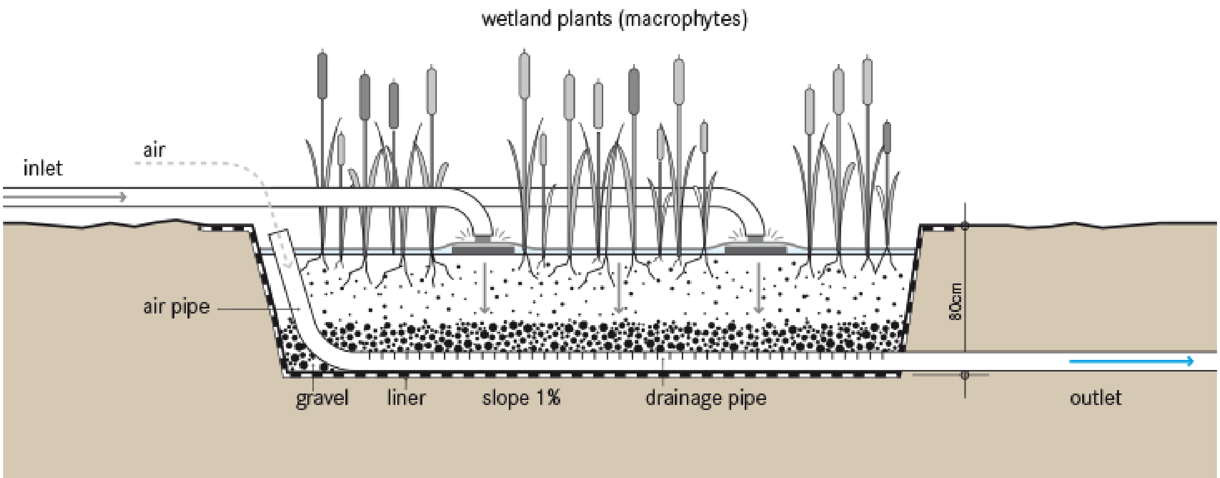



Fig 2.5: VerticalFlow Constructed Wetlands

### 2.4.5 HYBRID CONSTRUCTED WETLAND SYSTEM

Different types of constructed wetlands can be combined in order to achieve higher treatment efficiency by using the advantages of individual systems. Most hybrid constructed wetlands combine vertical filter and horizontal filter stages. The vertical- horizontal filter system was originally designed in the late 1950s and the early 1960s but the use of hybrid systems was very limited. In the 1980s hybrid constructed wetlands were built in France and United Kingdom. At present, hybrid constructed wetlands are in operation in many countries around the world. They need expert design, but they can be built mostly with locally available material and the community can be trained for operation and maintenance. The effluent can be used for e.g. irrigation and aquaculture or safely be discharged to receiving water bodies.

hybrid systems are comprised most frequently of vertical flow and horizontal flow systems arranged in a staged manner. Horizontal flow systems cannot provide nitrification because of their limited oxygen transfer capacity. Vertical flow systems, on the other hand, do provide good conditions for nitrification but denitrification does not really occur in these systems. In hybrid systems (also sometimes called combined constructed wetland) the advantages of the horizontal and vertical flow systems can be combined to complement processes in each system to produce an effluent low in BOD, which is fully nitrified and partly denitrified and hence has much lower total-N outflow concentrations. At present, hybrid constructed wetlands are in operation in many countries around the world and they are used especially when removal of ammonia-N and total-N is required.

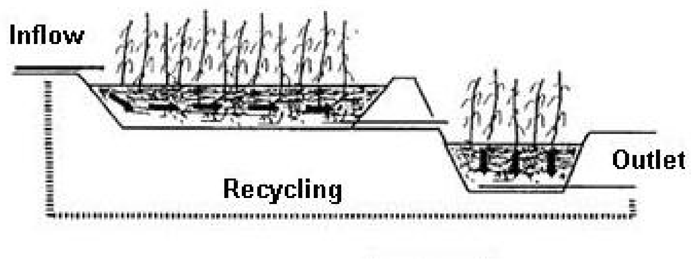



Fig 2.6: hybrid constructed wetlands

**2.5 COMPONENTS OF CONSTRUCTED WETLAND**

Constructed wetlands comprises of the following five major components

● Wetland Vegetation

● Soil or Substrate (Media) Supporting Vegetation

● Water Basin

● Living Organisms

**2.5.1 WETLAND VEGETATION**

Originally, the basis for employing constructed wetlands for wastewater treatmentis the ability of water plants to translocate oxygen to their roots, and the surroundingwater (wastewater, in case of treatment wetlands) environment. Although a number ofother pollutant removal processes have been identified, the wetland plants play a  in the occurrence of most of these processes. Within the water column, the stemsand leaves of the wetland plants significantly increase surface area for biofilm development.Plant tissues, moreover, are colonized by photosynthetic algae as well as bybacteria and protozoa. Likewise, the roots and rhizomes that are buried in the wetlandsubstrate provide for attached growth microorganisms (Brix, 1997).

### 2.5.1.1 Major roles of vegetation in constructed treatment wetlands :

| Wetland plant part | Role |
|---|---|
| Aerial plant tissues | • Light attenuation → reduced growth of phytoplanktons<br>• Influence on microclimate → insulation during winter<br>• Reduced wind velocity → reduced risk of resuspension of solids<br>• Aesthetic appearance<br>• Nutrient storage |
| Plant tissue in water | • Filtering effect → filter out large debris<br>• Reduced current velocity → increased rate of sedimentation, reduced risk of resuspension<br>• Surface area for attached microorganisms<br>• Excretion of photosynthetic oxygen → increased aerobic degradation<br>• Nutrient uptake |
| Roots and rhizomes | • Stabilising the sediment surface → less soil erosion<br>• Prevents the medium from clogging in vertical flow systems<br>• Release of oxygen increase organic degradation and nitrification<br>• Nutrient uptake<br>• Secretion of antibiotics for detoxification of root zone → pathogen removal |

Table2.3: Major Roles of Macrophytes in Constructed Wetlands

### 2.5.1.2The general requirements of plants suitable for use in constructed wetland wastewater treatment systems:

1. Ecological acceptability, that is, no significant weed or disease risks or dangerto the ecological or genetic integrity of surrounding natural ecosystems;
2. Tolerance of local climatic conditions, pests and diseases;
3. Tolerance of pollutants and hypertrophic water-logged conditions;
4. Ready propagation, and rapid establishment, spread and growth; and
5. High pollutant removal capacity, either through direct assimilation or storage,or indirectly by enhancement of microbial transformations.

**2.5.1.3 With the available experiences the following list of species can be given**

● Phragmitesaustralis (reed)
● Phragmiteskarka (reed)
● Arundodonax (mediteranean reed)
● Typhalatifolia (cattail)
● Typhaangustifolia (cattail)
●Juncus (bulrush)
● Iris pseudacorus
● Schoenoplectuslacustris (bulrush)

**2.5.2 SOIL OR SUBSTRATE (MEDIA) SUPPORTING VEGETATION**

The media that physically supports vegetation in a constructed wetland is vitalas it forms an integral link in treatment processes that occur in the wetland. While soil will generally be the support media in natural wetlands, constructed treatmentwetlands more often rely on coarse and fine gravel. Apart from supporting vegetation,the substrates also act as the principal storage of all biotic and abioticcomponents that exist in a wetland. In addition, coarse sand and gravel substratesprovide surface area for attached growth microorganisms and promote filtrationand settling of suspended solids.Hydraulic conductivity of the substrate is a major factor in constructed treatmentwetlands. Maintenance of hydraulic conductivity is required to stabilize thehydraulic retention time of the wetland system. Wetland systems with fine and soil

based substrate will have low hydraulic conductivity, while coarse sand and gravel based medium display higher conductivity. Soils will have a hydraulic conductivityof 10–5 ms–1 or less, whereas a uniform gravel in the range of 3 to 6 mm or 5to 10 mm will have an initial values in the order of 10–2 ms–1 or higher (Chen etal. 1993). A common problem in constructed wetland operation is clogging. Several studies with soil based treatment wetlands have reported problems of clogging and causing overflows of wastewater resulting in bed erosion and poor plant growth (Cooper and Hobson, 1990). Characteristics of various types of media and their hydraulic conductivity are presented in tablebelow.

**Media Characteristics**

| Media type | Effective size ($D_{10}$) mm | Porosity ($\eta$) | Hydraulic conductivity ($k_s$, $ms^{-1}$) |
|---|---|---|---|
| Coarse sand | 2 | 0.32 | $1.2 \times 10^{-2}$ |
| Gravelly sand | 8 | 0.35 | $5.8 \times 10^{-2}$ |
| Fine gravel | 16 | 0.38 | $8.7 \times 10^{-2}$ |
| Medium gravel | 32 | 0.40 | $11.6 \times 10^{-2}$ |
| Coarse rock | 128 | 0.45 | $115.7 \times 10^{-2}$ |

Source: Adapted from Chen et al., 1993

Table2.4: Characteristics of media used in CW bed

Infilling and occlusion of interstitial spaces by solids will reduce the effective volume available within the substrate, leading to increasing flow velocities, decreasing hydraulic retention times, and short-circuiting. Many cases of surface flow problems investigated by USEPA (1993) were attributed to inadequate hydraulic design, or introduction of fine inorganic sediments during construction and planting, which clogged void spaces in the bed. Thisphenomenon leads to bypassing and hence reduced treatment performance. Therefore,soil is usually not recommended as substrate for wastewater treatment wetlands,and gravel has been used in reed bed systems in several countries. Gravelallows through-flow of water from the start, and, if the bed gradually starts to clogwith solids, this can be counterbalanced by the growth of rhizomes and rootsopening up the bed. The rate of clogging in gravel-bed wetlands willinitiallydepend only on influent solids loading and efficiency of retention. In the longerterm, factors such as the degradable fraction of the suspensions and their rate of microbial and chemical degradation under the wetland environment will determinethe solids accumulation and hence the clogging rate.

**2.5.3 WATER BASIN**

Wetlands are likely to form where landforms direct surface water to shallow basins and where a relatively impermeable subsurface layer prevents the surface water from seeping into the ground. These conditions can be created to construct a wetland. A wetland can be built almost anywhere in the landscape by shaping the land surface to collect surface water and by sealing the basin to retain the water. Hydrology is the most important design factor in constructed wetlands because it links all of the functions in a wetland and because it is often the primary factor in the success or failure of a constructed wetland. While the hydrology of constructed wetlands is not greatly different than that of other surface and near-surface waters, it does differ in several important respects:

● small changes in hydrology can have fairly significant effects on a wetland and its treatment effectiveness

● because of the large surface area of the water and its shallow depth, a wetland system interacts strongly with the atmosphere through rainfall and evapotranspiration (the combined loss of water by evaporation from the water surface and loss through transpiration by plants)

● the density of vegetation of a wetland strongly affects its hydrology, first, by obstructing flow paths as the water finds its sinuous way through the network of stems, leaves, roots, and rhizomes and, second, by blocking exposure to wind and sun.

Systems have been designed with bed slopes of as 1 to 3 % to achieve the hydraulic gradient. Newer systems have used a flat bottom or slight slope and have employed an adjustable outlet to achieve the hydraulic gradient and also to surface to avoid the development of channels and pools and allow for evenly flooding in vertical systems. It also helps in horizontal systems to flood the surface at certain times to suppress weed growth.

### 2.5.4 LIVING ORGANISM

A variety of beneficial micro- and macroorganisms is an integral part ofwetland ecosystem. While the presence of vertebrates and invertebrates (higher level animals) may not be essential for the functioning of CTWs, microbial forms of organisms play a critical role. Microorganisms that are naturally found in water and wastewater, such as bacteria, fungi, protozoa, etc., thrive in wetlands, which provide suitable environmental conditions for their survival and proliferation. The microbial biomass is a major sink for organic carbon and many nutrients. Microbial activity:

- transforms a great number of organic and inorganic substances into innocuous or insoluble substances
- alters the reduction/oxidation (redox) conditions of the substrate and thus affects the processing capacity of the wetland
- is involved in the recycling of nutrients.

Some microbial transformations are aerobic (that is, they require free oxygen) while others are anaerobic (they take place in the absence of free oxygen). Many bacterial species are facultative anaerobes, that is, they are capable of functioning under both aerobic and anaerobic conditions in response to changing environmental conditions.Constructed wetlands provide habitat for a rich diversity of invertebrates and vertebrates also.Invertebrate animals, such as insects and worms, contribute to the treatment process by fragmenting detritus and consuming organic matter. The larvae of many insects are aquatic and consume significant amounts of material during their larval stages, which may last for several years. Invertebrates also fill a number of ecological roles; for instance, dragonfly nymphs are important predators of mosquito larvae.

## 2.6 CONSTRUCTED WETLAND HYDROLOGY

The hydrology of a constructed wetland is perhaps the most important factor in its effectiveness. However, the design of constructed wetland treatment systems is still in a state of flux and there remain a number of uncertainties that will not be answered until the results of longer and more numerous operational studies become available. Many wetland designs have been based on the design used for conventional ponds and land treatment systems. While the design of conventional systems is usually based on hydraulic residence time (and therefore water volume), some wetland treatment systems show a more consistent correlation with area and hydraulic loading rate than with hydraulic residence time. This seems reasonable since a wetland is a shallow water system with large surface area in relation to its volume, and receives energy inputs (sun, rain, gases) on an area1 basis that is not related to volume. Also, because of the depth limits of wetland plants, the biomass of microbes attached to plants and sediments does not increase proportionally to depth except in a narrow range. Hydrologic considerations include climate and weather, hydroperiod, hydraulic residence time, hydraulic loading rate, groundwater exchanges (infiltration and exfiltration), losses to the atmosphere (evapotranspiration), and overall water balance.

### 2.6.1 CLIMATE AND WEATHER

wetlands are shallow water bodies open to the atmosphere, they are strongly influenced by climate and weather. Rainfall, snowmelt, spring runoff, drought, freeze, and temperature can all affect wetland treatment.

### 2.6.2 HYDROPERIOD

Hydroperiod is the seasonal pattern of water level fluctuations and is described by the timing, duration, frequency, and depth of inundation. The hydroperiod of a wetland results from the balance of inflow, outflow, and storage. Hydroperiod determines the availability of water throughout the year, the extreme wet and dry conditions that can be expected, the extent of storage and drainage that may be required, and the criteria to be used in designing the water control facilities. While hydroperiod can be engineered to control surface flow and to reduce its variability, the hydroperiod of a wetland will be strongly affected by seasonal differences in precipitation and evapotranspiration.

### 2.6.3 HYDRAULIC RESIDENCE TIME

The period of time that the wastewater is retained within the wetland is critical to the various treatment processes that occur. Required detention time vary depending on the pollutant and the desired level of treatment. Typical detention times are 2 to 5 days for BOD removal. The period of time that wastewater physically resides within the reed bed is called Hydraulic residence time or detention time. The following equation gives an approximate estimate of detention time.

$t = ( n \times V_{bed} )/Q_{av}$

where , t is the average detention time

n is the porosity of reed bed substrate,

$V_{bed}$ is the volume of reed bed [surface area ($m^2$) x depth of reed bed (m)]

$Q_{av}$ is the average discharge or flow rate ($m^3$/day)

### 2.6.4 HYDRAULIC LOADING RATE

Hydraulic loading rate (HLR) refers to the loading on a water volume per unit area basis.

Hydraulic Loading Rate is calculated using the following expression: [HLR = Flow rate/ Surface area of bed receiving influent]

### 2.6.5 EVAPOTRANSPIRATION

Evapotranspiration (ET) is the combined water loss through plant transpiration and evaporation from the water surface. In wetlands, the amount of surface area is large relative to the volume of water and ET is an important factor. Also, many wetland plants do not conserve water during hot, dry weather as most terrestrial plants do, and can transfer considerable amounts of water from a wetland to the atmosphere in summer. If ET losses exceed water inflows, supplemental water will be required to keep the wetland wet and to avoid concentrating pollutants to toxic levels.

### 2.6.6 WATER BALANCE

The overall water balance for a constructed wetland is an account of the inflow, storage, and outflow of water. Water inflow to the wetland includes surface water (the wastewater or storm water), groundwater infiltration (in unlined wetlands), and precipitation: Storage is the surface water plus that in the pore spaces of the substrate. Outflow comprises evaporation from the water surface, transpiration by plants, effluent discharge, and exfiltration to groundwater. During design and operation, the wetland water balance is important for determining conformance with desired limits for HLR, hydroperiod range, HRT, and mass balances. A simple water balance equation for a constructed wetland is expressed as:

$S = Q + R + I - O - ET$

Where: S = net change in storage

Q = surface flow, including wastewater or stormwater inflow,

R = contribution from rainfall

I = net infiltration (infiltration less exfiltration)

O = surface outflow

ET= loss due to evapotranspiration.

## 2.7 POLLUTANT REMOVAL MECHANISMS

Removal of pollutants in a constructed treatment wetland is believed to be accomplished in the following ways:

- Direct uptake of pollutants by the plants
- Plants and substrate media provide large surface area for proliferation of microorganisms that degrade pollutants
- Sedimentation of solids due to the decreasing velocity of flow through CTWs
- Filtering of large particles occurs through root and reed masses
- Adsorption of nutrients (such as nitrates and phosphates) by soil and substrate media
- Wetland detention time allowing for natural die-off of pathogens
- UV radiation and excretion of antibiotics by plants to destroy pathogens Pollutant removal processes occur by interaction with wetland vegetation, the water column, and the wetland substrate. Table 2.5 sets out details of process types and the pollutants removed. The processes may be physical, chemical, or biological.

| Pollutants Removed | Processes |
|---|---|
| Organic material measured as BOD | Biological degradation, sedimentation, microbial uptake |
| Organic contaminants such as pesticides | Adsorption, volatilization, photolysis and biotic/abiotic degradation |
| Suspended solids | Sedimentation, filtration |
| Nitrogen | Sedimentation, Nitrification/denitrification, microbial uptake, plant uptake, volatilization. |
| Phosphorus | Sedimentation, filtration, adsorption, plant and microbial uptake. |
| Pathogens | Natural die-off, sedimentation, filtration, predation, UV degradation, adsorption |
| Heavy metals | Sedimentation, adsorption, plant uptake. |

Table2.5: Process of pollutants removal

### 2.7.1 NITROGEN REMOVAL

Nitrogen removal is a key point in CW technology, as many full-scale systemshave been designed for nitrogen removal as well as organic matter removal.Full-scale facilities often combine vertical and horizontal SSF CWs to achievemore effective treatment, and these hybrid systems are particularly effectivefor removing nitrogen. Vertical SSF CWs successfully remove ammonium,but the presence of very low denitrification rates means that they often donot remove sufficient quantities of nitrate. In contrast, horizontal SSF CWsprovide conditions that are more conducive to denitrification but are lesseffective at nitrifying ammonium. Vymazal (2007) noticed that the processes involved in nitrogen transformationand removal during wastewater treatment in SSF CWs vary accordingto the prevalent N chemical species. Nitrogen transformation and removal mechanisms in CWs include mineralization(ammonification), ammonia volatilization, nitrification, denitrification,plant and microbial uptake, nitrogen fixation, nitrate reduction, anaerobicammonia oxidation (ANAMMOX), adsorption, desorption, burial, andleaching (Vymazal, 2007). Denitrification is generally the dominant N removalprocess in mature SSF CWs. Alternative microbial N removal processes includingANAMMOX may have a great effect in SSF CWs designed to treatammonium-rich wastewaters (Tanner, 2004). Horizontal SSF CWs show ahigh potential for nitrate reduction due to the presence of anaerobic conditions. This behavior increases the retention time of the inflowing N withrespect to the hydraulic retention time, produces long delays in the treatmentsystem response to changes in N loading, and reduces the short-termfluctuations in N loading.Nitrogen removal in SSF CWs is affected by the hydraulic retentiontime (HRT), the temperature, the vegetation type and the properties of themedium. HRT and temperatureusually have a strong effect on the removal efficiencies for totalKjeldahl nitrogen (TKN) and ammonium. Nitrogen removal rates at a water temperature greater than 15◦C are significantly higher than those observed at lower temperatures (Akratos&Tsihrintzis, 2007; Caselles-Osorio & Garc´ıa,2007). TKN and ammonium removal is also affected by the levels of available oxygen (Wallace et al., 2000).

**Ammonification**

Ammonification in CWs has not been studied as extensively as other nitrogen transformation processes. It consists in the conversion of organic N in ammonia through exoenzymatic activity from enzymes excreted by microorganisms as a part of extracellular metabolism (Vymazal, 2007). A wide range of ammonification rates have been reported for CWs, with values ranging from 0.004 to 0.53 g N $m^{-2}$ $d^{-1}$ (Tanner et al., 2002; Vymazal, 2006).

**Ammonia Volatilization**

Ammonia volatilization is a physicochemical process in which ammonia derived from ammonification reactions or from wastewater is transferred from water to the atmosphere. This process is controlled by pH and can only be a significant mechanism for ammonia removal when the pH is above 10. Consequently, ammonia volatilization is not thought to be a major ammonia removal mechanism in SSF CWs treating urban wastewaters because the pH usually ranges from 7 to 8.5 (Vymazal, 2007). This may not be the case in systems used to treat wastewaters or wastes that are rich in ammoniacal nitrogen, such as pig manure (Poach et al., 2003).

**Nitrification**

Nitrification is defined as the biological oxidation of ammonium to nitrate with nitrite as an intermediate in the reaction sequence. Nitrification itself cannot remove nitrogen from wastewaters, but nitrification coupled with denitrification seems to be the major removal pathway in many CWs (Mayo &Bigambo, 2005; Tanner et al., 2002; Vymazal, 2007). Nitrification limits nitrogen removal in many CWs because ammonia is the dominant species of nitrogen in urban and other industrial wastewaters. The degree of nitrification is determined by oxygen availability (Cottingham et al., 1999). Therefore, vertical SSF CWs are more conducive to nitrification than horizontal SSF CWs. Tanner et al. (2002) carried out detailed research into nitrogen removal and transformations in experimental horizontal SSF CWs operating in series and planted with *Schoenoplectustabernaemontani*. They found that nitrification occurred concurrently with organic matter removal, even in the upstream stages of wetlands that received higher-strength wastewater inflow.

**Denitrification**

Denitrification is the biochemical reduction of nitrate and nitrite to nitricoxide, nitrous oxide, and nitrogen gas, and is considered a major removalmechanism for nitrogen and organic matter in most types of CWs. However,nitrate concentrations are usually very low in wastewaters (with the exceptionof drainage water from agriculture and some industrial wastewaters), sodenitrification should generally be coupled with nitrification to attain satisfactorynet N removal. Environmental factors known to influence denitrificationrates include the absence of $O_2$, redox potential, the moisture content of themedium, temperature, pH value, the presence of denitrifiying bacteria, themedium type, the presence and type of organic matter, the nitrate concentration,and the presence of overlying water. The presence of oxygen fornitrification and the absence of oxygen for denitrification are often the principalfactors that limit overall nitrogen removal rates in CWs (Vymazal, 2007).Denitrification has a lesser environmental impact than ammonia volatilization and is therefore a more desirable nitrogen removal mechanism (Poachet al., 2003).

**Plant Uptake**

Nitrogen can be removed in SSF CWs by harvesting the aboveground biomass of emergent plants, although this technique is not particularly suitable for urban wastewater treatment systems. In tropical regions, seasonal translocation activity is very low, and several harvests can be made during the year, so plant uptake could play a significant role in nitrogen removal, especially in lightly loaded systems (Vymazal, 2007). The potential rate of nutrient uptake by plants is limited by their net productivity and the concentration of nutrients in plant tissues. The nitrogen standing stock in emergent wetland plants is in the range 14–156 g $N/m^2$, but more than half of this amount may be stored below ground (Vymazal, 2007). Vymazal (2007) found that aboveground N standing stock values reported in previous studies were in the range 0.6–88 g $N/m^2$.

### 2.7.2 PHOSPHORUS REMOVAL

Phosphorus removal rates are rather low in CWs. Vymazal (2005a) reviewed phosphorus removal rates in horizontal SSF CWs throughout the world and calculated an average mass removal rate of 45 g P $m^{-2}$ $year^{-1}$ and an average mass-based efficiency of 32%. Average effluent concentration was 5.15 mg $L^{-1}$, which is above the permitted discharge limit in most countries. P-removal rates in vertical systems seem to be more variable than Nremoval rates, and different authors have reported average concentrationbased total phosphorus (TP) removal efficiencies of 25–40% (Verhoeven & Meuleman, 1999), 26–70% (Rousseau et al., 2004b), 0–40% (Esser et al., 2004), and 45–91% (Weedon, 2002). In all of these studies, Total P effluent concentrations (mostly in secondary treatment) were above 2 mg $L^{-1}$ and increasedover time.There are three main factors that lead to low P-removal rates. First,microbial phosphorus removal is only a temporary sink. Second, as in thecase of nitrogen, plant uptake tends to have a relatively small effect on removal.Third, most substrates used as granular media have low P-sorptionand P-complexation capacities: in the case of gravel, from the start of theoperating period; in the case of sandy media, after a limited period oftime due to the depletion of sorption sites and complexing agents.

### 2.7.3 MICROBIAL REMOVAL

Unlike denitrification, in which nitrite and nitrate are mainly converted into harmless nitrogen gas that escapes from the wetland, microbial P-removal exhibits no similar sink. Bacteria can only take up and store P, which is a partly reversible removal mechanism. The continuous cycle of growth, die-off, and decay releases most of the initially assimilated phosphorus, and only some refractory fractions become a permanent sink for P. Consequently, once the CW start-up phase has been completed, net microbial P-removal is generally very low. Mander et al. (2003b) recorded a cumulative P-retention of 52.8 kg in a 40-person-equivalent (PE) horizontal SSF CW after an operating period of five years, of which only 4.4% (2.3 kg) was due to microbial immobilization. To the best of our knowledge, there is only one preliminary study on the potential for enhanced biological phosphorus removal (EBPR) in constructed wetlands due to the presence of phosphate-accumulating organisms (PAOs). In this study, Alas et al. (2003) showed that different water regimes and therefore different oxygenation conditions could stimulate microbial P-removal. Recent findings made by Edwards et al. (2006) confirm that microbial P-consumption is higher in aerobic regions of the rhizosphere, whereas P-mineralization is predominant in the anaerobic regions.

### 2.7.4 BOD REMOVAL

Wastewater organic contents include both biodegradable and nonbiodegradable forms. Each of these two forms is further divided into particulate and dissolved organics. In a biological reactor, particulates (biodegradable/nonbiodegradable) are generally removed by physical processes such as filtration and sedimentation. The biodegradable particulates are subjected to metabolism (i.e. adsorption on biocells, hydrolysis etc.), after being trapped by the physical processes (Haandel and Lubbe, 2007). On the other hand, biodegradable dissolved organics generally penetrate through biocells, where such contents are subjected to biological metabolism. Nonbiodegradable dissolved organic contents usually escape all treatment barriers, leaving the biological reactor without being treated. Illustrates different forms of organics of wastewaters (expressed as chemical oxygen demand (COD)), and subsequent treatments in a typical biological reactor. In a subsurface flow wetland reactor, organics are biologically degraded via aerobic and anaerobic routes as described in the following subsections. In aerobic degradation (of organic compounds), aerobic chemo-heterotrophs oxidize organic compounds in the presence of oxygen and produce $CO_2$, $NH_3$, and other stable chemical compounds.

Anaerobic organic is accomplished in the absence of oxygen through four sequential steps, such as (a) hydrolysis, (b) acidification, (c) acetogenesis, and (d) methanogenesis. A brief description of anaerobic organic degradation route is available in the following paragraphs. Hydrolysis is the first step of an anaerobic organic degradation route, where large molecules such as proteins, poly saccharides, and fats are degraded(by fermentative bacteria) into small products for example peptides, saccharides, and fatty acids. Since hydrolysis is a slow process, it often limits the overall digestion rate. Acidification is the second process of anaerobic digestion, where hydrolyzed products are converted into simple molecules (by strictly anaerobic bacteria), such as volatile fatty acids (acetic acid, propionic acid, and butyric acid), alcohol, aldehydes, and gases ($CO_2$, $H_2$, and $NH_3$).

## 2.8 ADVANTAGES OF CONSTRUCTED WETLANDS

Constructed wetlands are a cost-effective and technically feasible approach to treating waste-water and runoff for several reasons:

● wetlands can be less expensive to build than other treatment options
● operation and maintenance expenses (energy and supplies) are low
● operation and maintenance require only periodic, rather than continuous, on-site labor
● wetlands are able to tolerate fluctuations in flow
● they facilitate water reuse and recycling. In addition:
● they provide habitat for many wetland organisms
● they can be built to fit harmoniously into the landscape
●they provide numerous benefits in addition to water quality improvement, such as wildlife habitat and the aesthetic enhancement of open spaces
● they are an environmentally-sensitive approach that is viewed with favor by the general public.

## 2.9 LIMITATIONS OF CONSTRUCTED WETLANDS

There are limitations associated with the use of constructed wetlands:

● they generally require larger land areas than do conventional wastewater treatment sys-terns. Wetland treatment may be economical relative to other options only where land is available and affordable.
● performance may be less consistent than in conventional treatment. Wetland treatment efficiencies may vary seasonally in response to changing environmental conditions, including rainfall and drought. While the average performance over the year may be acceptable, wetland treatment cannot be relied upon if effluent quality must meet stringent discharge standards at all times.
● The biological components are sensitive to toxic chemicals, such as ammonia and pesticides
● Flushes of pollutants or surges in water flow may temporarily reduce treatment effectiveness
● While wetlands can tolerate temporary drawdown, they cannot withstand compete drying

# LITERATURE REVIEW

### 3.1 REVIEW OF LITERATURE

**Antonina Torrens Armengol et al. (2015)** studied the treatment of swine slurry with constructed wetlands. The purpose of the study is to evaluate the viability of hybrid sub surface flow constructed wetland to treat swine slurry to obtain a quality suitable for land application or discharge into water bodies. The specific objectives to achieve this main goal are:

●To fully characterize swine slurry

● To specifically design a hybrid pilot plant consisting of a VFCW and a HFCW to treat swine slurry and operate it for 20 months

● To evaluate treatment efficiency of the hybrid SSFCW, monitoring nitrogen dynamics, physic-chemical parameters and bacterial indicators.

● To study the capacity of nitrification/denitrification of a hybrid system treating partially settled swine slurry.

● To study the influence on VFCW's treatment efficiency and hydraulic performance of design parameters, operational parameters and deposits filter surface.

The study was carried out at a private pig farm, Can Corominas, in Viver I Serrateix, in the Bergueda region of Catalonia (Spain), at an altitude of 606.4 m above sea level, with a Mediterranean climate and an average annual temperature of 12.9° C and average daily temperature ranging from 1°C to 29°C. Annual rainfall is 660mm. The farm has an area of 1 hectare, and it accommodates approximately 580 sows and 2000 piglets upto 18 kg.

**Keffala.C et al. (2005)** studied Nitrogen and Bacterial removal in constructed wetlands treating domestic wastewater in Tunisia. The work carried out on removal rate of carried out for a performance of to combined system of vertical and horizontal sub surface flow. "in vertical flow bed was planted with phragmites australis and horizontal flow bed planted with typha latifolia and other wetland was unplanted. The experiment was carried out from February to august 2003 with a hydraulic loading rate of 0.024 $m^3$/j and organic loading of 208kg/COD/ha-d at flow rate of 6 lit/hr. the collection of influent and effluent water was taken from fixed location equivalent to the four tanks sample and were analyzed for TKN, $NH_4$, $NO_3$-$NO_2$ and total Colliform. The removal rate for nitrogen was 27% for planted, 5% for unplanted and nitrogen ammonia 19% for planted and 6% for unplanted. Removal rate for nitrate nitrogen unplanted system is greater than planted system, 4% for planted and 13% for unplanted and bacterial removal in both systems was same. In the horizontal flow bed nitrate and nitrite removal are about 27% for planted and 24% for unplanted. The denitrification depending on flow type was nutrient uptakes in horizontal flow system. The work concluded that removal of nitrogen in vertical flow bed system was support to the nitrification and horizontal flow system support to denitrification.

**M.Y. Sklarz et al. (2009)** developed a recirculating vertical flow constructed wetland (RVFCW) for the treatment of grey water. The overall aim of this research was to apply the RVFCW, a decentralized, small-scale system, to the treatment of domestic wastewater (DWW), modifying it, where necessary, to produce effluents that conform to Israeli regulations for urban landscape irrigation. Two RVFCWs were operated with and without a soil-plant component and with various recirculation flow rates (RFR) and treatment times. Without plants, at a RFR of 4.5 $m^3$/hrand 12hr treatment time, the average biological oxygen demand (BOD5) and total suspended solids concentrations of the treated effluent were 5 and 10 mg/lit, respectively. A kinetic analysis showed that even 6hr were sufficient to achieve the required effluent quality. Addition of the soil-plant component, which necessitated a reduction in the RFR, caused no changes in effluent quality, and its role in the treatment remained undetermined. In all operational modes, counts of *E. coli* were reduced from the order of 106 to 103 Colony Forming Unitper 100 ml, and further reduction to less than 10 CFU per 100 ml was attained with a UV irradiation unit. In conclusion, the RVFCW produces high quality effluents, and can treat DWW at a potential organic load of over 120 gm BOD5 $m^{-2}$ $d^{-1}$.

**Meng Li et al. (2019)** studied the releasing behaviors of maize cobs with or without alkali (i.e. NaOH) pretreatment in seawater and distilled water, and to evaluate the effects of maize cobs addition (solid biomass andlixivium) on nitrogen removal in saline constructed wetland (CW) treating marine recirculating aquaculturesystem (RAS) effluents. Results revealed NaOH-treated maize cobs released carbon more efficiently, whether inseawater or in distilled water. Compared to distilled water, seawater conditions promoted carbon releasing. CWwith maize cobs biomass and lixivium addition had high NO3-N removal efficiencies without significant difference,i.e. 94.9 ± 6.0% and 87.1 ± 13.2%, respectively. While CW with maize cobs biomass addition hadhigher effluent COD concentrations (16.3 ± 3.6 mg L−1) compared with those adding lixivium(2.1 ± 0.4 mg L−1). The study suggested adding maize cobs lixivium to be feasible and effective way to enhancenitrogen removal in saline CW. Based on this study, NaOH pretreatment improved carbon releasingfrom maize cobs, whether in seawater or in distilled water. Besides,seawater conditions promoted carbon releasing. Adding biomass directlyand adding lixivium of maize cobs into saline CW could enhancenitrogen removal at the same level, but adding maize cobs biomassdirectly into CW would cause high COD concentrations in effluent. Insum, adding lixivium of NaOH pre-treated maize cobs is a feasible andeffective way to enhance nitrogen removal in CW treating marine RASeffluents.

**Anwaruddin Ahmed Wurochekke et al. (2014)** studied the treatment of household greywater by constructed wetlands. The release of domestic greywater from various sources can cause contamination of water bodies. In this study, a pretreatment system and mini wetland were constructed at village dwelling for greywater treatment. The main purpose of this study was to investigate the greywater loading characteristics, provide appropriate on site mini wetland and to measure the effectiveness of the wetland treatment system. The greywater samples were collected from the effluent of single house, at influent, pre-treatment model (particle material), mini wetland model (plant tube sedge *Lepironia Articulata*), and control model (without plant) at two sampling period. The mini wetland model shows high removal performance of 81.42 % BOD, 84.57 % COD, 39.83 % AN, 54.70 % SS, and 45.01 % turbidity. Generally, the results show that the constructed mini wetland was effective to remove contaminants and suitable for treatment of greywater sources. In view of future application, further explorations should consider other aquatic plants and disinfection system to achieve more efficient treatment. The greywater loading flow rate (Q) was 5.012 x 10-5 m3/s, wetland volume (V) was 8.568 x 10-3 m3 andhydraulic retention time (HRT) was 4 min. The concentrations of parameters in the influence of rawgreywater were 309 mg/L of BOD, 1103 mg/L of COD, 153 mg/L of SS, 3.83 mg/L of AN, and 132 NTU ofturbidity. Meanwhile, the concentrations removal performance of parameters in the effluent of constructing a mini wetland was 81.42 % of BOD, 84.57 % of COD, 39.83 % of AN, 54.70 % of SS, and 45.01 % of turbidity. The collective results lead to the conclusion that this filter media and constructed wetland could be feasible for greywater treatment. The constructed mini wetland system seems to be available alternative for reducing the organic matter content from bathroom, washing machine and kitchen grey water from individual house.

**Thomas J. Carlislelet al. (1991)** studied the hydrological functions of wetlands; the use of artificial wetlands for stormwater management in threeareas of the United States is examined. The paper concludes by suggesting five possible research opportunities to aid in the implementation of this technology for Ontario. Urban stormwater runoff increasingly has become an important water management issue in the development of municipalities in Ontario. Conventional approaches to the mitigation of urban runoff have involved the utilization of detention or retention ponds. An innovative strategy to control flooding and assimilate pollutants is the construction of artificial wetlands. The case studies have demonstrated that artificial wetland creation for stormwater management in urban and urbanizing areas is possible from a technological and engineering perspective. This concept is considered a proven technology in the United States having been successfully implemented in varying degrees in Florida' Maryland, and California. Although naturalwetlands have been used for stormwater control, it has been argued that stormwater discharges have significant ecological and environmental impacts on natural wetlands including:

1 ) sedimentation buildup, 2) bioaccumulation of pollutants in food chains, 3) negative effects of detention time and water levels on vegetation succession pattern and 4) detrimental effects of toxicants on groundwater.Thus, the use of wetlands to treat stormwater runoff should be limited to artificial wetlands where conditions can be better controlled and periodic maintenance such as dredging and/or harvesting of vegetation can be undertaken.

**G.D. Gikas, V.A. Tsihrintzis et al. (2012)** designed and studied the performance a small-scale vertical flow constructed wetland (VFCW) system, for on-sitetreatment of domestic wastewater. The system serves a two-story, two-family (8 persons)building, and comprises three treatment stages: two settling tanks in series, a VFCW and a zeolite tank.The treatment performance of the system was monitored on a weekly basis for about forty months.Results show a satisfactory performance with the following mean removal efficiencies: 96.4% for BOD,94.4% for COD, 90.8% for TKN, 92.8% for ammonia, 61.6% for OP and 69.8% for TP. The zeolite was found tooffer additional removal of nitrogen, total phosphorus and organic matter. The zeolite saturation time isestimated. From the 40-month period of operation and monitoring, it seems that the on-site VFCW facility operates quite satisfactorily, showing high removals for BOD, COD, ammonia, TKN, phosphorus, TSS and TC. The zeolite tank offers further CW effluent polishing.

**Yue Zhang et al. (2012)** Municipalities in the Intermountain West are facing water shortages based on their current population growth projections. Utah has the second highest per-capita culinary water use in the United States. Among other cities, Mount Pleasant, Utah, is seeking innovative and cost-effective ways to reduce culinary water use. This study presents a feasibility analysis of and a design for using a free water surface constructed wetland system to treat the city’s wastewater. The study further presents a cost-benefit assessment of using the treated water for landscape irrigation in the city. The study is based on an analysis of existing wastewater quality, local climatic and site biophysical conditions, and future water use projections. The proposed constructed wetland system is composed of two reactors in series: a stabilization lagoon followed by a constructed wetland. The study involves retrofitting the existing wastewater sewage lagoons and designing a constructive wetland and a storage pond for reclaimed water. The study results show that after a relatively long retention time, the overall biochemical oxygen demands will be reduced by 93.6% to 97.8% and the total suspended solids will be reduced by 87.2% to 87.9%. The treated water is sufficient to irrigate approximately 45 acres of turf grass or 37 acres of pasture grass. In contrast to complex high-maintenance treatment systems, constructed wetlands provide ecologically-sustainable wastewater treatment. For municipalities that are facing similar challenges, this study provides an example of reducing culinary water use and achieving other sustainable development goals by reclaiming and reusing treated wastewater. The results show that pollutant levels in the wastewater could be reduced by 87% to 97% after treatment of 6.7 days by the 3.7-acre facility currently in use. The entire system, including the existing lagoon, is 20.4 acres in size (not counting the auxiliary facilities). In the majority months (except winter), the system has the capacity to clean about 240,000 gallons of influent wastewater and discharge 198,055 gallons of 90% treated water which could irrigate over 44.8 acres of turf landscape every day.

**Z.M. Chen et al. (2008)** presented an integrated cost and efficiency analysis of a pilot vertical subsurface-flow constructed wetland (CW) built up in 2004 near the Longdao River in Beijing, China. The CW has been monitored over one year and proved to be a good solution to treat the polluted water and restored the ecosystem health of the Longdao River. The modified CW system in accordance with local conditions costs less in construction, operation and maintenance than traditional wastewater treatment system and occupies less land than conventional CW. Also, derived from the efficiency analysis, the Longdao River CW provides better elimination effects for nutrient substances in the polluted river water and has stable performances in cold seasons. In the northern China, serious shortage of available water resources becomes a critical factor hindering the regional sustainable development due to the combination of unbalanced spatial distribution, large population and heavy water pollution. The CW has a treating cost of 0.23 RMB/m3 for wastewater, lower than those of the conventional wastewater treatment systems. The pilot CW occupied less than half of the area by conventional CW due to the use of new materials and improved design. As field data show, the average removal efficiencies during the first year of $BOD_5$, COD, TSS and TP were 87.2%, 81.8%, 85.1% and 98.8%, respectively, and were all within the designed effluent standard for water quality. Even as the NH3–N concentration in the effluent water was higher than that of the designed effluent standard, a high removal efficiency of 77.4% was obtained.

**Rawaa Al-Isawi et al. (2017)** studied and compared the performance, design and operation variables of two wetland technologies treating domestic wastewater: an experimental artificial pond system and a mature experimental vertical-flow constructed wetland system. The wetland system planted with Phragmites australis(Cav.)Trin. ex Steud. (Common reeds) was operated between June 2011 and October 2015, while the pondsystem was only operated between July 2015 and October 2015. Three different types of ponds were compared: ponds with wastewater; ponds with wastewater and reeds; and ponds with wastewater, reeds and aeration. Findings regarding the performances of mature wetlands showed that the wet-land systems improved the water quality except for ortho-phosphate-phosphorus (PO4−P), where the treatment performance reduced slightly over time. In general, the aerated pond systems showed better treatment performances in terms of ammonia-nitrogen (NH4−N) and PO4−P. Both systems were linked with medium to high levels of five-day biochemical oxygen demand (BOD) removal. The highest CODand SS removals were observed for wetlands in comparison to ponds. Moreover, mature wetlands were better in removing NH4−N and PO4−P than ponds unless the ponds were aerated. The nitrate-nitrogen (NO3−N) concentration increased in the aerated ponds reflecting the high oxygen availability.

**Melayib Bilgin et al. (2014)** Activated sludge-vertical flow subsurface constructed wetland systems (AS/VFSCW) were investigated in order to remove COD and N in sewage of Aksaray. Over a study period of 25 days, the system was able to achieve moderate total nitrogen removals with the range of removal efficiencies of 35.28% and 59.84% at organic loading rates of 940mgTN/$m^2$ d. In the effluent of the system, COD and TN observed was higher than those by last of operation as roots of plant were decomposed and dissolved in the effluent of the system. Conventional wastewater treatment plant could not remove N and P in sewage in order to prevent eutrophication in receiving water bodies. CWs may be an economical option for N and P removal in the effluent of secondary treatment such as activated sludge, trickling filter of oxidation ponds because conventional nutrient removal is much costly and complex compared to natural treatment systems. The findings of this study have shown that the system was efficient in the removal of COD and N removal. The NO3-N removal efficiencies were obtained as 97% at nitrate loading rates of 245mg/$m^2$ d in VSFCF while the mean percentage of TN removal was 46.6% (n=8, σ= 9.5) in the AS/VSFCW system. Based on experimental results of this and other studies nutrient (N, P) removal is possible and these systems are very cost effective compared to classic nutrient removal system. Constructed wetlands have been implemented as wastewater treatment facilities in many parts of the world, but to date, the technology has been largely ignored in developing countries where effective, low cost wastewater treatment strategies are critically needed. Conventional wastewater treatment plant could not remove N and P in sewage in order to prevent eutrophication in receiving water bodies. CWs may be an economical option for N and P removal in the effluent of secondary treatment such as activated sludge, trickling filter of oxidation ponds because conventional nutrient removal is much costly and complex compared to natural treatment systems such as CW and oxidation ponds.

**Jun- jun Chang et al. (2012)** studied two pilot-scale integrated vertical-flow constructed wetlands (IVCWs) in parallel which were employed to evaluate domestic wastewater treatment performance at a loading rate of 250 mm/d, and each was planted with two different plant species: Typha orientalis and Arundo donax var. versi color (Plot 1), and Canna indica and Pontederia cordata (Plot 2). The results showed that different plant combinations offered no significant improvement in pollutant removal efficiencies ($p > 0.05$). The mean removal efficiencies associated with Plot 1 and Plot 2 were 59.9% vs. 62.8% for COD, 15.0% vs. 12.8% for TN, and 52.0% vs. 51.1% for TP, respectively. The mean mass removal rates (g m−2 d−1) were 44.3 vs. 46.4 for COD, 1.27 vs. 1.08 for TN, and 0.393 vs. 0.386 for TP, respectively. It was noted that nitrification was the limited step for TN removal. Dissolved oxygen (DO) in the wetland beds was a dependence factor for the removals of organic matter and nitrogen, and it could be used to predict removal rates of chemical oxygen demand (COD) and total nitrogen (TN). Low temperatures had a negative impact on nutrient removals, especially for TN. Mean removal efficiencies of 61.4% and 51.6% for COD and TP, respectively, were achieved by the IVCW plots treating domestic wastewater at a loading rate of 250 mm/d. DO was a dependence factor for the eliminations of organic matter and NH4+ N, and it could be employed to predict removal rates of COD and TN. Nitrification was the limited step for TN removal due to the insufficient DO concentration, and temperature was another key factor influencing nitrogen removal.

**Gargi Sharma et al. (2014)** studied vertical up-flow constructed wetlands which were constructed and used as bio-filter to improve the water quality of secondary treated effluent. The reduction pattern is studied in this research and correlated with plant species and presence of plant. The plant species used in the constructed wetlands were *canna* and *phragmitis*. The fibrous rooting system of *canna* species causes the high aerobic conditions throughout the treatment bed which in turn facilitates higher removal in comparison to *phragmitis* planted wetland. Removal of nitrogenous compounds like ammonia-nitrogen, TKN and nitrate were observed better in *canna* planted wetlands than others.Percentage COD removal range was from 38 to 47%while treating domestic wastewater through vertical flow system. The study showed lower CODremoval in one case of non-planted wetland than planted one. This is contradictory observation to other reported studies where the higher organic matter removal is achieved in planted wetlands as the plants increases the surface area which increases growth of bio-film within the treatment beds. Removal of ammonia-nitrogen in planted and unplanted system was 52.99% and 36.17% respectively which greatly supports the significance of presence of macrophytes.

**B. Kim et al. (2014)** studied performance of partially saturated vertical-flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters. The use of vertical flow constructed wetlands (VFCW) is growing rapidly in Europe for domestic wastewater treatment in small communities. In order to improve denitrification and dephosphatation as comparedto classical VFCW, the Azoé-NP® process has been developed. The process line consists of: a biological aerobic trickling filter as a primary treatment stage, ferric chloride (FeCl3) addition for phosphorus treatment and two stages of partially saturated VFCW. A municipal wastewater treatment plant using Azoé-NP® process has been monitored during eight years through 44 campaigns of 24 h time-proportional inlet–outlet sampling followed by analyses of TSS, BOD5, COD, TKN, NO3–N and TP concentrations. The results revealed good performances of the overall treatment. To better characterize the performance of each treatment step, five additional 24 h monitoring campaigns were performed with samples taken from four different points along the treatment line. Results showed a good performance in dissolved carbon removal and nitrification by the trickling filter. The main part of the treatment was found to be doneby filtration throughout the first filtration stage. Nitrate removal was achieved principally at the second filtration stage. Phosphorus migration through the first stage and its slight retention at the second stage was observed. The results shown in this study were obtained from a series of 44 campaigns conducted between 2004 and 2012 to evaluate the performance of a municipal partially saturated VFCWs designed and operated according to the Azoé-NP® system for the treatment of the municipal wastewater of the small city of Vercia (Jura, France).The field data thus obtained showed firstly that the overall rates of COD and organic nitrogen removals were quite stable and very good (never below 94%). COD removal and nitrification were found to be achieved by the aerobic biological trickling filter and the first stage of partially saturated VFCW. Denitrification was mostly achieved in the flooded zone of the partially saturated VFCW without requiring the injection of additional carbon source. COD, nitrogen and phosphorus were present predominantly under dissolved forms afterthe 1st VFCW stage underlining its very good filtration efficiency.

**Alexandros I. Stefanakis et al. (2009)** studied the performance of pilot-scale vertical flow constructed wetlands treating simulated municipal wastewater and effect of various design parameters. Ten pilot-scale, cylindrical, vertical flow constructed wetland units, of diameter 0.82 m and height 1.5 m, were designed, constructed, and operated treating a simulated municipal wastewater in parallel experiments. The operation scheme was 2 days feeding and 6 days resting. The 10 wetland units had various porous media materials (i.e., carbonate material, material from river bed, zeolite, and bauxite), two vegetation types (i.e., common reeds and cattails), and three total thicknesses of the porous media (i.e., 50, 80, and 90 cm). Water quality samples were collected at the inlet and the outlet of each unit, and were analyzed in the laboratory for BOD5, COD, TKN, ammonia nitrogen, nitrate, nitrite, TP, and ortho-phosphate. This article presents the results obtained after operation of these systems for one full year. Organic matter removal proved to be very good in all 10 units, since it reached on the average 71.1% and 66.9% for BOD5 and COD, respectively. Nitrogen removal was also satisfactory (47.1% for TKN and 42.2% for NH4+--N). TP and ortho-phosphate retention rates reached about 36.9% and 37.9%, respectively.

**J. Nivala et al.(2014)** studied vertical flow constructed wetlands for decentralized wastewater treatment in Jordan and optimization of total nitrogen removal. The baseline performance of two full-scale vertical flow (VF) constructed wetlands operating in the arid climateof Jordan is presented in this study, within the context of the Jordanian Standards for reuse of treated wastewater. One system was a recirculating VF wetland, and the other was a single-pass two-stage VF wetland. Operational modifications were made to each treatment system, with the aim of improving Total Nitrogen (TN) removal. For the recirculating VF system, attached-growth mediawas added to the recirculation tank to provide increased surface area for growth of denitrifying bacteria. The modification showed a small but significant improvement in TN removal (8mg/L less than the baseline phase; p=0.004). Statistical analysis showed that 30% and 4.5% of the increase in compliance with the TN limits (Class A and Class B/C, respectively) could be attributed to the modification. The two-stage VF wetland was modified with a step-feeding line that introduced carbon-rich raw wastewater to the intermediate pump shaft just upstream of the second-stage filter. The modification also resulted in a small but significant improvement in TN removal (13mg/L less than the baseline phase; p=0.005). The increase in compliance with the TN standard due to the modification was estimated at 20% and 22% for Class A and B/C, respectively. The simple operational modifications proved to be effective for improving total nitrogen removal in arid climate VF wetland systems.The performance of two full-scale VF wetland systems in Jordan was assessed with special focus on total nitrogen removal within the construct of the Jordanian Standards for reuse of treated wastewater. For the recirculating VF wetland, TN removal was limited to 45%. An operational modification was made, which introduced attached-growth media into the recirculation tank. TN removal in the recirculating VF wetland decreased by 8 mg/L in the post-modification phase (p = 0.004). Treatment efficacy for COD, CBOD5 and TSS did not change significantly as a result of the modification. A second system, a two-stage VF wetland, also exhibited limited TN removal in the baseline monitoring phase, with a mean effluent TN concentration of 77 mg/L, which corresponded to TN removal of only 26%. A step-feeding line was implemented in the two-stage VF wetland system, bringing carbon-rich water into contact with nitrified effluent from the first stage filter in an intermediate pump well upstream of the second stage filter. As a result of the modification, the average effluent TN concentration decreased by 13 mg/L in the post-modification phase (p = 0.005).

**Ülo Mander et al. (2000)** studied constructed wetlands forwastewater treatment in Estonia. His work presents preliminary results from two constructed wetlands for municipal wastewater treatment in Estonia: (1) a free water surface constructed wetland (a cascade of 4 serpentine ponds in which *Typha latifolia* and *Phragmites australis* have been planted (total area about 1.2 ha, mean depth of the ponds 0.5m) for secondary treatment of waste water from the town of Põltsamaa with about5,000 inhabitants and from a food processing factory, and (2) a two-chamber horizontal-flow sand-plant filter (two chambers, 30x6.25x1.0 m, each) filled with coarse sand, one planted with *Typha latifolia,* and the other with *Iris pseudacorus* and *Phragmites australis,* receiving a septic tank effluent of about 40 population equivalents in Kodijärve. The horizontal flow sand-plant filter showed satisfactory purification efficiency in terms of BOD7 and phosphorus (66-95% and 63-96%, respectively). However, nitrogen removal was relatively low, varying from 12 to85%. In the cascade of free water surface wetlands, the most critical parameter is phosphorus retention. Mean purification efficiency observed was about 73% fornitrogen, 68% for BOD7 and 24% for phosphorus. Purification efficiency in both wetland systems did not decrease during the cold season. The results show that the horizontal flow two-basin planted sand filter system for wastewater treatment in Kodijärve (Tartu County, Estonia) is a satisfactory system for phosphorus retention and organic material mineralization. In terms of nitrogen the purification efficiency is unsatisfactory (12 to 85%), which is mostly due to weak nitrification capacity. In Põltsamaa, free water surface wetland system preliminary results show satisfactory purification efficiency in terms of BOD7 and total nitrogen.

## 3.2 REVIEW OF CONTRUCTED WETLAND PROJECTS IN INDIA

### 3.2.1 Constructed wetland to treat Wastewater at Indian Institute of Technology, Powai, Mumbai

Indian Institute of Technology is situated adjacent to Lake Powai in Mumbai. The project was initiated by Centre for Environment Science and Engineering (CESE), IIT Powai and the constructed wetland plant is inside the campus about 1.25 km away from CESE building. This project demonstrates the effectiveness of the constructed wetland (horizontal sub-surface flow) to treat wastewater. The treatment system consists of primary settling tank followed by a 400 sq m of planted filter bed. The bed has wetland plants growing over the gravel media and is designed as a horizontal sub-surface flow (HSSF) system. The bed is rectangular in shape with gravel layer upto 0.8 m deep. The inlet and outlet zones are filled up with larger gravels of 50-100mm diameter. There is also a water regulation chamber before the final collection tank. The sewage generated from the IIT-Powai campus is treated through this system which was designed as an experiment pilot project. The water quality is monitored at various points throughout the bed via the monitoring ports. The treated wastewater from the system is discharged into the Powai lake. The research on this project has underscored the fact that the Constructed Wetland systems can be effectively combined with advanced tertiary treatment alternatives and the resulting high quality treated water can be successfully recycled into water production and sanitation applications. Presently, the results of the treated water quality after filtration from the constructed wetland system show case the capability to implement such projects at various scales.

### 3.2.2 Constructed wetland for wastewater treatment at Indian Agriculture Research Institute, Pusa, New Delhi

The decentralized wastewater treatment system is based on an engineered wetland technology. The aim of the project is to provide an alternate source of water for irrigation of the institute's agricultural fields. The system treats 2.2 MLD of wastewater with an annual irrigation potential of 132 Ha. The source of the wastewater is a nearby drain carrying wastewater from the adjacent Krishi Kunj and Lohamandi Colony.The wastewater treatment plant comprises of 3-treatment cells (each of 80 meter by 40 meter), where organic, nutrient and metal pollutant reductions (i.e. secondary and tertiary treatments) take place; besides 2-sewage wells and 1-grit chamber, where preliminary/ primary treatment takes place. Each treatment cell is stratified with a bed of gravels of varying sizes/ grades, onto which Typha latifolia – a hyper-accumulating emergent vegetation is planted. To make the whole system minimal energy consuming, a complete gravity flow of the wastewater, from the grit chamber to the treated water-collector sump of the system has been ensured. The flow of the wastewater in each treatment cell is so regulated that there is complete sub-surface flow, thereby leading to no ponding, foul smell, mosquito breeding or any direct contact with wastewater. The treated water is finally collected in an treated water-collection tank(80 meter by 40 meter by 2 meter), from where it is finally pumped, through a riser and a set of hydrants, into the irrigation network of the Indian Agricultural Research Institute farm. Long term monitoring of treatment capacity of the constructed wetland treatment system reveals that it is capable to remove turbidity (99%), BOD (87%), Nitrate (95%), Phosphate (90%) and heavy metal (81 - 99%). In terms of standard cost-accounting, the proposed initiative has been found to be associated with Rs. 0.545 Crore per MLD of capital cost (CAPEX) and about Rs. 0.607 per Kilo litre (KL) of total O&M cost. Thus, in comparison to a comparable conventional wastewater treatment plant, the proposed initiative is associated with about 50-65% lower treatment costs. Further, in comparison to a conventional wastewater treatment plant, the proposed technology has less than 1% energy requirement and is associated with zero-chemical application and no sludge generation.

# OBJECTIVE AND SCOPE

## 4.1 OBJECTIVE

To develop a constructed wetland which would be energy efficient and would successfully treat domestic waste water which is discharged through out-fall drain and to study different criteria and variables of the treatment unit in order to understand how the wetland responds to toxic loadings overa short term period and for developing a design criteria.

## 4.2 SCOPE OF WORK

| | |
|---|---|
| **Part 1:** | **Model Unit Placement at the Regional Centre of School of water Resource Engineering at Jadavpur University**<br>1. To install an experimental model in order to handle flow of a nearby drainage canal effluent<br>2. To evaluate the physical, chemical, biological, and hydrologic performance of this experimental model |
| **Part 2:** | **Hydrologic Aspects of Constructed Wetlands**<br>1. To monitor inflows, outflows, and water levels within the subsurface wetland model<br>2. To use the model to describe the spatial and temporal variations in water levels and effluent flows based on information on influent flows. |
| **Part 3:** | **Environmental Aspects of Constructed Wetlands**<br>1. Conduct routine water quality analyses of the constructed wetland model influent and effluent,<br>2. To develop an overall evaluation of the environmental behavior of the constructed wetland |

Table 4.1: Scope

### 4.3 STUDY AREA

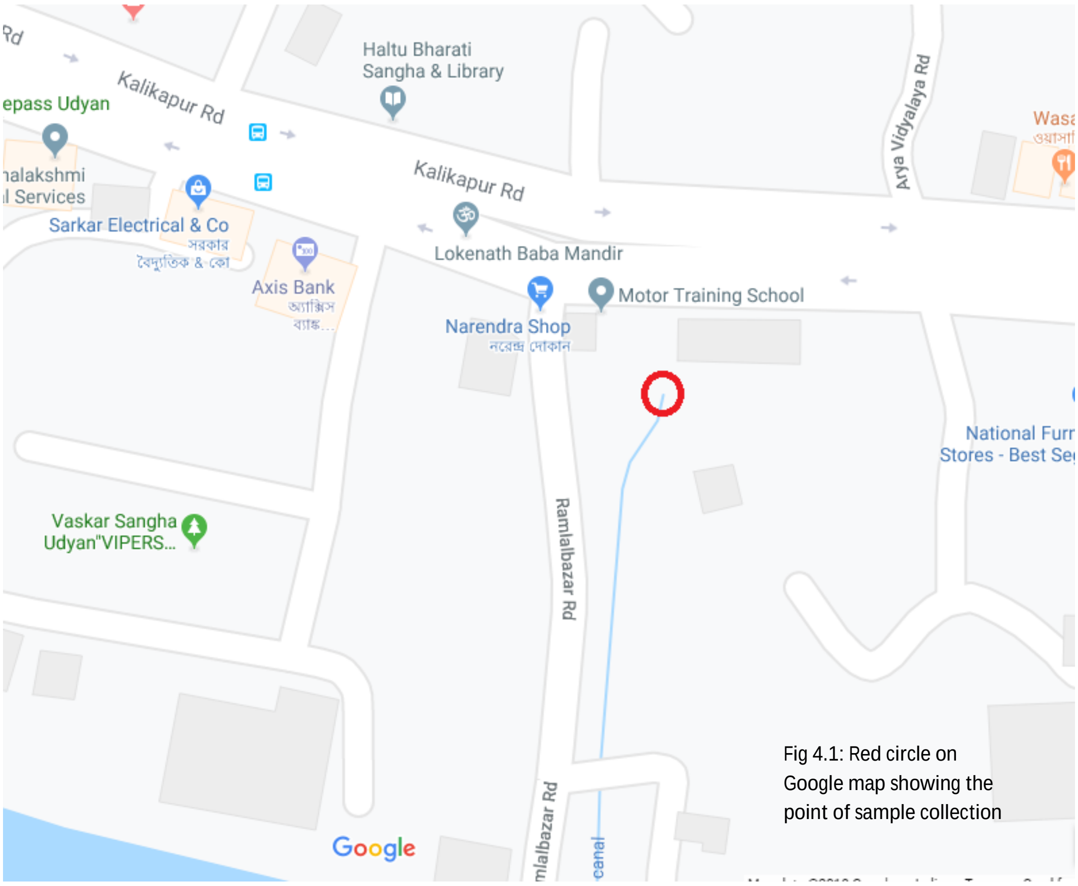



Fig 4.1: Red circle on Google map showing the point of sample collection

Raw sewage sample were collected from Safuipara nalla, Garfa, Kolkata-700078

Latitude: 22°30’07”N, Longitude: 88°22’56”

### 4.4 EXPERIMENTAL SETUP

For bench scale model study of Vertical Flow Constructed Wetland, a rectangular shape tank was fabricated with glass (dimension 1000mm x 300mm x 300mm). The tank was divided into 4 bed chambers and 1 outlet collection chamber with the help of four pair of glass plates such that they would act as baffles. After the tank was placed in the departmental building of Jadavpur University, the tank was packed with different gravel sizes varying from 2mm to 20mm. Then the setup was fed with raw sewage for one week for micro-organisms growth in the tank after which the model would be ready for experiment.

60 L of Municipal sewage was (Raw Water) was periodical passed (from January 2019 to May 2019) collected from Safuipara nalla, Jadavpur, Kolkata. After collection 16 ml raw water was kept in a bucket for 2 hours. Then the water was collected and transferred into another bucket, from which the waster was fed into the CW via tap. A freeboard of 50mm was maintained in the

first receiving bed chamber. The different flow rate with variable time was maintained by adjusting the knob of the tap. After different designed retention time, the outlet discharge (final treated) water was collected for laboratory analysis of different wastewater quality parameter. The setup was run with different BOD loading rates. The setup (CW) was carried out without planted condition. Then on regular basis these two samples (Raw sewage sample and final treated outlet water sample) were analyzed following parameter such as pH, Turbidity, TSS, COD, $BOD_3$, Phosphorus , TKN, TC ,FC as per standard method of APHA guidelines in the Water Quality Laboratory of SWRE, JU. Based on the wastewater quality parameters analysis results CW setup performance were evaluated.

Fig 4.2: Bench scale model of VSSF Constructed Wetland

## 4.5 TREATMENT PROCESS

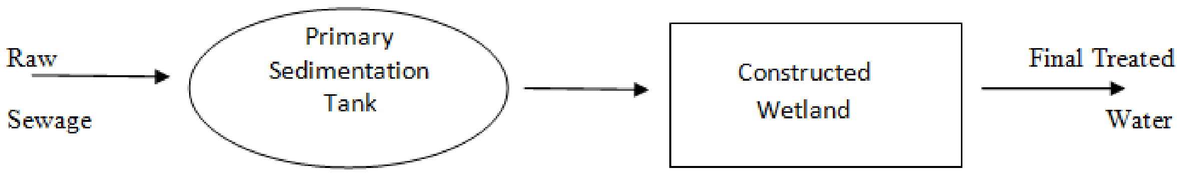



Fig 4.3: Flow chart of treatment process

### 4.6 DESIGN OF EXPERIMENTAL SETUP OF CONSTRUCTED WETLAND

- Length of tank = 1000mm
- Outer Width= 300 mm , Inner Width= 280 mm
- Height of tank = 300 mm
- Height of $1^{st}$ ,$2^{nd}$ , $3^{rd}$ and $4^{th}$ bed are 250mm, 230mm, 200mm and 180mm respectively
- Free board in $1^{st}$compartnent= 50 mm
- Total cross sectional area of 4 beds = (4 x 0.17 x 0.28) = 4 x 0.0476 $m^2$ =0.1904 $m^2$
- Total Volume (empty)of bed = (0.18+0.2+0.23+0.25)x0.17x0.28 = 0.0409$m^3$= 40.936 lit
- Volume of void(with gravel) in bed $V_o$ = 18.592 lit
- Porosity of bed= (18.592/40.936)=0.454 (Range= 0.3-0.5)

Assumption

- $C_o$ = inlet BOD = 100 mg/lit
- $C_t$ = outlet BOD = 5 mg/lit
- K = BOD reaction constant per day = 0.17 (for Indian condition)

We know that,

$A = Q ( \ln C_o – \ln C_t )/ k$

$0.1904 = Q ( \ln 100 – \ln 5 )/ 0.17$

- Designed average inflow Q = 0.010 $m^3$/d = 10 lit/d
- Hydraulic Retention Time =($V_o$/Q)= 18.592/10= 1.85 day (1 to 2 day)
- Hydraulic Loading Rate = [(Q/A)x1000]=(0.01/0.1904)x1000 = 52.52mm/d (range 40 to 80mm/d)
- BOD Loading Rate =[($C_o$ xQ)/(A x 1000)] =[(100x10)/(0.1904x1000)]= 5.25 g/$m^2$/d (range 17.5 to 35 g/$m^2$/d)

# PROJECT METHODOLOGY

## 5. WATER QUALITY ANALYSIS

One of the main purpose of the study was to measure concentration of the constituents in quantity for characterization of water before and after treatment. The parameters for water quality characterization to be measured were selected as per the guidance of the experienced faculties . For water quality testing samples were collected in clean plastic container.

- Raw sewage collected from nearby canal
- Finally treated effluent from CW outlet

The samples were analyzed using the "Standard methods for examination of water and waste water " specified by "American Health Association (APHA), 2000". Following parameters were tested in this study :

- Organoleptic and Physical Parameters

i) pH Value
ii) Turbidity (NTU)
iii) Total Suspended Solids (mg/L)

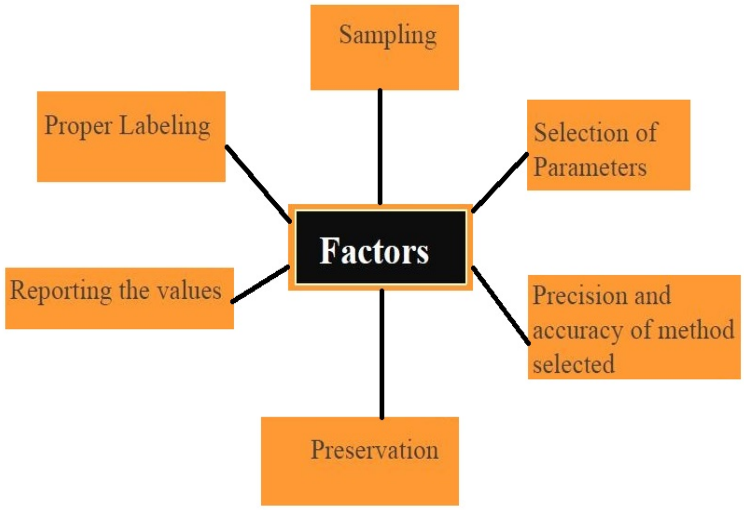
- Parameters Concerning Substances Undesirable

i) Chemical Oxygen Demand (mg/L)
ii) Biochemical Oxygen Demand, 3 Days at 27°C (mg/L)
iii) Phosphate as $PO_4$ (mg/l)
iv) Total Nitrogen as N (mg/L)

- Bacteriological Quantity

i) Total Coliform Count, MPN/100ml
ii) Fecal Coliform Count, MPN/100ml

Fig 5.1: Sample Collection Factors




## 5.1 DETERMINATION OF pH VALUE

pH is a scale used to specify how acidic or basic a water-based solution is. Acidic solutions have a lower pH, while basic solutions have a higher pH. At room temperature (25 °C), pure water is neither acidic nor basic and has a pH of 7. The pH scale is logarithmic and approximates the negative of the base 10 logarithm of the molar concentration (measured in units of molesper liter) of hydrogen ions in a solution. More precisely it is the negative of the base 10 logarithm of the activity of the hydrogen ion. At 25 °C, solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. The neutral value of the pH depends on the temperature, being lower than 7 if the temperature increases. The pH value can be less than 0 for very strong acids, or greater than 14 for very strong bases. The pH scale is traceable to a set of standard solutions whose pH is established by international agreement. Primary pH standard values are determined using a concentration cell with transference, by measuring the potential difference between a hydrogen electrode and a standard electrode such as the silver chloride electrode. The pH of aqueous solutions can be measured with a glass electrode and a pH meter, or a color-changing indicator. Measurements of pH are important in chemistry, agronomy, medicine, water treatment, and many other applications.

### 5.1.1 Methods Available

There are two methods in determination of pH values these are:

- Colorimetric Methods :- This method requires less expensive equipment but calorimetric method has often been used in preference to other technique because of its relative simplicity. A disadvantage of the calorimetric method has been the inhibitory effects of the indicator and of the carbonate-bicarbonate buffer. It is suitable for rough estimation.

- Electrometric Method :- The electrometric method which is considered standard is given by a glass electrode method. The glass electrode with its provision for the automatic measurement of solutions and washing of the reaction chamber permits the measurement of a considerable number of samples in a relatively short period of time and is relatively immune to the interference from color, turbidity and other factors.

Pure water undergoes dissociation in the following in the following ways:

$H_2O = H^+ + OH^-$

When the reaction reaches the equilibrium condition

$[H^+][OH^-]$ = equilibrium constant or ionization constant

$[H_2O] = K_{ion}$ [at 25°C Temperature $K_{ion}=1.82 \times 10^{-16}$]

Since the weight of one litre of water at 25°C = 997gm

Number of degree of gm/litre of solution =997/18 = 55.3

$[H^+][OH^-] = 55.3 \times 1.82 \times 10^{-16} = 10^{-14} = K_w$ [This $K_{ion}[H_2O] = K_w$ is called ion product constant of water]

Taking common logarithm on both side

$\log[H^+] + \log[OH^-] = \log K_w$

r $- \log[H^+] + \log[OH^-] = - \log K_w$

for equilibrium condition

$[H^+] = [OH^-] = 10^{-7}$ mole/litre

pH = pOH = 7

### 5.1.2 Apparatus

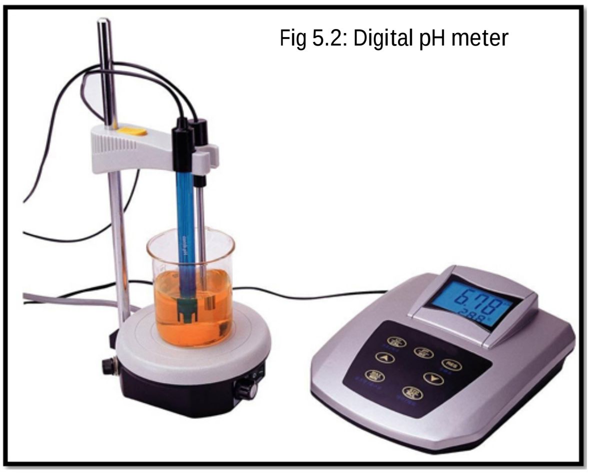



Fig 5.2: Digital pH meter

pH meter is an electronic instrument consisting of a special bulb that is sensitive to hydrogen ions that are present in the test solution. The signal produced by the bulb is amplified and sent to an electronic meter connected to the bulb, which measures and display the pH reading. It gives more precise values than the pH papers. For very precise measurement, the pH meter should be calibrated before each measurement. The calibration should be performed with at least two buffer solutions with known pH. For general purposes, buffer solutions with pH 4 and pH 10 are used. For more precise measurements, three buffer solution calibrations are preferred. After each single measurement, the bulb is rinsed with distilled water or deionized water to remove any traces of solution being measured. Then the bulb is blotted with a blotting paper to remove remaining water that could dilute the sample and alter the reading. When not in use, the bulb must be kept wet at all times to avoid dehydration of the pH sensing membrane.

### 5.1.3 Reagents

i)Potassium hydrogen phthalate buffer, 0.05M, pH 4.00. Dissolve 10.12 g $KHC_8H_4O_4$(potassium hydrogen phthalate) in 1000 mL freshly boiled and cooled distilled water

ii)0.025M Potassium dihydrogen phosphate + 0.025M disodium hydrogen phosphatebuffer, pH 6.86. Dissolve 3.387 g $KH_2PO_4$ + 3.533 g $Na_2HPO_4$ in 1000 mL freshly boiledand cooled distilled water.

iii)0.01M sodium borate decahydrate (borax buffer), pH = 9.18. Dissolve 3.80 g$Na_2B_4O_7.10H_2O$ in 1000 mL freshly boiled and cooled distilled water.

iv) Store buffer solutions in polyethylene bottles. Replace buffer solutions every 4 weeks

### 5.1.4 Procedure

i) Remove electrodes from storage solution, rinse, blot dry with soft tissue, place in initial buffer solution and standardise pH meter according to manufacturer's instructions.

ii) Remove electrodes from the first buffer, rinse thoroughly with distilled water, blot dry and immerse in second buffer preferably of pH within 2 pH units of the pH of the sample. Read pH, which should be within 0.1 unit of the pH of the second buffer.

Iii) Determine pH of the sample using the same procedure as in (b) after establishing equilibrium between electrodes and sample. For buffered samples this can be done by dipping the electrode

into a portion of the sample for 1 min. Blot dry, immerse in a fresh portion of the same sample, and read pH.
iv)With dilute poorly buffered solutions, equilibrate electrodes by immersing in three or four successive portions of the sample. Take a fresh sample to measure pH.
v)Stir the sample gently while measuring pH to insure homogeneity.

**5.2 DETERMINATION OF TURBIDITY**

Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid.


Fig 5.3: Nephelometric Turbidimeter

**5.2.1 Apparatus**

Nephelometric turbidity meter with sample cells

**5.2.2 Reagents**

i)Solution I. Dissolve 1.000g hydrazine sulphate, $(NH_2)_2.H_2SO_4$ in distilled water and dilute to 100 mL in a volumetric flask.
ii)Solution II. Dissolve 10.00g hexamethylenetetramine, $(CH_2)_6N_4$, in distilled water and dilute to 100 mL in a volumetric flask.

iii)4000 NTU suspension. In a flask mix 5.0 mL of Solution I and 5.0 mL of Solution II. Let stand for 24 h at 25 ±3°C. This results in a 4000 NTU suspension. Store in an amber glass bottle. The suspension is stable for up to 1 year.

iv) Dilute 4000 NTU stock solution with distilled water to prepare dilute standards just before use and discard after use.

### 5.2.3 Procedure

i) Calibrate nephelometer according to manufacturer's operating instructions. Run at least one standard in each instrument range to be used.

ii)Gently agitate sample. Wait until air bubbles disappear and pour sample into cell. Read turbidity directly from instrument display.

## 5.3 DETERMINATION OF TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) is the dry-weight of suspended particles, that are not dissolved, in a sample of water that can be trapped by a filter that is analyzed using a filtration apparatus. It is a water quality parameter used to assess the quality of a specimen of any type of water or water body, ocean water for example, or wastewater after treatment in a wastewater treatment plant. It is listed as a conventional pollutant in the U.S. Clean Water Act.[1] Total dissolved solids is another parameter acquired through a separate analysis which is also used to determine water quality based on the total substances that are fully dissolved within the water, rather than undissolved suspended particles.

### 5.3.1 Apparatus

Fig 5.4: TSS Filtration Apparatus

i) 100ml measuring cylinder
ii) Beaker
iii) Whatman grade 42 glass fibre filter paper
iv)Filtering apparatus
v) Conical flasks
vi) Hot air oven
vii) Digital weight machine
viii) Desiccator

### 5.3.2 Procedure

i)The filter paper was taken in the hot air oven at 105°C for 1hour and then it was kept in the desiccator (containing CaO) for 30 mins

ii) then the filter paper is weighted

iii) The 100ml sample was collected and then it was filtered through the filter paper.

iv) Then the filter is heated to dry in the hot air oven in 105°C by evaporating the water for around 1 hour.
v) Then these were kept in the desiccator for 30mins till it comes to room temperature.
vi) then the filter paper is weighed.

### 5.3.3 Calculation

TSS (mg/l) = $\frac{(W_2 - W_1) \times 1000}{volume\ of\ sample}$

Where
$W_1$ is weight of filter paper before passing sample
$W_2$ is weight of filter paper after passing sample

## 5.4 DETERMINATION OF CHEMICAL OXYGEN DEMAND

The chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is commonly expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per litre (mg/L). A COD test can be used to easily quantify the amount of organics in water. The most common application of COD is in quantifying the amount of oxidizable pollutants found in surface water or wastewater. COD is useful in terms of water quality by providing a metric to determine the effect an effluent will have on the receiving body.

### 5.4.1 Apparatus

- Reflux flasks, consisting of 250 mL flask with flat bottom and with 24/29 ground glass neck
- Condensers, 24/29 and 30 cm jacket Leibig or equivalent with 24/29 ground glass joint, or air cooled condensers, 60 cm long, 18 mm diameter, 24/29 ground glass joint.
- Hot plate or gas burner having sufficient heating surface.

### 5.4.2 Reagent

i)Standard potassium dichromate solution, 0.0417M (0.25N): Dissolve 12.259 g $K_2Cr_2O_7$, primary standard grade, previously dried at 103°C for 2 hours, in distilled water and dilute to 1Litre.
ii)Sulphuric acid reagent: Add 5.5g $Ag_2SO_4$ technical or reagent grade, per kg of conc. $H_2SO_4$, keep for a day or two to dissolve.

iii)Ferroin indicator solution: Dissolve 1.485g 1, 10-phenanthroline monohydrate and 695 mg $FeSO_4.7H_2O$ in distilled water and dilute to 100 mL.Commercial preparation may also be available.
iv)Standard ferrous ammonium sulphate (FAS), titrant, 0.25M: Dissolve 98g $Fe(NH_4)_2(SO_4)_2.6H_2O$ in distilled water, add 20 mL conc. $H_2SO_4$, cool and dilute to 1L, standardize daily as follows.
v)Standardisation: Dilute 10 mL standard $K_2Cr_2O_7$to about 100 mL, add 30 mL conc$H_2SO_4$, cool. Add 2 drops of ferroin indicator and titrate with FAS.

vi) Molarity FAS =$\left(\frac{\text{Volume of 0.0417M K2Cr2O7 ,mL}}{\text{Volume of FAS used, mL}}\right)\times 0.25$

vii)Mercuric Sulphate, $HgSO_4$, powder
viii)Potassium hydrogen phthalate (KHP) standard: Lightly crush and dry potassium hydrogen phthalate ($HOOCC_6H_4COOK$), at 120°C, cool in desiccator, weigh 425 mg in distilled water and dilute to 1L. This solution has a theoretical COD of 500 μgO2/mL, stable for 3 months in refrigerator.

**5.4.3 Procedure**

i)Add 50 mL of sample or an aliquot diluted to 50 mL with distilled water in a 500 mL refluxing flask. Add 1g $HgSO_4$, few glass beads, and 5 mL sulphuric acid reagent, mix, cool. Add 25 mL of 0.0417M $K_2Cr_2O_7$ solution, mix. Connect the flask to the condenser and turn on cooling water, add additional 70 mL of sulphuric acid reagent through open end of condenser, with swirling and mixing.
ii)Reflux for 2 hours; cool, wash down condenser with distilled water to double the volume of contents, cool.
iii)Add 2 drops of Ferroin indicator, titrate with FAS the remaining potassium dichromate, until a colour change from bluish green to reddish brown. Also reflux and titrate a distilled water blank with reagents.
iv)Use standard 0.00417M $K_2Cr_2O_7$, and 0.025M FAS, when analysing very low COD samples.
v)Evaluate the technique and reagents by conducting the test on potassium hydrogen phthalate solution.
vi)Do not add grease at the Leibig jacket to prevent jamming, use water instead.

### 5.4.4 Calculation

COD (mg /l)=$\frac{(A-B) \times N \times 8000}{S}$

where:
A = FAS used for blank, mL
B = FAS used for sample, mL
N = Normality of FAS solution =0.25(N)
S =ml of sample used for titration

## 5.5 DETERMINATION OF BIOCHEMICAL OXYGEN DEMAND

Biochemical Oxygen Demand (BOD, also called Biological Oxygen Demand) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a surrogate of the degree of organic pollution of water. BOD can be used as a gauge of the effectiveness of wastewater treatment plants. BOD is similar in function to chemical oxygen demand (COD), in that both measure the amount of organic compounds in water. However, COD is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biodegradable organic matter.

### 5.5.1 Apparatus

i) BOD bottles, 300 mL, narrow mouth, flared lip, with tapered and pointed ground glass stoppers.
ii) Air incubator or water bath, thermostatically controlled at 27 ± 1°C. Light entry must be prevented in order to avoid photosynthetic oxygen production
iii) Accessories: plastic tube, screw-pin and a 5-10 L water container.

### 5.5.2 Reagents

i)Phosphate buffer solution. Dissolve 8.5 g $KH_2PO_4$, 21.75 g $K_2HPO_4$, 33.4 g $Na_2HPO_4.7H_2O$ and 1.7 g $NH_4Cl$ in 1L distilled water.
ii) Magnesium sulphate solution. Dissolve 22.5 g $MgSO_4.7H_2O$ in 1L distilled water.
iii) Calcium chloride solution. Dissolve 27.5 g $CaCl_2$ in 1L distilled water.
iv) Ferric chloride solution. Dissolve 0.25 g $FeCl_3.6H_2O$ in 1L distilled water.
v) Acid and alkali solution. 1N NaOH and 1N $H_2SO_4$. Use for neutralising samples.

vi) Glucose-glutamic acid solution (prepare fresh). Dissolve 150 mg dry reagent grade glucose and 150 mg dry reagent grade glutamic acid in 1L distilled water
vii) Sample dilution water. Add 1 mL each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solutions per litre distilled water.

### 5.5.3 Procedure

i) Prepare required amount of dilution water at the rate of 1000 to 1200 mL per sample per dilution. Bring the diluted water temperature to 27°C. Saturate with air by shaking in a partially filled bottle, by bubbling with organic free filtered air or by storing in cotton-plugged bottles for a day.
ii) Some samples do not contain sufficient microbial population (for example, some industrial wastes, high temperature wastes, or wastes with extreme pH values). For such wastes, the dilution water is seeded using effluent from a biological treatment system processing the waste. Where this is not available, use supernatant from domestic wastewater after settling for at least 1 h but not more than 36 h. Seed from a surface water body receiving the waste may also be suitable. Add enough seed volume such that the DO uptake of the seeded dilution water is between 0.6 and 1.0 mg/L. For domestic wastewater seed, usually 4 to 6 mL seed / L of dilution water is required. Surface water samples usually do not require seeding.
iii) Dilution of sample. Dilutions must result in a sample with a residual DO (after 3 days of incubation) of at least 1 mg/L and a DO uptake of at least 2 mg/L. For preparing dilution in graduated cylinders, siphon dilution water, seeded if necessary, into a 1 to 2 L capacity cylinder. Siphoning should always be done slowly without bubbling, use a screw-pin on the tube to regulate the flow. Keep the tip of the tube just below the water surface as it rises. Fill cylinder half full, add desired quantity of sample and dilute to appropriate level, mix with plunger type mixing rod. Siphon mixed diluted sample in three BOD bottles, stopper without entraining any air. Determine initial DO on one bottle and incubate the other two at 27°C. Determine final DO in duplicate after 3days.
iv) Dilution water blank. Find the DO consumption of unseeded dilution water by determining initial and final DO as in c above. It should not be more than 0.2 mg/L
v) Seed control. Determine the DO uptake by seeding material according to the procedure in above.

### 5.5.4 Calculation

i) When dilution water is not seeded:

$BOD_3$ (mg/l) = $\frac{D_O - D_T}{P}$

ii) When dilution water is seeded:

BOD$_3$ (mg/l) = $\frac{(B_0 - B_T) \times (D_o - D_T) - f}{P}$

where:
$D_0$ = DO of diluted sample initially, mg/L
$D_T$ = DO of diluted sample after 3 day incubation at 27°C, mg/L
P = decimal volumetric fraction of sample used
$B_0$ = DO of seed control initially, mg/L
$B_T$ = DO of seed control after incubation, mg/L
f = ratio of % seed in diluted sample to % seed in seed control

**5.6 DETERMINATION OF PHOSPHORUS**

Total Phosphate can be divided into two categories orthophosphate and organic phosphate. Orthophosphate is determined by conversion of phosphorus form to soluble Ortho Phosphate and a digestion method, in which total organic matter is oxidized, determined total phosphate contain.

**Available Methods**

There are various methods which are followed for the phosphate test. Phosphate analysis embodies two general procedures:

- Conversion of the phosphorus form of interest to soluble orthophosphate
- Colorimetric determination of the soluble orthophosphate
- UV- Visible Spectro-photometer

**Colorimetric Method**

- Vanadomolybdate Method
- Stannous Chloride Method
- Ascorbic Acid Method

### 5.6.1 Vanadomolybdate Method

Phosphorous occurs in waters and wastewaters almost solely as phosphates. The forms of phosphates arise from a variety of sources. Some small amounts of orthophosphate are added to some water supplies during treatment. Larger amounts may be added when the water is used for laundering or other cleaning. In dilute orthophosphate solution, ammonium molybdate reacts under acid conditions to form a heteropoly acid, molybdophosphoric acid. In the presence of vanadium, yellow vanadomolybdophosphoric acid is formed. The intensity of the yellow color is proportional to phosphate concentration.

### 5.6.2 Apparatus

● Volumetric flasks

● Reagent bottles

● Conical flasks

● Beakers

● Pipettes

● Spectrophotometer to measure at 750nm

### 5.6.3 Reagent Preparation

● Phenolphthalein

● Concentrated HCL

● Vandate-molybdate reagent – Add 12.5gm Ammonium Molybdate [$(NH_4)$6Mo7$O_{24}$.4H2O] to 150ml distilled water. Add 0.625gm Ammonium Meta-Vandate ($NH_4Vo_3$) to 150ml distilled water. Now boil it for 20 min, and cool it at room temperature. Then mix 165ml HCL (conc.) with it.

### 5.6.4 Procedure

Take 10 ml sample then mix 1ml H2SO4 (Conc.) and 5ml HNO3 (Conc.) with it. Then boil the mixture and reduce the volume of the sample to 1ml. then cool it at room temperature. Now add 20ml distilled water to it. Then add 1 drop phenolphthalein indicator. After that add 1(N) NaOH till the colour of the sample changes to pink. Then add one tea spoon of charcoal, the color of the solution changes to white. Now filter it and collect the filtrate. Mix distilled water with the filtrate to make the solution 100ml. then pour the solution into a cleanand dry spectrophotometric cell and measure absorbance at 720nm.

## 5.7 DETERMINATION OF TOTAL NITROGEN

The Kjeldahl method is used to determine the nitrogen content in organic and inorganic samples. For longer than 100 years the Kjeldahl method has been used for the determination of nitrogen in a wide range of samples. The determination of Kjeldahl nitrogen is made in foods and drinks, meat, feeds, cereals and forages for the calculation of the protein content. Also the Kjeldahl method is used for the nitrogen determination in wastewaters, soils and other samples.

### 5.7.1 Apparatus

●Digestion apparatus, a heating device to provide temperature range of 375°C to 385 °C for effective digestion, adjusted to boil 250 mL of water in 800 mL total capacity Kjeldahl flask in about 5 min.

●Distillation apparatus, a borosilicate glass flask of 800 mL capacity attached to a vertical condenser, the outlet tip of the condenser is submerged in the receiving acid solution.

### 5.7.2 Reagents:

1. Digestion reagent ( dissolve 134g K2SO4 and 7.3g CuSO4 in about 800ml water carefully add 134ml coc H2SO4. Cool to room temperature, dilute to 1 lit with water . mix well keep at temp 200C to prevent vaporization).
2. Phenolphthalein indicator
3. Sodium hydroxide
4. Mixed indicator solution
5. Indicating boric acid solution
6. Standard sulfuric acid titrant.
7. Hydroxide thiosulfate reagent.

### 5.7.3 Procedure:

**A) Digestion**

1. Take 280ml of sample in a kjeldahl flask.
2. Add few glass beads to it then add 50ml digestion reagent
3. Mix , heat and continue boiling until solution remains 25-50ml.
4. Cool it and add distilled water to it to make the volume 300ml.

5. Add 0.5 ml phenolphthalein indicator.
6. Add 50 ml thiosulfate hydroxide reagent solution.
7. If pink colour does not appears then add more 50ml thiosulfate hydroxide reagent solution.

**B) Distillation**

1. In collect the distillate in a flask containing boric acid solution.
2. Collect 200ml distillate into 50ml boric acid solution

**C) Titration**

1. Titrate it against 0.02N $H_2SO_4$ solution until colour changes from purple to green.
2. carry the blank titration, following all steps of procedure.

### 5.7.4 Calculations:

Total Nitrogen (mg/L) = ((A-B)* 280) /ml of sample
A= volume of $H_2SO_4$ used for sample
B= Volume of $H_2SO_4$ used for blank

## 5.8 BACTERIOLOGICAL TEST

Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their waste. They are also found in plant and soil material. The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform count gives a general indication of the stationary condition of a water sample.

Total coliform include bacteria that are found in the soil, in water that has been influenced by surface water and in human or animal waste.

Fecal coliform are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm blooded animals. Because the origin of the fecal coliform are most specific than the origin than the origin of the more general total coliform group of bacteria, fecal coliform are considered a more accurate indication of animal or human waste than the total coliform. Coliform bacteria are a natural part of the microbiology of the intestinal tract of warm blooded mammals, including man.

The total coliform group is relatively easy to culture in the lab, and therefore has been selected as the primary indicator bacteria from the presence of disease causing organism. The total and fecal coliform bacteria test is a primary indicator of suitability for consumption. In measure the concentration of total coliform bacteria associate with the possible presence of disease causing organism. Fecal coliform indicate the presence of the sewage contamination of a water way and the possible presence of pathogenic bacteria.

### 5.8.1 Apparatus

- Test tubes
- Test tube stands
- Digital weight maching
- Autoclave
- Durham’s tubes
- Non- absorbant cotton
- 1ml pipettes
- 10ml pipettes
- 2000ml beaker
- Biological incubator
- Platinum loop
- Water bath

### 5.8.2 Reagents

1) Macconkey Broth

2) EC Broth

3)Briliant Green Bile Broth

### 5.8.3 Preparation Of Media

- Preparation of Macconkey Broth for presumptive coliform test
    - Macconkey broth powder – 80gm
    - Double Distilled (D/D) water – 1000ml

- If required, heat the solution to dissolve completely. This is double strength Macconkey Broth

- Preparation of Briliant Green Bile (BGB) broth for TC confirmatory test
  - BGB broth powder – 4gm
  - D/D water – 100ml
  - If required heat the solution to dissolve completely
- Preparation of EC broth for FC determination
  - EC broth powder – 3.7 gm
  - D/D water – 80ml
  - If required heat the solution to dissolve completely

### 5.8.4 Procedure

1) Plug all tube (for 1 sample 15 tubes) tightly with non absorbent cotton

2) Place all the tube in a wire mesh cage with either brown paper or aluminum foil.

3) Put 10ml Macon D.S in each tube

4) Among them add 9ml D/D to 5 tubes.

5) Add 9.9ml D/D to another 5 tubes

6) Sterilize all the tubes in autoclave for 15

7) Keep the tubes in autoclave for 15 min at a pressure 15 lb/inch$^2$

8) Remove the tubes from the autoclave and cool these tubes for 24 hrs as it comes to room temperature.

### 5.8.4.1 DETERMINATION OF TOTAL COLIFORM COUNT

1) Here number of tubes to be taken depends on the number of tubes showing positive results in the presumptive test. One tube for TC test should be taken against each positive tube of presumptive test
2) Take 5 ml of B.G.L.B broth in each tube and insert one Durham's tube in each of them. Plug and autoclave in similar way as mentioned for Macconkey broth.
Keep the tubes containing Briliant Green Bile broth both after inoculation at 37°C in incubation for 48 hours.

### 5.8.4.2 DETERMINATION OF FECAL COLIFORM COUNT

1)Here also number of tubes to be taken depends upon the number of tubes showing the positive results in the presumptive test. One tube for FC should be taken against positive presumptive test.
2) Take 5 ml of EC broth. Then inoculate it in autoclave.
3) With the help of a platinum loop add a little amount of solution (which is tested for presumptive test)
4) Keep the tubes containing FC broth after inoculation in 44$^{o}$C on water both for 24 hours.
5) The number of positive test tubes, where formation of gases takes place has been noted.

# RESULT AND DISCUSSION

During the monitoring period which started from January 2019 and continued till May 2019, samples were collected from the CW system and analyzed for each of the various physical, chemical and microbiological parameters.

## 6.1 TABULATED RESULTS

**Trial – 1 :**

Sampling Date: 08/01/2019 Flow rate = 10 Lit/day

| Sample | pH | Turbidity (NTU) | TSS (mg/L) | COD (mg/L) | BOD (mg/L) | P (mg/L) | TKN (mg/L) | TC (MPN/ 100ml) | FC (MPN/ 100ml) |
|---|---|---|---|---|---|---|---|---|---|
| Raw Sample | 7.3 | 30.7 | 58 | 80 | 56 | 18.6 | 13.3 | $345 \times 10^2$ | $69 \times 10^2$ |
| Final Treated Effluent | 8.04 | 5.2 | 15 | 42 | 23 | 2.33 | 1.2 | $221 \times 10^2$ | $33 \times 10^2$ |
| Removal Effeciency | | 83.06% | 74.13% | 47.5% | 58.92% | 87.4% | 90.9% | 35.94% | 15.38% |

Table 6.1: Concentration of Physico-chemical & biological parameters and percent removal in CW

- Hydraulic Retention Time = 18.592/10= 1.85 day (1 to 2 day)
- Hydraulic Loading Rate = (0.01/0.1904)x1000 = 52.52mm/d
- BOD Loading Rate =[(56x10)/(0.1904x1000)]= 5.25 g/m$^2$/d
- COD Loading Rate =[(80x10)/(0.1904x1000)]= 4.2 g/m$^2$/d

**Trial – 2 :**

Sampling Date: 23/03/2019 Flow rate = 10 Lit/day

| Sample | pH | Turbidity (NTU) | TSS (mg/L) | COD (mg/L) | BOD (mg/L) | P (mg/L) | TKN (mg/L) | TC (MPN/ 100ml) | FC (MPN/ 100ml) |
|---|---|---|---|---|---|---|---|---|---|
| Raw Sample | 7.75 | 30 | 23 | 46 | 60 | 11 | 13.6 | $345 \times 10^2$ | $160 \times 10^2$ |
| Final Treated Effluent | 8.58 | 2.8 | 5 | 27 | 5 | 0.78 | 1.54 | $150 \times 10^2$ | $60 \times 10^2$ |
| Removal Effeciency | | 90.66% | 78.26% | 41.3% | 91.66% | 92.9% | 88.67% | 56.52% | 62.5% |

Table 6.2: Concentration of Physico-chemical & biological parameters and percent removal in CW

- Hydraulic Retention Time = 18.592/10= 1.85 day (1 to 2 day)
- Hydraulic Loading Rate = (0.01/0.1904)x1000 = 52.52mm/d
- BOD Loading Rate =[(60x10)/(0.1904x1000)]= 3.15 g/m$^2$/d
- COD Loading Rate =[(46x10)/(0.1904x1000)]= 2.41 g/m$^2$/d

**Trial – 3 :**

Sampling Date: 14/04/2019 Flow rate = 10 Lit/day

| Sample | pH | Turbidity (NTU) | TSS (mg/L) | COD (mg/L) | BOD (mg/L) | P (mg/L) | TKN (mg/L) | TC (MPN/ 100ml) | FC (MPN/ 100ml) |
|---|---|---|---|---|---|---|---|---|---|
| Raw Sample | 8.17 | 16.7 | 19 | 80 | 47 | 5.4 | 96 | $542 \times 10^2$ | $9 \times 10^2$ |
| Final Treated Effluent | 8.6 | 4.5 | 9 | 35 | 7 | 0.58 | 3 | $1 \times 10^2$ | 1 |
| Removal Effeciency | | 73.05% | 52.63% | 56.25% | 85.10% | 89.25 | 96.87% | 99.8% | 99.8% |

Table 6.3: Concentration of Physico-chemical & biological parameters and percent removal in CW

- Hydraulic Retention Time = 18.592/10= 1.85 day (1 to 2 day)
- Hydraulic Loading Rate = (0.01/0.1904)x1000 = 52.52mm/d
- BOD Loading Rate =[(47x10)/(0.1904x1000)]= 2.46 g/m$^2$/d
- COD Loading Rate =[(80x10)/(0.1904x1000)]= 4.2 g/m$^2$/d

**Trial – 4 :**

Sampling Date: 21/05/2019 Flow rate = 10 Lit/day

| Sample | pH | Turbidity (NTU) | TSS (mg/L) | COD (mg/L) | BOD (mg/L) | P (mg/L) | TKN (mg/L) | TC (MPN/ 100ml) | FC (MPN/ 100ml) |
|---|---|---|---|---|---|---|---|---|---|
| Raw Sample | 8.01 | 5.4 | 15 | 41 | 12 | 1.37 | 13 | 900 x $10^2$ | 100 |
| Final Treated Effluent | 8.24 | 1 | 4 | 30 | 8 | 0.22 | 3 | 170 x $10^2$ | 1 |
| Removal Effeciency | | 81.48% | 73.33% | 26.82% | 33.33% | 83.94% | 76.92% | 81.11% | 99% |

Table 6.4: Concentration of Physico-chemical & biological parameters and percent removal in CW

- Hydraulic Retention Time = 18.592/10= 1.85 day (1 to 2 day)
- Hydraulic Loading Rate = (0.01/0.1904)x1000 = 52.52mm/d
- BOD Loading Rate =[(12x10)/(0.1904x1000)]= 0.63 g/$m^2$/d
- COD Loading Rate =[(41x10)/(0.1904x1000)]= 2.15 g/$m^2$/d

## 6.2 GRAPHICAL REPRESENTATION OF RESULTS

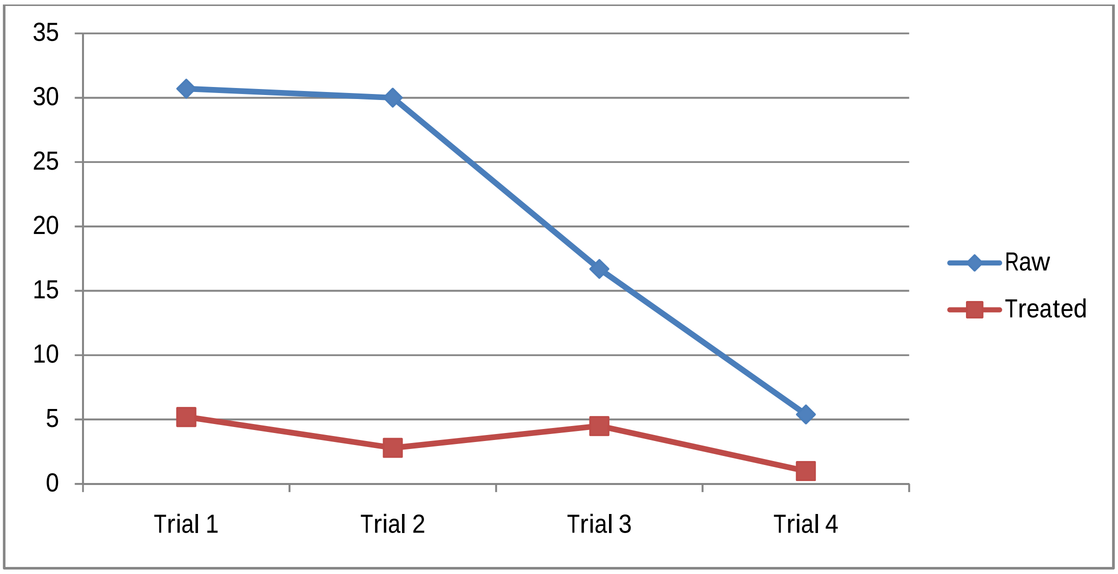



Fig 6.1:Extent Of Turbidity Removal In CW

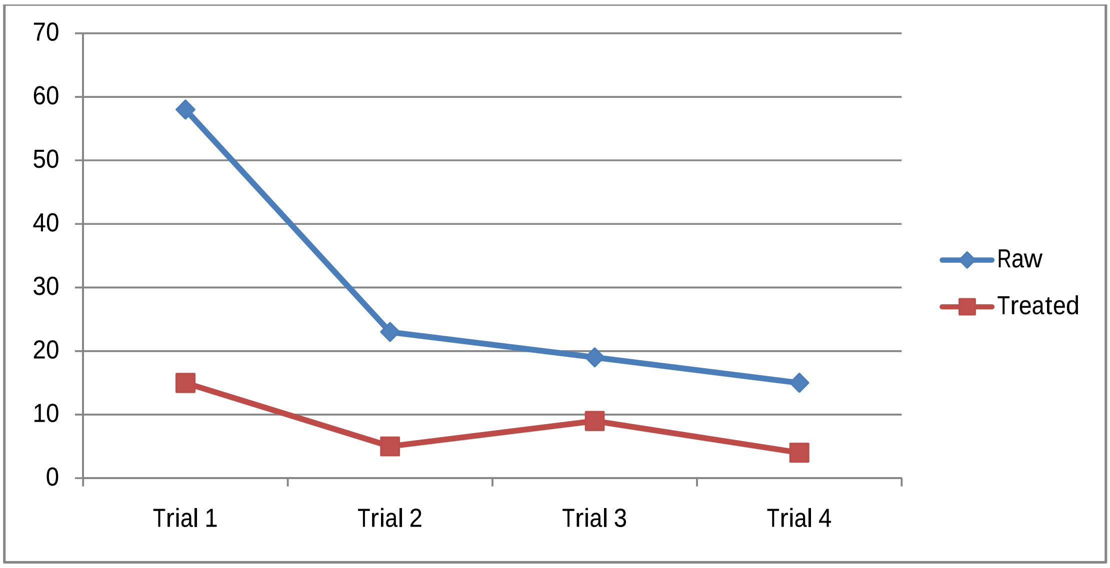



Fig 6.2:Extent Of TSS Removal In CW

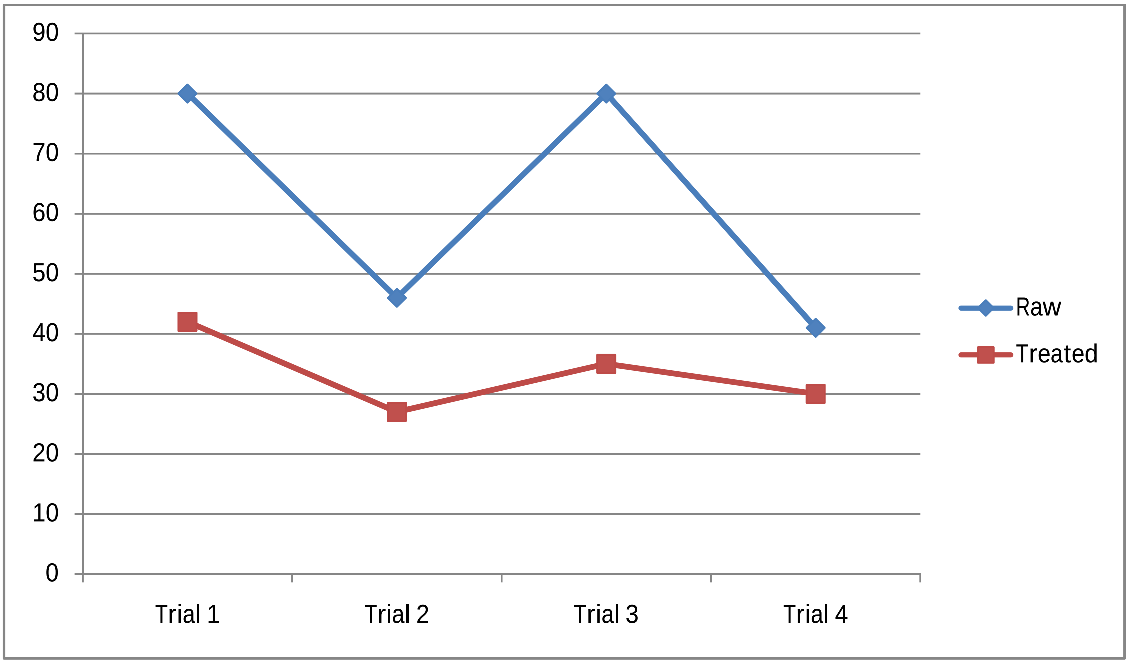



Fig 6.3:Extent Of COD Removal In CW

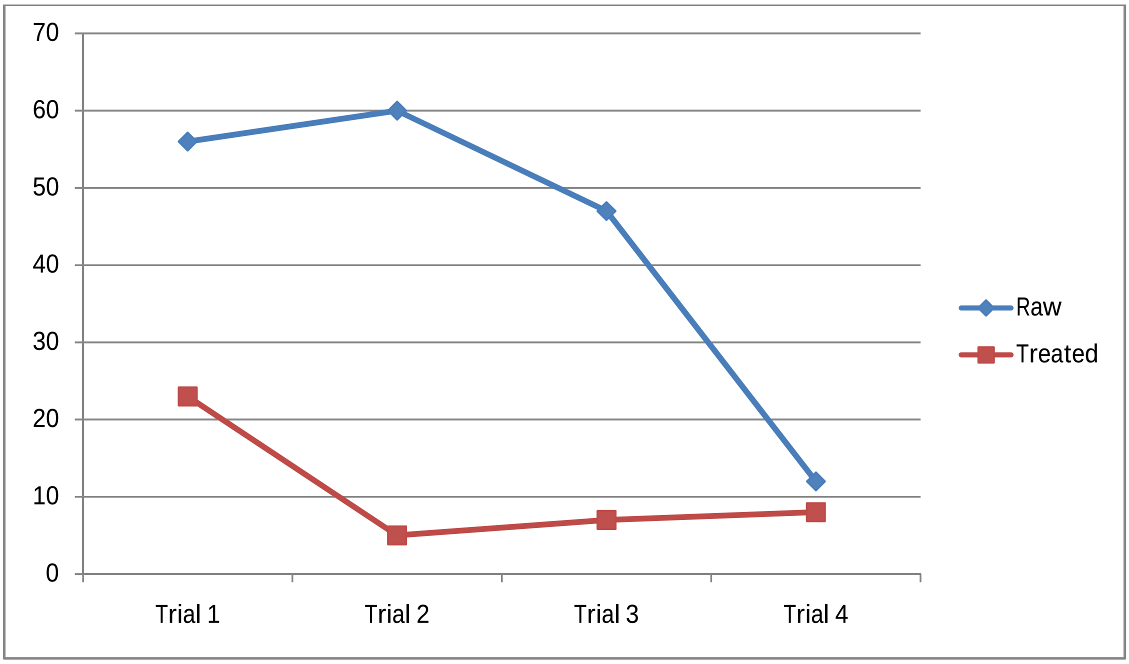



Fig 6.4:Extent Of BOD Removal In CW

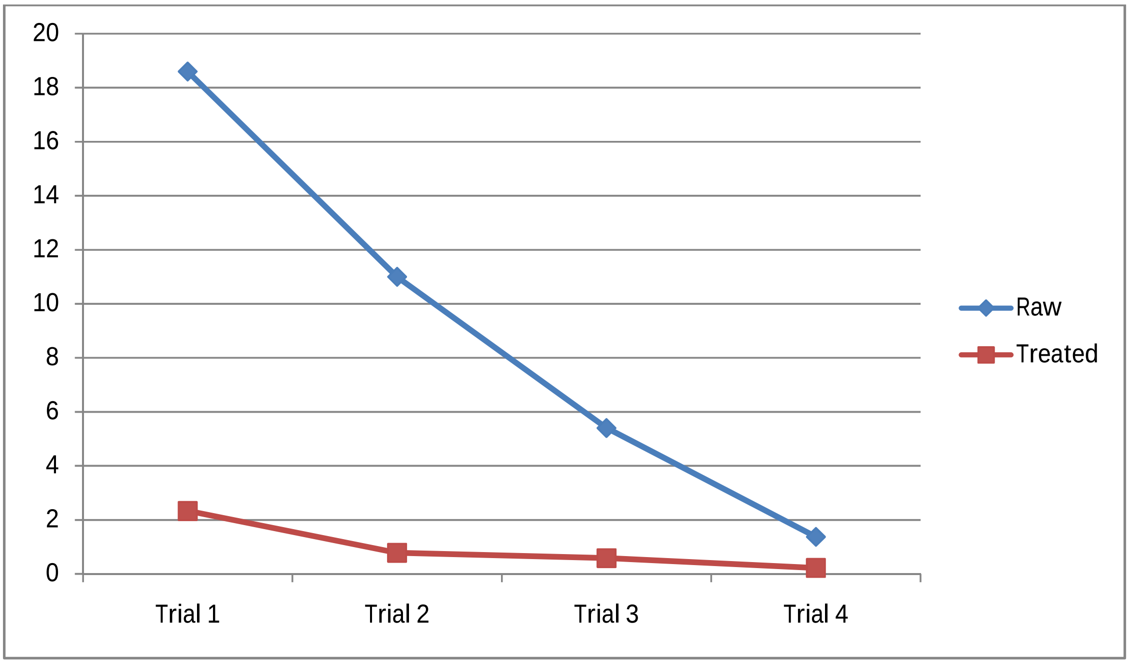



Fig 6.5: Extent Of Phosphorus Removal In CW

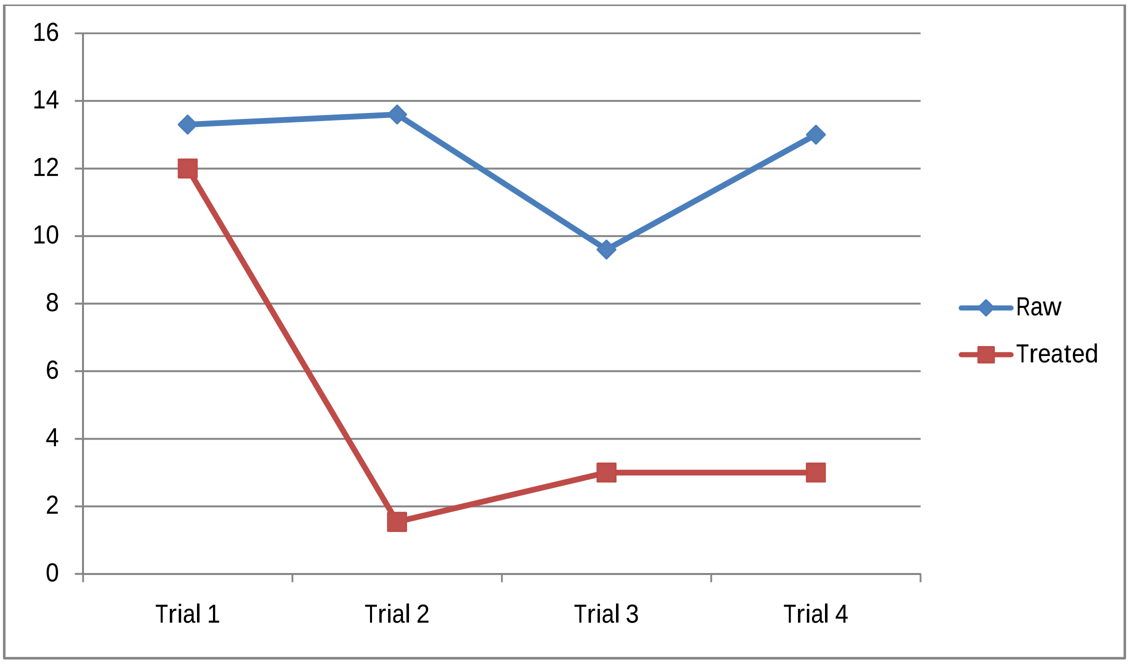



Fig 6.6: Extent Of Phosphorus Removal In CW

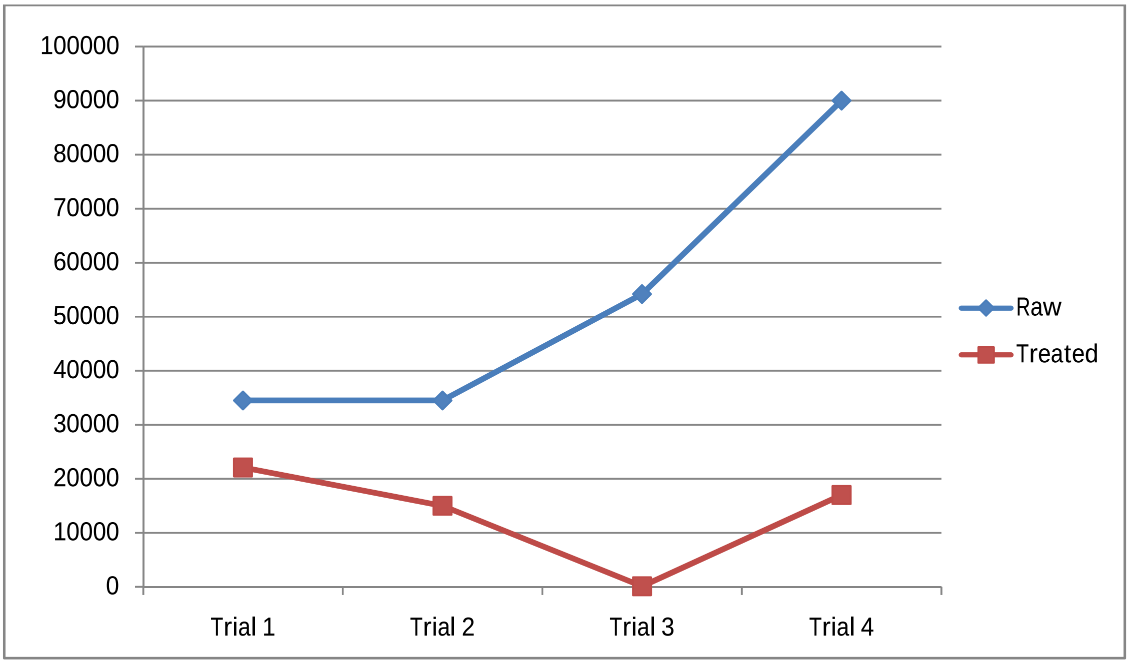



Fig 6.7: Extent Of TC Removal In CW

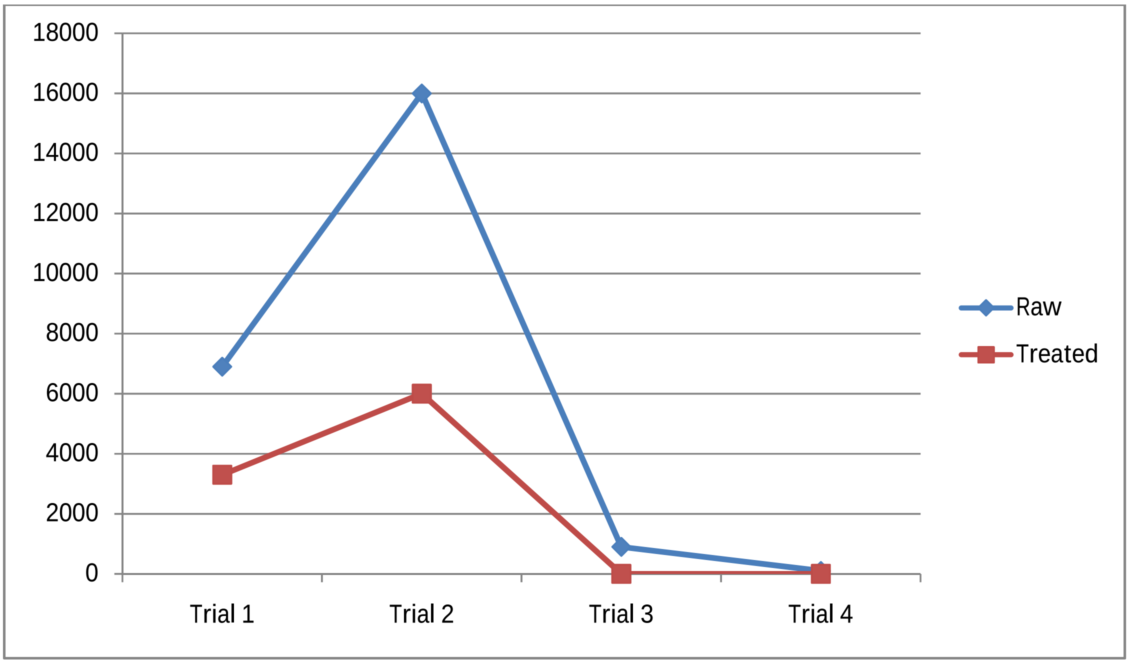
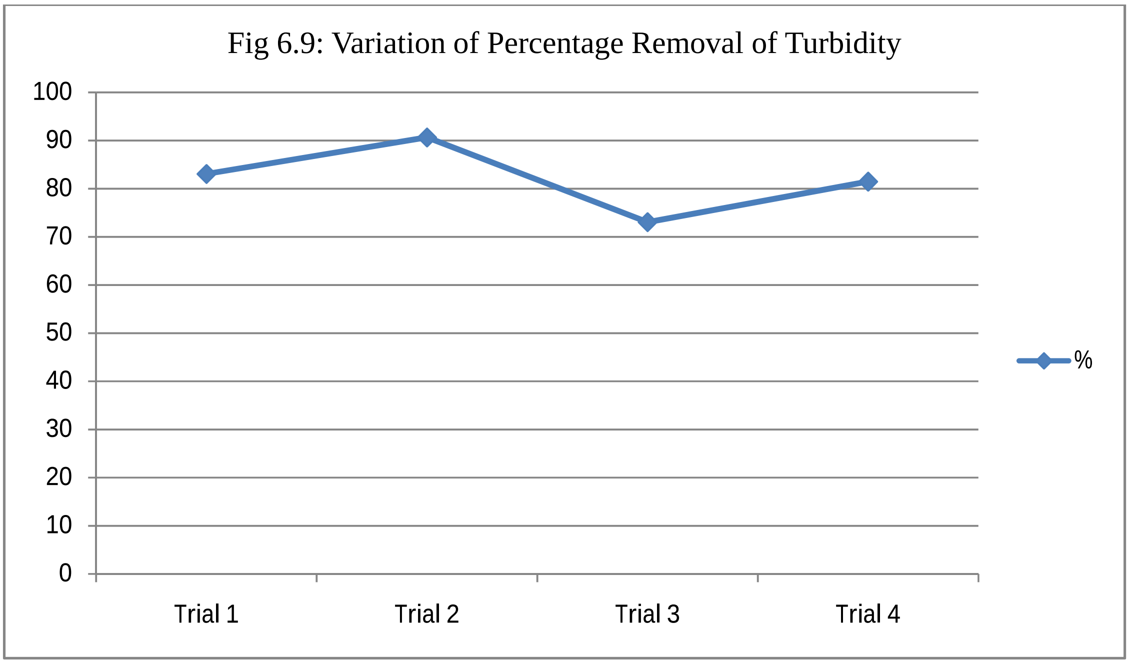



Fig 6.8: Extent Of Phosphorus Removal In CW

## 6.3 EFFICIENCY CURVES



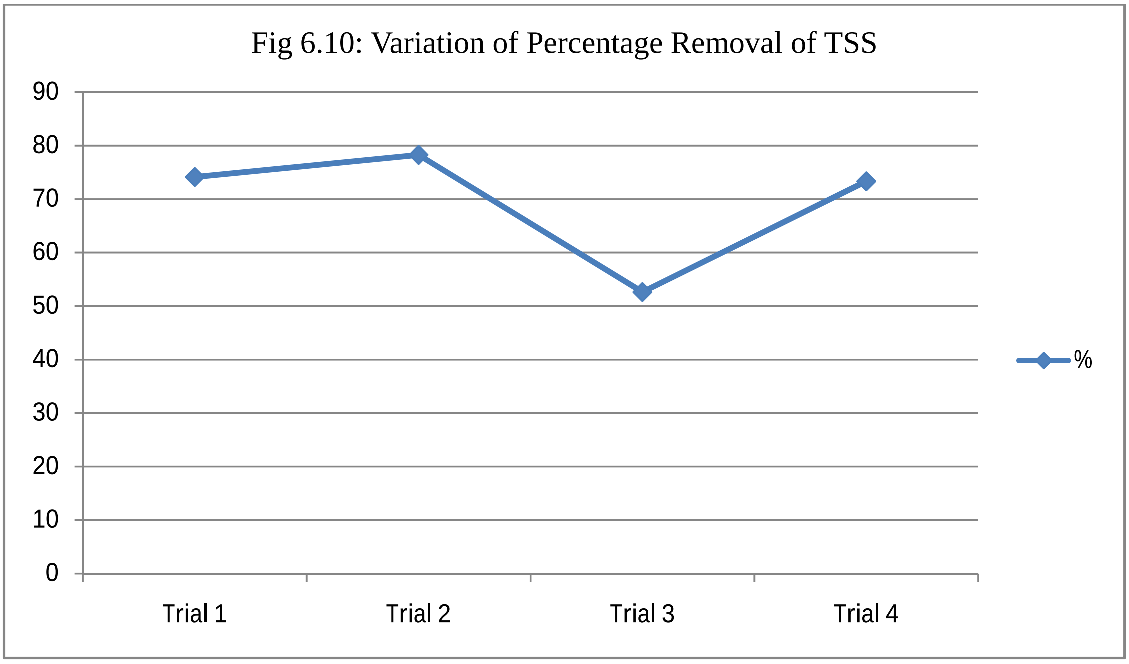



Fig 6.11: Variation of Percentage Removal of COD

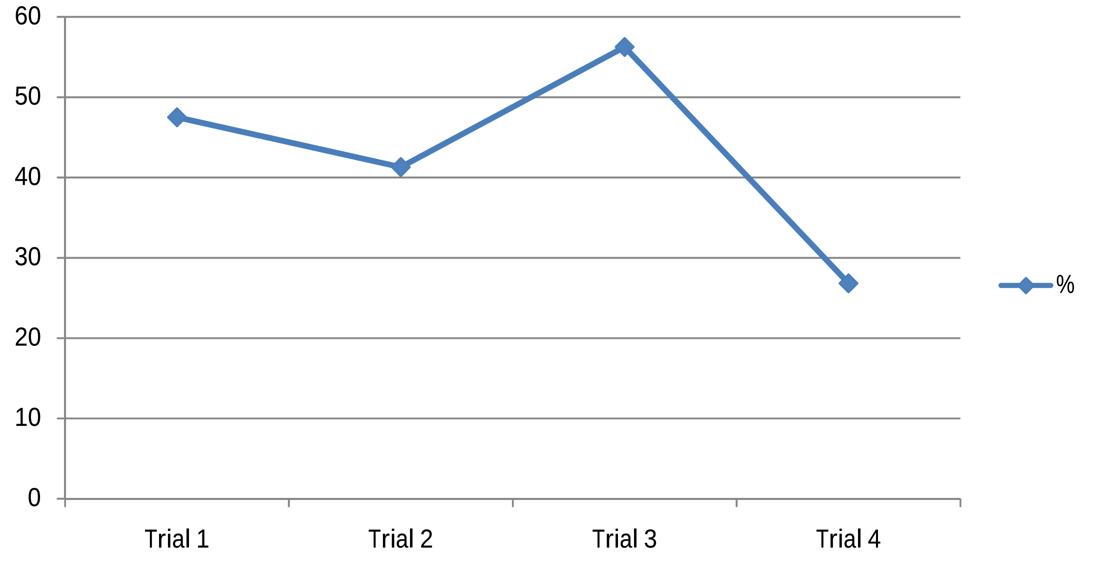



Fig 6.12: Variation of Percentage Removal of BOD

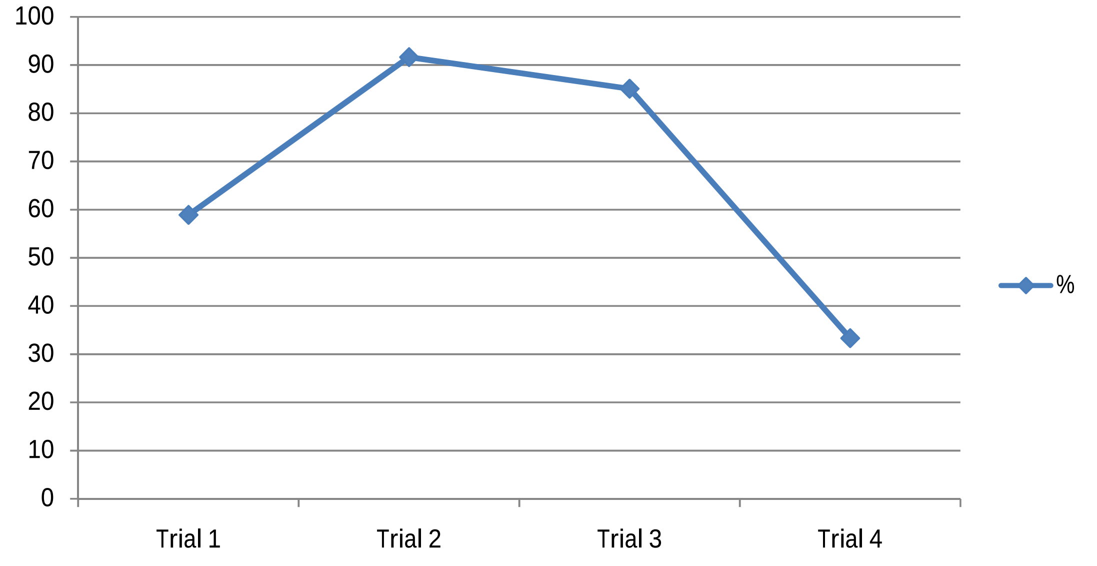


Fig 6.13: Variation of Percentage Removal of Phosphorus

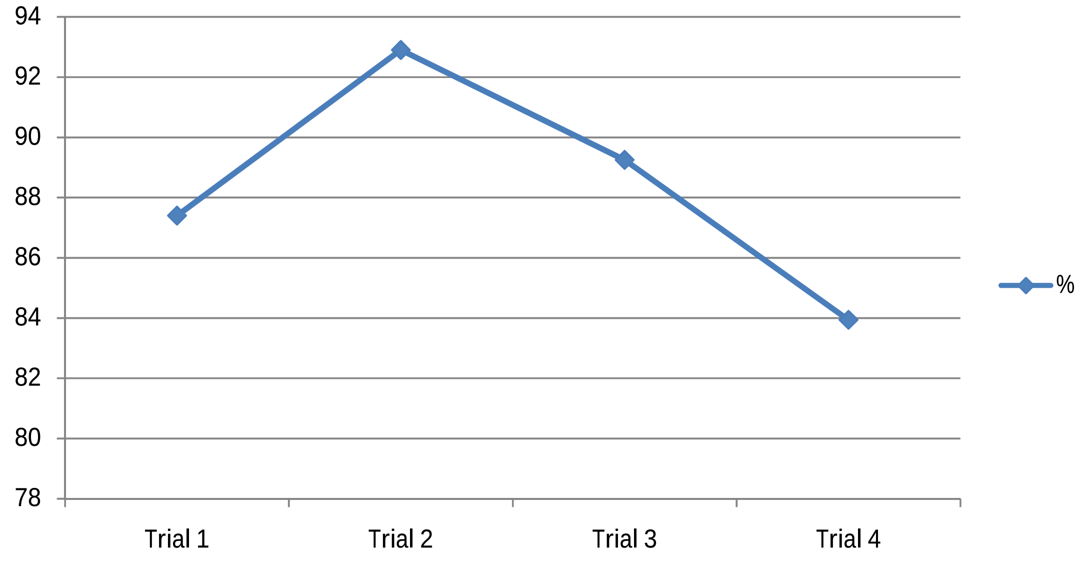



Fig 6.14: Variation of Percentage Removal of TKN

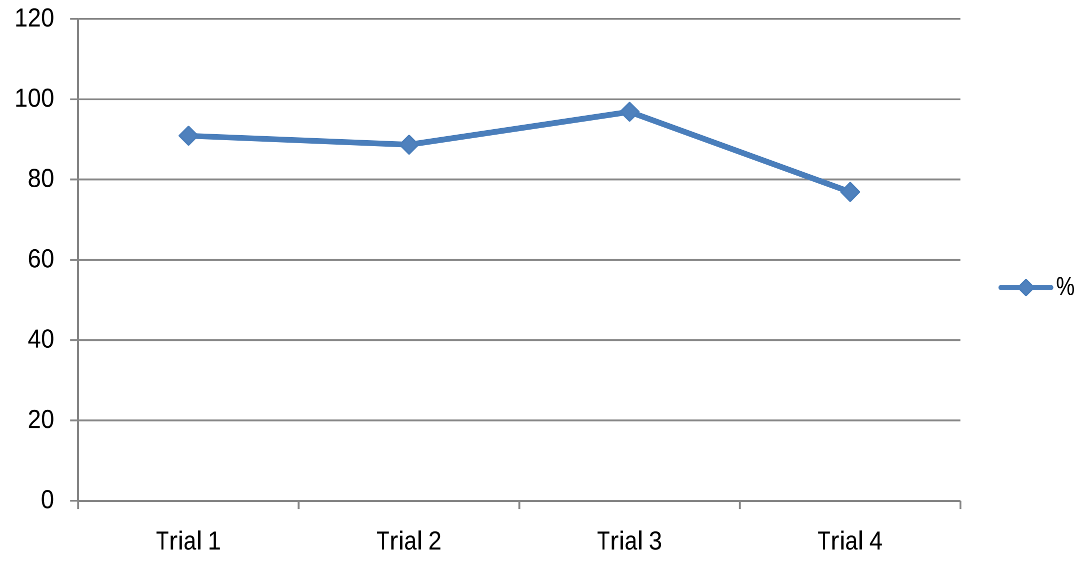


Fig 6.15: Variation of Percentage Removal of TC

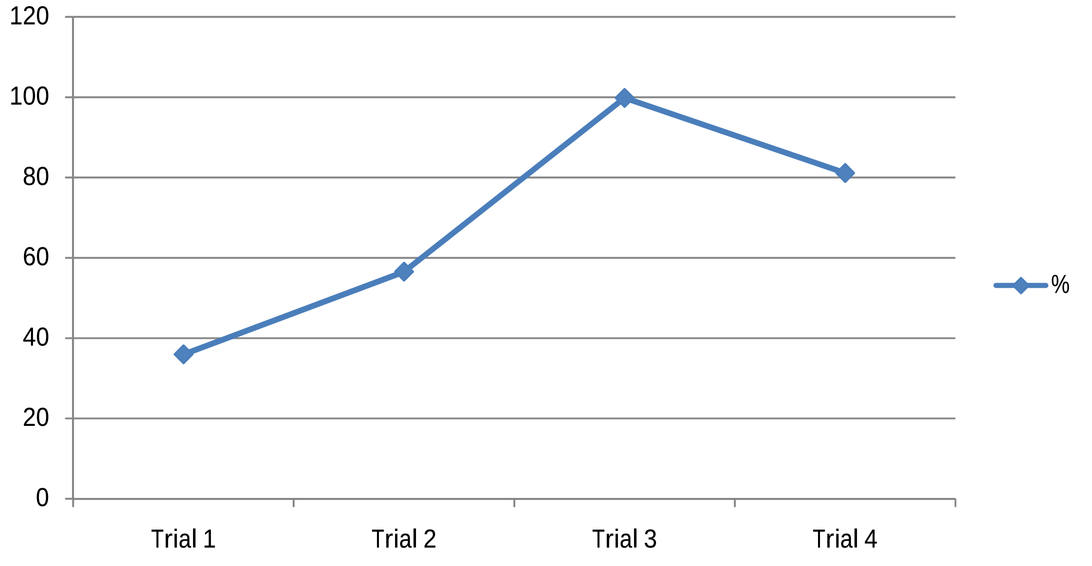
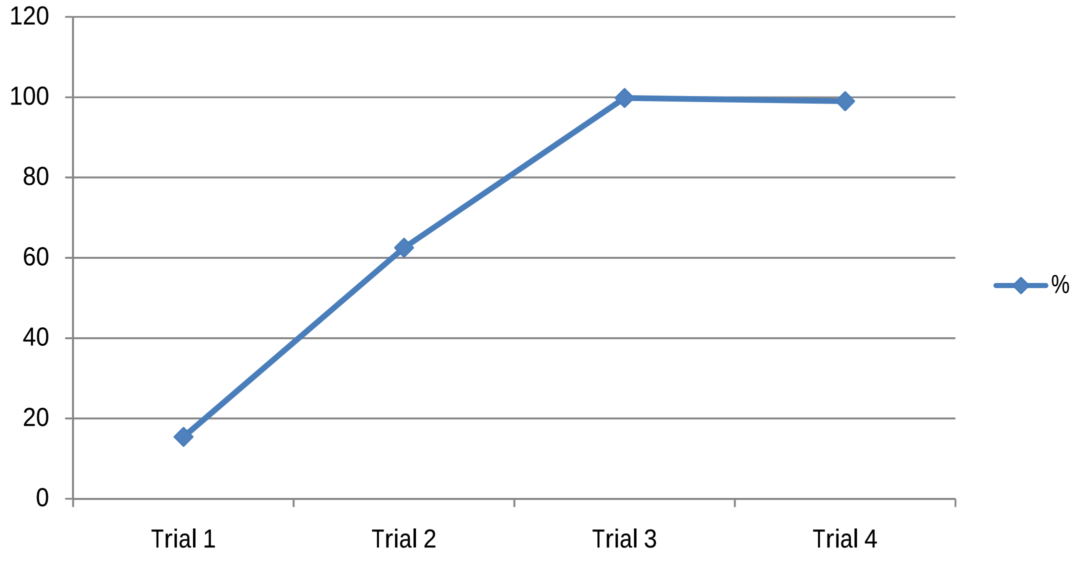



Fig 6.16: Variation of Percentage Removal of FC



### 6.4 DISCUSSION

The concentration of analyzed water quality parameters in raw sewage, Primary Treated Effluent and Final Treated Effluent found are tabulated below:

| PARAMETER | RAW SEWAGE | FINALLY TREATED EFFLUENT |
|---|---|---|
| pH | 7.8 | 8.36 |
| Turbidity (NTU) | 20.7 | 3.37 |
| TSS (mg/L) | 28.75 | 8.25 |
| COD (mg/L) | 61.75 | 33.5 |
| BOD (mg/L) | 43.75 | 10.75 |
| Phosphorus (mg/L) | 9.09 | 0.97 |
| Total Nitrogen (mg/L) | 33.97 | 1.49 |
| TC (mg/L) | $535 \times 10^2$ | $135 \times 10^2$ |
| FC (mg/L) | 5975 | 2325 |

Table 6.5: Average concentration of water quality parameters of raw and finally treated effluent

The range and average value of Turbidity removal efficiency in CW are 73% - 90.6% and 82.06%

The range and average value of TSS removal efficiency in CW are 52.6% - 78.2% and 69.58%

The range and average value of COD removal efficiency in CW are 26.8% - 56.2% and 42.96%

The range and average value of $BOD_3$ removal efficiency in CW are 33.3% - 91.6% and 67.25%

The range and average value of Phosphorus removal efficiency in CW are 83.9% - 92.9% and 88.37%

The range and average value of TKN removal efficiency in CW are 76.9% - 96.8% and 88.34%

The range and average value of TC removal efficiency in CW are 35.9% - 99.8% and 68.34%

The range and average value of FC removal efficiency in CW are 15.3% - 99.8% and 69.17%

| PARAMETER | AVERAGE REMOVAL EFFICIENCY |
|---|---|
| Turbidity (NTU) | 82.06% |
| TSS (mg/L) | 69.58% |
| COD (mg/L) | 42.96% |
| BOD (mg/L) | 67.25% |
| Phosphorus (mg/L) | 88.37% |
| Total Nitrogen (mg/L) | 88.34% |
| TC (mg/L) | 68.34% |
| FC (mg/L) | 69.17% |

Table 6.6: Average removal efficiency of constructed wetland

### 6.4.1 FINAL DESIGN OF CONSTRUCTED WETLAND

- $C_o$ = inlet BOD = 43.75 mg/lit
- $C_t$ = outlet BOD = 10.75 mg/lit
- K = BOD reaction constant per day = 0.17 (for Indian condition)
- Designed average inflow Q = 0.010 $m^3$/d = 10 lit/d

We know that,

$A = Q\ ( \ln C_o - \ln C_t )/ k$

$A = 0.01 \times ( \ln 43.75 - \ln 10.75 )/ 0.17$

A = 0.082 $m^2$ (Actual bed area required for experimental setup)

Suggested dimension,

- Length = 300 mm
- Width = 280 mm
- Height = 300 mm
- Free board = 50 mm
- Volume of empty bed = 0.3 x 0.28 x (0.3 - 0.05) = 0.021$m^3$ = 21 litres
- Bed Porosity = 0.454
- Volume of void(with gravel) in bed = (21 x 0.454) = 9.53 litres
- Hydraulic Retention Time = 9.53/10= 0.95 day (approx 1 day)
- Hydraulic Loading Rate = [(Q/A)x1000]=(0.01/0.082)x1000 = 121.9 mm/d
- BOD Loading Rate =[($C_o$ xQ)/(A x 1000)] =[(43.75x10)/(0.082x1000)]= 5.33 g/$m^2$/d

## CONCLUSION AND DELIVERABLES

## 7.1 CONCLUSION

Water reclamation and reuse as a sustainable strategy in water management needs to be implemented in communities of Kolkata and its Suburbs, due to the increasing demands placed on freshwater resources driven by population growth and climate change. A properly designed municipal wastewater treatment system will facilitate water management and reuse practices. These sustainable practices will bring economical environmental benefits for future development. Compared to the conventional engineering treatment systems, Constructed Wetlands provide various advantages. They are low energy consuming and biologically self-designing and are of social and economic adherence. They also produce quality treated water that is suitable for almost any type of reuse.This study demonstrates the feasibility of constructed wetland system for municipal wastewater treatment and an attempt to reduce pollutants accumulation and preserve the East Calcutta Wetlands. Integrating this treatment system with the East Calcutta Wetlands would not only improve wastewater quality draining through it but also save a large amount of water that could be used for other purposes such as irrigation. The results show that pollutant levels in the wastewater could be reduced after treatment.

## 7.2 DELIVERABLES

Constructed Wetlands would benefits existing landscapes, flora and fauna. A question which deserves future study is how to integrate landscape value and recreation needs, while serving wastewater treatment function simultaneously. East Calcutta Wetlands desires more recreational facilities in the future, which would increase people's awareness regarding the importance of wetland ecosystem and it also affects the meteorological aspects of Kolkata and its outskirts. The East Calcutta Wetlands includes a large portion of the open lands and presents ample space for future growth of these facilities. The quality of the treated wastewater would be qualified for landscape irrigation and public access. Finally, more recreational parks could be built. This study will also act as a reference for future studies made on other types of constructed wetlands.

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