STUDY ON THE PERFORMANCE OF HORIZONTAL SUB-SURFACE FLOW USING CONSTRUCTED WETLAND SYSTEM FOR TREATMENT OF WASTEWATER

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ABSTRACT

Horizontal constructed wetlands (HCWs) are an innovative and sustainable technology for wastewater treatment that harness natural processes to improve water quality. HCWs are engineered systems designed to replicate natural wetland functions, utilizing a horizontal flow of wastewater through a planted bed of gravel or soil. The primary mechanisms involved include physical filtration, microbial degradation, and plant uptake. This abstract outlines the principles of HCWs, their design considerations, and their effectiveness in treating various types of wastewater, including municipal, industrial, and agricultural effluents. Key factors such as substrate characteristics, plant species selection, and hydraulic loading rates significantly influence performance. HCWs offer several advantages, including low operational costs, energy efficiency, and ecological benefits. India generates approximately 62 billion liters of wastewater daily, derived from both urban and rural domestic sources, as well as industrial activities. The total installed capacity of wastewater treatment plants (WWTPs) in India is about 50 billion liters per day. Currently, approximately 30-35% of the total wastewater generated is treated. This means that a significant portion of wastewater either remains untreated or inadequately treated, posing environmental and public health challenges. To develop energy efficient constructed wetland technology for in-situ treatment of wastewater flowing through out-fall 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 Horizontal Subsurface Constructed Wetland was collected. A rectangular shape tank was fabricated with glass dimension 30cm ×18cm × 18cm as the experimental model. Wastewater was collected from Jadavpur University campus. The different flow rates with variable time was maintained by the tap. After different retention time the water was collected for laboratory analysis of different wastewater quality parameter. The experiment was carried with the ***'canna indica'*** plant. From the bench scale model study analysis of constructed wetland, it showed that the removal efficiency of **Turbidity (NTU)-57.41%, TSS (mg/L)-76.47 %, Nitrate (mg/L)-65.71 %, Nitrite (mg/L)-22.95 %, Phosphate (mg/L)-99.1 %, TKN (mg/L)-81.03 %, DO (mg/L)-27.14 %, BOD (mg/L)-79.12 %, COD (mg/L)-82.62 %, Total Coliform (MPN/100 ml)-61.11 %, Fecal Coliform (MPN/100 ml) -72% respectively**. According to the removal efficiency of wastewater quality parameter it showed good performance.

CONTENTS

CHAPTER **Pg. NO.**

Certificate of Recommendation

Certificate of Approval

Declaration

Acknowledgement

Abstract

1. INTRODUCTION

CHAPTER 1 ..... **1**

1 INTRODUCTION **1**

1.1 Global Water Scenario **1**

1.2 Scenario in India **2**

1.3 Municipal Wastewater: Indian Scenario **3**

1.3.1 Status of Municipal Wastewater Generation and Treatment Capacity of Metropolitan Cities in India **3**

1.3.2 Status of Municipal Wastewater Generation and Treatment Capacity of Class-I Cities in India: **5**

1.3.3 Status of Municipal Wastewater Generation and Treatment Capacity of Class-II Cities in India: **7**

1.4 Future Scenario of sewage Generation in India **8**

1.5 Status of Sewage Generation and Treatment in West Bengal **9**

1.6 Effects of Untreated sewage on Surface Water Bodies **10**

1.7 Effects of Untreated sewage on Human Health **10**

1.8 Need for Sewage Treatment System **10**

1.9 Present Scenario of Urban Sanitation in India **11**

1.10 Water Management and Reuse **12**

CHAPTER 2 ..... **14**

2 LITERATURE REVIEW **14**

2.1 Review of Literature **15**

2.2 Review of projects in India on Constructed Wetlands **26**

CHAPTER 3 ..... **28**

3 WASTEWATER TREATMENT TECHNOLOGIES **28**

3.1 Treatment of Sewage **28**

3.1.1 Preliminary Treatment **28**

3.1.2 Primary Treatment **29**

3.1.3 Secondary Treatment **30**

CONTENTS

3.1.4 Tertiary Treatment 30
3.2 Treatment Process According to Their Treatment Mechanism 31
3.2.1 Technical Treatment System 31
3.2.1 Natural Treatment System 34
CHAPTER 4 38
4 OVERVIEW OF CONSTRUCTED WETLAND SYSTEM 38
4.1 Constructed Wetland 38
4.2 Classification 38
4.2.1 Free Surface Flow Constructed Wetland 39
4.2.2 Sub-surface Flow Constructed Wetland 40
4.2.3 Horizontal Flow Constructed Wetland 40
4.2.4 Vertical Flow Constructed Wetland 40
4.2.5 Hybrid Constructed Wetland 41
4.3 Component and Design Criteria of Constructed Wetland 42
4.4 Hydrology of Constructed Wetland 47
4.5 Contaminant Removal Mechanism 49
4.5.1 Suspended Solids Removal 49
4.5.2 BOD Removal 50
4.5.3 Nitrogen Removal 50
4.6 Advantages of Constructed Wetland 51
4.7 Limitations of Constructed Wetland 51
CHAPTER 5 53
5 OBJECTIVE AND SCOPE OF RESEARCH WORK 53
5.1 Objectives of the Study 53
5.2 Scope of Work 53
5.3 Study Area 53
5.4 Experimental Setup & Methodology 53
5.5 Flow Diagram of Treatment Process 54
5.6 Design of Experimental Setup of Costructed Wetland 54
CHAPTER 6 56
6 MATERIAL AND METHODOLOGY 56
6.1 pH 56
6.1.1 Methods Available 57
6.1.2 Apparatus Used 58
6.1.3 Procedure 58

CONTENTS

6.2 TOTAL SUSPENDED SOLIDS (TSS) 59

6.2.1 Apparatus Used 59

6.2.2 Procedure 60

6.3 BIOCHEMICAL OXYGEN DEMAND (BOD3, 27° C) 60

6.3.1 Principle 61

6.3.2 Available Methods 61

6.3.3 Reagents Used 62

6.3.4 Reagent Preparation 62

6.3.5 Apparatus Used 63

6.3.6 Procedure 63

6.4 DISSOLVED OXYGEN (DO) 65

6.4.1 Available Methods 65

6.4.2 Procedure (Azide Modification) 66

6.4.3 Reagents Preparation 66

6.4.4 Standardization 66

6.4.5 Calculation 67

6.5 CHEMICAL OXYGEN DEMAND (COD) 67

6.5.1 Available Methods 67

6.5.2 Principle 68

6.5.3 Apparatus Used 69

6.5.4 Reagents Used 69

6.5.5 Reagent Preparation 69

6.5.6 Standardization 70

6.5.7 Procedure 70

6.5.8 Calculation 71

6.6 BACTERIOLOGICAL TEST 71

6.6.1 Available Method 71

6.6.2 Membrane Filter Method 72

6.6.3 Multiple Tube Method (MPN) 72

6.7 TOTAL PHOSPHATE 74

6.8 TOTAL KJELDAHL NITROGEN (TKN) 75

6.8.1 Apparatus Used 75

6.8.2 Reagent Preparation 75

6.8.3 Procedure 76

6.8.4 Calculation 77

6.9 NITRATE NITROGEN 77

CONTENTS

6.9.1 Available Methods 77
6.9.2 Cadmium Reduction Method 77
6.10 NITRITE NITROGEN 80
6.10.1 Apparatus Used 80
6.10.2 Reagent Preparation 80
6.10.3 Procedure 81
6.11 PHOSPHATE 81
6.11.1 Available Methods 81
6.11.2 Colorimetric Method 82
CHAPTER 7 84
7 RESULT AND DISCUSSIONS 84
7.1 Tabulated Results Week-1 84
7.2 Tabulated Results Week-2 85
7.3 Tabulated Results Week-3 86
7.4 Tabulated Results Week-4 87
7.5 Tabulated Results Week-5 88
7.6 Tabulated Results Week-6 89
7.7 GRAPHICAL REPRESENTATION- 90
7.8 Growth Rate of plant 96
7.9 Discussion 96
CHAPTER 8 99
8 CONCLUSION AND RECOMMENDATIONS 99
8.1 Conclusion 99
8.2 Limitations of the Present Study 100
8.3 Future Directions 101
REFERENCES 103
APPENDIX-A: LIST OF FIGURES 108
APPENDIX-B:LIST OF TABLES 109
APPENDIX-C: LIST OF ABBREVIATIONS 110

CHAPTER 1

1 INTRODUCTION

The process of treating wastewater involves turning water that is no longer needed or suitable for its most recent use into an effluent that may be reused or returned to the water cycle with little to no negative environmental effects. Wastewater is referred to as sewage and is treated as such if it comes mostly from municipal sources, such as homes and small businesses. Treatment is the process of eliminating contaminants from water, and certain techniques can be used on both wastewater and water. "Wastewater treatment plant" refers to the actual infrastructure utilized for wastewater treatment. The general field of Public Works - Environmental includes the treatment of wastewater along with the management of solid waste, water treatment, sewage treatment, stormwater (drainage) management, and human waste. Wastewater treatment plants are also capable of treating their byproducts, which include grit, screens, and sewage sludge. Wastewater is referred to as sewage and is treated as such if it comes mostly from municipal sources, such as homes and small businesses.

1.1 Global Water Scenario

The most essential component for life on Earth, water, is becoming one of the major environmental problems that our ecosystems are currently dealing with. The three main problems that affect the quality of life on Earth are quantity, quality, and availability of water. The evaluation of the world's water resources has the potential to scare us in the future. Since water-related concerns are covered within Agenda 21 of the United Nations Environment Program (UNEP), water crises pose difficulties to the worldwide environmental communities (Rijsberman et al. 2000). The amount of freshwater available is rapidly decreasing. Freshwater resources are not equally distributed, with most of the water being located far from populated areas. Worldwide, there are thought to be 263 significant international river basins, which account for over 45% of the planet's land area NW (Arnell et al. 1999). Ninety percent of the freshwater available is derived from groundwater resources, meeting the drinking water needs of around 1.5 billion people.75% of the water available globally is used by the agriculture sector, which also accounts for 20% of water consumption worldwide. The remaining 5% is used by the household sector. By the end of the next 20 years, two thirds of the world's population is predicted to be compelled to live under

stressful conditions underwater. By 2025, 25 nations in Africa alone will experience water stress (less than 1,000 cubic meters per person annually). Approximately 450 million people in 29 countries are currently experiencing a shortage of water. The availability of clean drinking water and proper sanitation continue to be the key worldwide issues, with 20% of the world's population lacking access to either. Another important issue in emerging nations is water contamination, which affects 1.2 billion people and claims the lives of around 15 million children every year (Choukiker et al. 2005).In addition to human life, a range of human activities pose serious dangers to coastal and marine ecosystems. Unplanned development projects pose a threat to around half of the world's coastlines. Eighty percent of marine pollution originates from land-based activities, which causes significant eutrophication in many seas. Since inland and marine aquaculture production accounts for 30% of the world's total fish supply, rising marine pollution is leading to a decline in the yield of marine fisheries. Increasing air pollution contributes to climate change, which raises sea levels and submerges low-lying coastal areas. Due to their heavy reliance on marine resources, humans will become more vulnerable in other areas (Rosch et al. 2000).

1.2 Scenario in India

India makes up 16% of the world's population, although it only has 2.45% of the world's land area and 4% of its water resources. Only 28% of the water in the nation comes from precipitation; the total estimated utilizable water resource is 1123 BCM (690 BCM from surface and 433 BCM from ground). Currently, irrigation uses about 85% (688 BCM) of the water used, and by 2050, that number might rise to 1072 BCM. Groundwater is a major source for irrigation VK Gupta et al. (2014). About 433 BCM of groundwater recharge occurs year, of which 212.5 BCM are used for irrigation and 18.1 BCM are used for residential and commercial purposes (CGWB, 2011). Water use for residential and commercial uses could reach 29.2 billion cubic meters by 2025. It follows that a decrease in water availability to 162.3 BCM for irrigation is anticipated. By 2050, the population is predicted to surpass 1.5 billion at the current rate of 1.9% annual population growth (Dubey et al. 2026). The per capita average yearly freshwater availability has been declining since 1951, from 5177 m^3 to 1869 m^2 in 2001 and 1588 m^3 in 2010, as a result of the nation's growing population and overall growth. A further decrease to 1341 m^3 in 2025 and 1140 m^3 in 2050 is anticipated. Therefore, it is imperative to manage water resources effectively through waste water recycling and improved water consumption efficiency.

1.3 Municipal Wastewater: Indian Scenario

In India, 38255 MLD of municipal wastewater is generated overall. Out of the total MLD, 26467 MLD are disposed of as untreated; only around 11788 MLD (30%) are treated by STP before disposal. Among all STP's 38% are utilizing Activated Sludge procedure, 28% are using Waste Stabilization Pond, 20% are using Upflow Anaerobic Sludge Blanket, 14% are using others treatment procedure. 60% ASP is the portion of the total treated water volume that has been treated using various treatment technologies 26% WSP, 6% UASB, and 8% other (Kazmi et al. 2019).

1.3.1 Status of Municipal Wastewater Generation and Treatment Capacity of Metropolitan Cities in India

In India, there are 35 major cities with a population of above 10 lac; these cities produce 15,644 million liters of sewage per day (MLD). For 8040 MLD, or 51% of the total MLD, treatment capacity is established. Delhi has the highest treatment capacity among the metropolitan areas, with 2330 MLD (30% of the overall treatment capacity of metropolitan areas). Mumbai is the metropolis with the second-highest capacity among metropolitan areas, with a capacity of 2130 MLD, after Delhi VV Ranade et al.(2014). Thus, together, Delhi and Mumbai account for 55% of the metropolitan cities' treatment capacity. Some cities have treatment capacities that match the volume of generation, including Hyderabad, Vadodara, Chennai, Ludhiana, and Ahemedabad. Cities with more over 50% capacity include Dhanbad and Delhi, whereas the remaining cities have less than 50% capacity.

Table:1. Status of Municipal Wastewater Generation and Treatment Capacity of Metropolitan Cities in India: (as per CPCB).

Sl no.	Name of the city	Sewage generation (MLD)	Sewage treatment capacity (MLD)	Percent of treatment capacity
1	Hyderabad	426.21	593	100
2	Vishakhapatnam	134.99	-	-
3	Vijaywada	128.39	-	-
4	Patna	279.14	105	37

5	Delhi	3800	2330	61
Sl no.	Name of the city	Sewage generation (MLD)	Sewage treatment capacity (MLD)	Percent of treatment capacity
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
Sl no.	Name of the city	Sewage generation (MLD)	Sewage treatment capacity (MLD)	Percent of treatment capacity
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

1.3.2 Status of Municipal Wastewater Generation and Treatment Capacity of Class-I Cities in India:

India is expected to have 498 Class-1 Cities with a population of more than one lac. Of the 498 cities, Andhra Pradesh, Maharashtra, Tamilnadu, Uttar Pradesh, and West Bengal contain nearly 52% of the cities. Sewage generation in class-1 cities was calculated at 3558.12 million liters. Only Class-1 cities create 93% of all wastewater. Class-1 cities are estimated to have a total sewage treatment capacity of 11553.68 MLD, or 32% of the sewage generation. Eighty-40 MLD, or 69%, of the 11553.69 MLD sewage treatment capacity is treated in 35 metropolitan cities HM Malano et al. (2009). This shows that 462 Class-1 cities have a capacity of just, aside from metropolitan areas,given in table 2.

Table:2. Status of Municipal Wastewater Generation and Treatment Capacity of Class-I Cities in India: (as per CPCB).

Sl no.	State/Union Territory	No. of Cities	Population(in year 2008)	Sewage Generation(MLD)	Sewage Treatment Capacity(mld)
1	Andaman & Nicobar	1	107200	12	-
2	Andhra Pradesh	47	20143050	1760.60	654
3	Assam	5	1417820	380.14	-
4	Bihar	23	5783554	1009.7	135.5
5	Chandigarh	1	994820	429.76	164.5
6	Chhattisgarh	7	2515100	350.47	69
7	Delhi	1	148/58800	3800	2330
8	Goa	1	122330	9.79	-
9	Gujrat	28	14678240	1680.92	782.5
10	Haryana	20	5494110	626.69	312
11	Himachal Pradesh	1	163490	28.94	35.63
12	Jammu & Kashmir	2	1910060	213.93	-
13	Jharkhand	14	4964171	830.47	-
14	Karnataka	33	15102373	1790.40	43.44
15	Kerala	8	3778516	575.17	-
16	Madhya Pradesh	25	10795000	1248.72	186.1
17	Maharashtra	50	40255170	9986.29	4225.25
18	Manipur	1	249870	26.74	-
19	Meghalaya	1	186030	20.84	-

20	Mizoram	1	282550	5.71	-
Sl no.	State/Union Territory	No. of Cities	Population(in year 2008)	Sewage Generation(MLD)	Sewage Treatment Capacity(mld)
21	Nagaland	1	171810	13.62	-
22	Orissa	12	3335930	660.73	53
23	Pondicherry	2	504130	56.46	-
24	Punjab	19	6329860	1528.26	411
25	Rajasthan	24	9611490	1382.37	54
26	Tamilnadu	42	16852940	1077.21	333.42
27	Tripura	1	214327	24	-
28	Uttar Pradesh	61	25762280	3506.01	1240.13
29	Uttarakhand	6	1249380	176.97	18
30	West Bengal	60	19818471	2345.21	505.92
Total		498	227652872	35558.12	11553.68

1.3.3 Status of Municipal Wastewater Generation and Treatment Capacity of Class-II Cities in India:

Of the 225 class-II cities, or approximately 50%, the majority are found in Andhra Pradesh, Maharashtra, Tamilnadu, Uttar Pradesh, and Gujarat. 2696.70 MLD of wastewater is produced overall in class II towns. Class-II towns have a total sewage treatment capacity of 233.7, or 8% of the total sewage output (Vigneswaran et al. 2010)

Table: 3. Status of Municipal Wastewater Generation and Treatment Capacity of Class-II Cities in India: (as per CPCB)

Sl. No.	State/Union Territory	Population in 2008	No of Class-2 Towns	Sewage generation of Class-2 Towns (MLD)	Sewage Treatment Capacity (MLD)
1	Andhra Pradesh	3448610	52	217059	10.42
2	Assam	573290	8	6.46	-

3	Bihar	1113800	14	107.42	2
4	Chhattisgarh	566080	7	40.82	-
5	Goa	172850	2	13.89	18.18
6	Gujrat	2180590	31	227.55	-
7	Haryana	544040	7	43.52	-
8	Jammu & Kashmir	244990	4	27.86	-
9	Jharkhand	826300	10	78.21	-
10	Karnataka	1800258	26	233.37	12.18
11	Kerala	1686660	26	231.32	-
12	Madhya Pradesh	1745050	23	130.9	9
13	Maharashtra	2503080	34	213.73	29
14	Meghalaya	81750	1	11.25	-
15	Nagaland	126520	1	1.36	-
16	Orissa	904510	12	78.42	-
17	Pondicherry	79690	1	7.984	-
18	Punjab	1109670	14	157.4	42.80
19	Rajasthan	1599260	21	147.79	-
20	Tamilnadu	324950	42	184.67	29.3
21	Uttar Pradesh	3382520	46	345.7	12.61
22	Uttrakhand	69490	1	9.07	6.33
23	West Bengal	2004440	27	180.42	61.88
Total		30018398	410	2696.70	233.7

1.4 Future Scenario of sewage Generation in India

The Population of India is likely to be stabilized by 2050 at the level of 1700 million people. As per the census of 2001 the urban population is 285 million and keeping in view of population projection for the year 2051 is likely to be of the magnitude of 1000 million. In view of the population increase, demand of freshwater for all uses will become unmanageable R Kumar et al(2016) . It is estimated that the projected wastewater from urban areas may cross 120,000 MLD by 2051 and that rural India will also generate not approx. 50,000 MLD in view of water supply designs for community supplies in rural areas (as per CPCB).

Table :4. Future Scenario of sewage Generation in India.

Year	Urban Population(million)	Per capita Wastewater generation(lpcd)	Gross wastewater generation(mld)
1977-78	72.8	116	7007
1989-90	122.7	119	12145
1994-95	151.6	130	16662
2003-04	243.5	121	26254
2009-10	316.15	121	38254
2051(projected)	1000	121	120000

1.5 Status of Sewage Generation and Treatment in West Bengal

- It was estimated that about 527 million liters of waste water fall into the river Ganga from the 15 class I cities located along its bank. The Calcutta Metropolitan Development Authority (KMDA) under the Department of Urban Development, Government of West Bengal was designated as the nodal organization for implementation of the GAP Phase 1 schemes with the help of KMWSA and the Public Health Engineering Department (Karmakar et al. 2023).
- Different conventional sewage treatment technology was adopted at various locations. 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 in satisfactory but the influent vowage strength in terms of its neganic matter content (MOD value) in ment locations was found to be low in comparison to the price assumption. Thus the STPs are meatly operated an 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 Beharampur is non-functional due to absence of sewage. A

stretch of 150 meter 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 STP's are required to take consent to operate under the Water Act 1974.

  It was observed that none of them have taken consent from the West Bengal Pollution Control Board S Koley et al.

  The STPs were not provided with stand-by power arrangement. However, the power supply was reasonably stable at the ASPs and trickling filter.

1.6 Effects 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 on Ecological Balance

1.7 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-washed diseases- Scabies, Trachoma etc.

1.8 Need for Sewage Treatment System

Sanitation can be perceived as the conditions and processes relating to people's health, especially. The systems that supply water and deal with the human waste. Such a task would logically cover other matters such as solid wastes, industrial and other special / hazardous wastes and storm water drainage. However, the most potent of these pollutants is the sewage. When untreated sewage accumulates and is allowed to become septic, the decomposition of its organic matter leads to

nuisance conditions including the production of malodorous gases. In addition, untreated sewage contains numerous pathogens that dwell in the human intestine tract. Sewage also contains nutrients, which can stimulate the growth of aquatic plants and may contain toxic compounds or compounds that are potentially mutagenic or carcinogenic. For these reasons, the immediate and nuisance-free removal of sewage from its sources of generation followed by treatment, reuse or disposal into the environment in an eco-friendly manner is necessary to protect public health and environment (Zhang et al. 2019). The major needs to treat waste water are as follows:

- To remove organic and inorganic matter this would otherwise cause pollution
- To remove pathogenic (disease causing) organisms
- To safeguard the environment and public health

1.9 Present Scenario of Urban Sanitation in India

The problem of sanitation is much worse in urban areas due to increasing congestion and density in cities. Indeed, the environmental and health implications of the very poor sanitary conditions. Are a major cause for concern. The study of Water and Sanitation Programme (WSP) of the World Bank observes that when mortality impact is excluded, the economic impact for the weaker section of the society accounting to 20% of the households is the highest. The National Urban Sanitation Policy (NUSP) of 2008 has laid down the framework for addressing the challenges of city sanitation. The NUSP emphasizes the need for spreading awareness about sanitation through an integrated city-wide approach, assigning institutional responsibilities and due regard for demand and supply considerations, with special focus on the urban poor (Nath et al. 2017). As per the 2011 Census, 81.4% households have toilet facilities within their premises. This Includes 70.9% households having water closets; 8.8% households having pit latrines; 1.7% Households having other toilets (connected to open drains, night soil removed by human etc…Which are unsafe). Out of the 70.9% households, 32.7% households have water closets connected to sewer system and 38.2% households are having water closets with septic tank (Ghosh et al. 2014). The remaining 18.6% households do not have toilet facilities within their premises. This includes 6.0% households using public toilets and 12.6% households defecating in the open. According to the report on the Status of Wastewater Generation and Treatment in Class-1 Cities and Class-II towns of India, December 2009, published by Central Pollution Control Board (CPCB), the estimated

sewage generation from 498 Class-I cities and 410 Class-II towns (Population estimated for 2008 based on 2001 census) together is 38,524 MLD. Out of this, only 11,787 MLD (31%) is being treated with a capacity gap of 26,737 MLD (Ghosh et al. 2014). CPCB has carried out an inventorization of Sewage Treatment Plants (STPs) located in India in the year 2014-15. There are 816 STPs having capacity of 23277MLD in 28 States/UTs of India.Out of 816 STPs, 522 STPs are operational, 79 STPs are Nonoperational. 145 STPs are under construction and 70 STPs are proposed for construction. For the urban poor (22% of total urban population), women, children and the elderly. The loss due to diseases caused by poor sanitation for children under 14 years alone in urban areas amounts to Rs.500 Crores at 2001 prices (Planning Commission-United Nations International Children Emergency Fund UNICEF, 2006). Inadequate discharge of untreated domestic/ municipal sewage has resulted in contamination of more than 75 % of all surface waters across India.

1.10 Water Management and Reuse

With the increasing water usage and thereby water demand, and the most importantly the fact that water is a limited resources has forced mankind to go for water reuse and recycle for sustainable development of the human race. Since the environmental protection has now become a global issue, a cleaner and greener technology is warranted for the abatement of the industrial pollution. Reduction of fresh water consumption is one of the main concerns in process industries; including food and beverage industry where water cost represent considerable part of the total cost. Because of the rising freshwater and effluent treatment costs that total cost of water supply and wastewater treatment is about the same as the energy cost for most industries (Bahri, 1999).Water recycling is reusing treated wastewater for beneficial purpose such as:

- Agriculture
- Landscape
- Public parks
- Golf course irrigation
- Cooling water for power plants and oil refineries
- Processing water for mills, plants

- Toilet flushing
- Dust control,
- Construction activities
- Concrete mixing
- Artificial lakes
- Replenishing a ground water basin

Water reuse offers resource and financial saving. Wastewater treatment can be tailored to meet the water quality requirement of planned reuse. Water is sometimes recycled and reused onsite. For example, when an industrial facility recycles. Water used for cooling process. A common type of recycled water is water that has been reclaimed from municipal wastewater, or sewage. Then term water is generally used synonymously with water reclamation and water reuse. Grey water is reusable wastewater from residential, commercial and industry, bathrooms, sinks bath tub, shower drains and clothes washing equint drains. Grey water is reused onsite typically for landscape irrigation. Use of toxic, non-toxic and non-sodium substance is required to protect vegetation when grey water is used for irrigation. As for many water source that is not proper treated, health problem could arise from drinking or being exposed to recycled water if it content disease causing organisms or other contaminants.

CHAPTER 2

2 LITERATURE REVIEW

The history of constructed wetlands can be traced back to 1995s when Dr. Kaithy Seidel examined in Northern Germany the possibility of wastewater treatment by wetland plants, and Kickuth extended this work in Europe in the late 1970s.Interest in the subject started in the United States started in early 1980s with the studied of Wolverton et al. (1983) and Gersberg et al. (1985). In the last 3 decades, accumulating research has demonstrated that wetlands may provide water quality improvement (Nichols 1983; Richardson 1985; Knight et al. 1993; Mashauri et al. 2000; Blahnik and Day 2000; Kadlec 2003; Kadlec 2009) at lower capital costs compared to other water treatment methods (Brix 1999; Ko et al. 2012). This may not be surprising. Since year-round occurrence of water stimulates vegetation growth and microbiological activity which make wetlands one of the most productive ecosystems on Earth (Kadlec and Wallace 2009). Through high microbiological productivity, aided by sunlight, wind and soil. Wetlands can transform a variety of pollutants into less harmful by-products or life-supporting nutrients. Hence, using wetlands, it is possible to meet water quality standards with negligible use of fossil-based energy and chemicals (Gearheart 1992; Martin et al. 1999; Scholz et al. 2010). These benefits have created a global interest in constructing wetlands for the main purpose of wastewater treatment (Kadlec and Wallace 2009; Isosaari et al. 2010; Vymazal 2011). Based on differences in the water flow, two main groups of CWs can be distinguished: free water surface (FWS) CWs and subsurface flow (SSF) CWs. In FWS CWs the water surface is exposed to the atmosphere and flows horizontally over the soil surface. The mean water depth is usually less than 0.4 m, and thus, FWS CWs are frequently dominated by rooted emergent or submersed, or floating vegetation depending on the water depth. In SSF CWs, the water surface is kept below the surface of the substrate, which may support different types of rooted emergent vegetation. The SSF CW type may be further divided into vertical and borizontal flow systems (Kadlec and Wallace 2009). The focus in this thesis is on SSF CWs receiving relatively constant point-source wastewater. According to Wallace and Knight (2006), in 2006 there were more than 400 small-scale wastewater treatment CWs (water flow < 2000 m^3 per day) in operation in North America. Also, since CWs have relatively low construction, operational and maintenance costs, there is a growing interest in implementing them in developing countries (Kivaisi 2001). In Sweden, mainly as a result of the Swedish Environmental Quality Objectives

implemented in 1999, the construction of at least 12 000 hectares of wetlands were stated as a numeric objective (Government Bill 1997/98:145; Government Bill 2000/01:130). A study by Strand and Weisner (2013) reported that the wetland construction programme in Sweden has been a cost-effective method for decreasing transport of diffuse pollution from arable land. However, despite increasing use of CWs for wastewater treatment, several studies have demonstrated that the technique may have problems to meet local water quality standards demonstrated Clausen 1997; Li et al. 2008; Rodriguez and Lougheed 2010; Forbes et al. 2011; Kantawanichkul and Duangjaisak 2011; Brix et al. 2011). Unpredictable and undesirable treatment behaviour reveals that we have insufficient knowledge to be able to optimize CWs for wastewater treatment. Thus, more studies are needed to find biological and physical features that regulate the complex pollutant removal processes in CWs (Gottschall et al. 2007).

2.1 Review of Literature

Sonavane. P.G et al. (2008) studied the performance of a pilot scale model of HF CW consists of a Reactor bed, inlet and outlet chambers, with dimension of 3m x 1.2m x 1m and 30cm free board. They planted Canna Indica in 6mm-12mm gravel in reactor bed. They fed CW with effluent of septic tank continuously for 7days. Then, they collected and analyzed the samples of inlet and outlet for BOD, SS, TKN and TP by standard method of APHA (1992). The BOD reduction was found to be 65-82% with 55-90% suspended solids removal, 26-66% TKN and 12-26% phosphorus removal during 4-7 days retention. The results seem to be encouraging to adopt the technique as a secondary treatment method to treat septic tank effluent before its safe disposal.

Mohammed. A et al. (2008) investigated the treatment of municipal wastewater using engineering constructed Reed Bed wetland system at Al- Nahrain University, Iraq. A reed bed pilot plant, for treating $2m^3$/day of municipal wastewater was designed, constructed and was running for 12 months. The system was based on the principles of sub-surface flow constructed wetlands. It consisted of two beds (two steps), filled with gravel and sand layers as filter media. The first and second bed were designed to give 2 and 5 days retention time respectively and were capable of handling hydraulic surface flow up to 170 lit/m^2 day. The two beds were planted with Phragnmites communis (common reed). The general aim of this research work was to start implementing this new technology, for the first time, in Iraq and put the basis for future research work on this promising eco-technology in attempts to overcome the problems facing the wastewater treatment sector in general and the existing conventional treatment system in particular and to find the right

solution for healthy environment. The findings of this research work can be summarized as follow, the improvement of the pollutant removal was proportional to the maturity of reed plants and the results obtained after running the pilot plant for nearly 12 months were, 95% for BOD_5, 97% for TSS, 65% for TP, 41% for NO_3-N, 39% for NH_4-N and with no pathogenic (disease- causing) organisms found in the treated wastewater, were obtained. The results were good and the design is expected to give better results when the reed plants reach their maturity state. Finally they concluded that the designed pilot plant was not only capable of removing pollutant to the required level for the preset quantity of wastewater but also showed that the plant was robust and require hardly any maintenance.

Gauang. S et al. (2009) Studied on Purification efficiency of sewage in constructed Wetland with different plants in China, with three different plants and HRT's to treat the Wastewater. The plants were used for experiment cattails, common reed and acorus calamus with a HRT's of 3days, 4days and 5days. The analyses were carried out for COD, NH-N and TN. Overall removal rate of COD was 54.9%, NH_4-N was 54.8% and TN was 90% with 3- day HRT and Cattail. The proposed work concluded that removal efficiency was higher in the 3 days of HRT as compare to other two HRT's and cattails was better than common reed and acorus calamus plants.

Sharp. J.L et al. (2002) conveyed a study on managing Cattail (Typha latifolia) growth in wetland systems. Whose objectives were,

A. Measure soluble reactive phosphorous (SRP), nitrate-nitrogen (NO3-N), and ammonical-nitrogen (NH3-N) at various points in a constructed wetland for one year to evaluate whether nutrient levels differ between planted areas by diverse wetland plants and planted areas by Cattail stands.
B. Examine cattail seedling germination and growth as influenced by competitive effects of other wetland species.
C. Determine cattail seedling germination rates, seedling survival, and growth at multiple Water depths.
D. Ascertain cattail establishment under different conditions associated with three moist soil management strategies.

They found that SRP and NH3-N (low values) concentrations were not affected by either cattails or the diverse community of plants, However, NO3-N decreased from the beginning to the end of the wetland, with significant differences in the nutrient decreases associated with the diverse community of plants or cattails. Finally they concluded that a diverse community of plants in constructed wetlands is more desirable and its development and maintenance should be the goal of wetland managers. The competition study revealed that an established plant colony surrounding cattail seeds reduced or prevented seed germination and Survival (at a depth of 2.5cm above soil). This implies that when other aquatic emergents are established in a wetland colony, cattails may have difficulty establishing from seed. Study alho showed that Fluctuating water levels reduce cattail expansion. Reducing the water depth dating Typha latifolia's growing season can reduce germination and seedling. Both the water depth study and the sois Browigen sent technique study showed that the most optintal depth fr Cattail establishment was between lem and 40cm. The results from this study suggest that Banipulating water levels may be a useful and effective tool in managing wetlands to their greatest functionality.

Ramprasad. C. et al. (2012) analyzed the wastewater generated from quarters, hostel and university block of Chennai University campus, before and after treatment by conventional STP and by HF Constructed wetland. The CW was fed by Primary treated wage taken from the Sewage Treatment Plant (STP) of University campus. The plant used in CW was Phragmitis australis, which is locally known as NANAL. The plant used parameters namely BOD, COD, TDS, TSS and pH were analyzed. The procedure followed for calculating the parameters are the standard methods (APHA, 1992). Conventional treatment method and the method of purification using Reed bed for the treatment of effluent were compared. The removal efficiency found in STP and HFCW of the following water quality parameters are, TSS-65%, 72%, TDS-25%, 34%, BOD-66%, 85%. COD-57%, 73%. And finally they conclude that There is a remarkable reduction in BOD, COD by Reed bed treatment and the treated water has become fit enough to be let out directly into a receiving water body as the concentrations are below allowable limits. Whereas, for the water treated by conventional treatment plant, some more treatment is needed before it can be discharged. Thus the root zone treatment can be used independently or as an addition to conventional treatment so as to make the final output fit enough for discharge into a natural water body. Root zone system achieves standards for tertiary treatment with no operating cost or any hidden cost included in its operation. For Example: there is no consumption of electricity.

A pilot scale vertical flow constructed wetland unit (VFCW) with a surface area of 457.56m ^ 2 was built within the vicinity of a wastewater treatment plant, North Cairo, Egypt by **Sohair I. A et al. (2012)**. The wetland unit was planted with three kinds of plants namely: Canna, Phragmites australis and Cyprus papyrus. The wetland unit was fed with primary treated municipal wastewater at influent flow rate of $20m^3$/day and surface loading rate ranged between 26.2 kg BOD ha^{-1} day and 76.5kg BOD $ha^{-1}day^{-1}$ and a detention time of 7.7 days. The efficiency of VFCW after two years evaluated in terms of both mass removal and water quality improvement, both physico-chemically and biologically. The hiological analysis was carried out for total coliform, fecal coliform, and Escherichia coli. The accumulation of the elements in the plants organs and their uptake with the harvested macrophyte were also measured. The results obtained showed that the average removal efficiency of COD, BOD,TSS , TKN, TP, NH_4 – N and TC/FC in the final effluent were 88%,90 %, 92%,53%, 62%, 57% and 95% . The amount of nutrients the plants which represented by total phosphorus and total kjeldahl nitrogen were 32.55 g /m^2 and 68.1g /m^2 represented by totalucion of total cofiform, fecal coliform were achieved To quality of treated effluent proved that the use of VFCW as a post treatment ep is an ers the quality of treated effluent ler treatment and use for irrigation in rural areas and small communities.

Yadav. S. B et al. (2012) studied the function of a the integrated constructed wetland unit combined with surface flow and planted with Eichhornia crassipes was built near Technology Department, Shivaji University, Maharashtra. The integrated subsurface flow artificial wetland constructed with brickwork of size 3 m x 1.25 m having a depth of 0.6 m. The constructed wetland cell is of 3.06 m^2 area and length to width ratio 2.45:1.25. The depth of the bed is 0.6 m. The daily inlet and outlet wastewater physico-chemical parameters were analyzed during the period of two months. The parameters studied were BOD, COD, Total Suspended Solids, Total Dissolved Solids, Nitrogen and Phosphorus. The percentage removal of the parameters were analyzed and found 86.19%, 87.35%, 76%, 70%, 43.33%, 45% removal efficiency respectively.The study showed that the surface flow constructed wetlands are best alternative among modern treatments.

Stottmeister. U et al. (2003) studied the mechanisms of both plants in constructed wetlands and the microorganisms in the root zone which come into play when they remove contaminants from wastewater. The supply of oxygen plays a crucial role in the activity and type of metabolism performed by microorganisms in the root zone. Plants' involvement in the input of oxygen into the

root zone, in the uptake of nutrients and in the direct degradation of pollutants as well as the role of microorganisms are all examined in more detail. Their finding was type of CW chosen has an important influence on the contaminants' biological degradation pathways and removal mechanisms. Whereas anaerobic processes predominate in subsurface flow systems, aerobic processes usually prevail in surface flow systems. The hydraulic retention time, including the length of time the water is in contact with the plant roots, affects the extent to which the plant plays a significant role in the removal or breakdown of pollutants. Whereas plants significantly affect the removal of pollutants in horizontal subsurface systems with long hydraulic retention times used to clean municipal wastewater, their role is minor in pollutant removal in periodically loaded vertical filters, which usually have short hydraulic retention times. Also they found the amount of phosphorous which can be taken up in the surface biomass of Schoenoplectus lacustris is about 6.7gm m^2 y^1. Less than 5% of the phosphorus load in municipal wastewater is taken up by the plants. The uptake of nitrogen into the plant biomass is also of minor importance from a technical viewpoint, since harvesting the aboveground biomass would remove only 5- 10% of the nitrogen. They estimated the nitrogen concentrations in helophytes in the aboveground biomass to be between 15 and 32 mg N g^1 dry mass. They also suggest some future scope of the work on processes take place in CW.

- The microbial process of anoxic ammonium oxidation and possibilities of stimulating.It in constructed wetlands;
- The behavior of toxicologically highly active trace substances such as persistent drug residues in the complex system of the constructed wetland, which theoretically ought to allow better cleaning effectiveness;
- The behavior of persistent compounds in connection with how they can be removed from wastewater in this complex system and how they can either be detoxified or made safe by means of their long-term immobilization:
- The mechanisms of wastewater disinfection, with particular attention to the role of biolytic processes;
- Although the effect of root growth on hydraulic conductivity (especially in small grained Soil) has been much discussed, so far, only a few plant species have been investigated in this regard;

- The use of plants, which have been adapted to a specific wastewater problem, will continue to remain an important topic of future research. Genetic engineering provides a growing number of methods to breed plants, which can, for instance, better accumulate heavy metals or break down persistent contaminants more effectively in constructed wetlands. However, attention must always be paid to how these 'new' plant species can stand up in the long term to the many competing influences such as wild species in these complex technical ecosystems-just as crops in the field permanently have to compete with weeds.
- The Interactions of various substance cycles (e.g. carbon, nitrogen, and sulfur), taking into account above all the variability of redox states in the rhizosphere.

Rebeca. F.A et al. (2013) studied to develop a constructed wetland model that is adapted to local conditions and able to effectively treat wastewater coming from Had Yai municipality. Specifically, this study Identified issues and problems related to the wastewater treatment project and constructed wetland and analyzed the water quality parameters of the constructed wetland. They conducted an experiment to determine an effective model for adoption on a large scale to solve the problem of poor water quality emerging from the existing constructed wetland & developed an appropriate constructed wetland model to reduce the amount of green algae and the amount of nutrients that influence their growth in the wastewater. And percentage of removal they found in the different types of CW such as. Water surface HFCW with cattail, free water surface HFCW with hydrilla, free water surface, Free HFCW with hyacinth, Sub- surface flow HFCW with 2cm gravel and cattail. Sub-surface flow HFCW with 4cm gravel and tube sedge were BOD_5-27%, 26%, 53%, 73%, 67%. TSS-55%, 61%, 80%, 88%, 87%.TKN-41%, 36%, 51%, 74%, 57%. TP-64%, 36%, 88%, 88%, 85%. They concluded that the Sub-surface flow HFCW with 2 cm gravel with Cattail is the most efficient model.

Ebrahimi. A et al. (2013) was assessed the treatment of municipal wastewater from Yazd city (center of Iran) by constructed wetland vegetated with Cyperus alternifolius. Two identical wetlands with a total working volume of 60 1. And 10 cm sandy layer at the bottom were used. First wetland (W1) was control and had no Cyperus alternifolius plant. Second wetland (W2) had 100 Cyperus alternifolius shrubs with 40 cm height. Influent wastewater was provided from Yazd's septic tanks effluents and after a 4-day retention time in wetlands, reactors effluent was sampled for parameters analysis. Results show that chemical oxygen demand (COD), NO_3-N,

NH_4-N, and PO_4-P in W1 were reduced to 72%, 88%, 32%, and 0.8%, and in W2, these parameters were removed in values of 83%, 81%, 47%, and 10%, respectively. In both wetlands, the highest and lowest removal efficiencies were related to COD and phosphorus, respectively. Also, the removed phosphorus can be released to stream when the soil saturated or influent phosphorus decreased and when the plant died. After a 4 day-retention time, the W2 wetland showed a statistically significantly lower COD and NH_4- N in comparison with W2 wetland.

Avila. C et. Al. (2013) was developed an experimental hybrid constructed wetland system consisting of 3 stages of different wetland configurations (i.e. two vertical flow beds (1.5m² each) alternating feed-rest cycles followed by a horizontal subsurface flow (2m²) and a free water surface(2m²) wetlands in series) is constructed and were planted with Phragmites australis. The treatment plant operated at a constant flow of approximately 200L/d during the whole experimental period, giving an average HLR and OLR for VFs of 0.06m/d and 8.9g BOD/m²/d, with HRT 7 days. Mean overall removal rates were as 97% TSS, 78% COD, 91% BOD_5, 94% NH_4-N, 46% TN and 4% PO_4-P. Vertical flow beds achieved high organic matter retention (77% BODs) and great nitrification capacity (74%NH_4-N removal). In general, the three-stage hybrid constructed wetland system has proven to constitute an appropriate eco-technology for wastewater treatment and reuse in small communities of warm climate areas.

Mustafa. A et al. (2013) conducted a study on treatment performance of a pilot-scale constructed wetland (CW) commissioned in in Karachi, NED University of Engineering & Technology, was evaluated for removal efficiency of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia-nitrogen (NH_4-N), ortho-phosphate (PO_4-P), total coliforms (TC) and faecal coliforms (FC) from pretreated domestic wastewater. Monitoring of wetland influent and effluent was carried out for a period of 8 months. NED wastewater treatment plant (WWTP) treats wastewater from campus and staff colony. The wastewater contains domestic sewage and low flows from laboratories of various university departments. The constructed wetland is planted with common wetland plant (Phragmites karka). The key features of this CW are horizontal surface flow. Treatment effectiveness was evaluated which indicated good mean removal efficiencies; BOD (50%), COD (44%), TSS (78%), NH_4-N (49%), PO_4-P (52%), TC (93%) and FC (98%).

Kallimani. K.S et al. (2015) conducted a study with basic objectives of treatment of untreated wastewater from campus through horizontal subsurface flow constructed wetland and compare the efficiency of two different plants. The pilot scale model of horizontal subsurface flow constructed wetland consists of 0.6m x 0.4m x 0.3m dimensions and total wetland volume was 0.03363m3 provided with suitable outlets. Sand and gravels were used as bed media and plants were used for experiment were Phragmites Austrails (CW1) andCanna Indica (CW2). They evaluated performance of Pharagmites Austrails (CW1) and of pollutants such as chemical oxygen demand (COD), Biochemical oxygen demand (BOD) Total solids (TS) Total suspended solids (TSS), Total dissolved solids (TDS) and Phosphate at different Hydrolic retention time. After the study they concluded that the constructed wetland with Phragmites Austrails plant is more efficient in treating campus wastewater compared to the wetland with Canna Indica plant.

Tilak. A.S et al. (2016) commissioned a field scale constructed wetland at Sangareddy campus of SAB MILLER to explore and evaluate the bioremediation potential for the treatment of brewery effluent. The CW was comprised of two chambers, one sub-surface cell with dimensions of 20m x 20m x 1m and one holding tank for the treated wastewater of equal Dimensions. The sub-surface cell was having a 20 cm large gravel layer at bottom, covered with successive 20 cm layers of medium gravel and small gravel each. A 15 cm layer of coarse sand covering the small gravel layer constituted the top layer. Vegetation introduced initially were Napier (Penisetumpurpurem) and Bamboo (Bambuseae spp.). Because of long stabilization period and poor survival rate these were subsequently replaced with Cana indica. After the introduction of Cana Indica the CW exhibited an average COD, TSS and Inorganic Nitrogen removal efficiency of 54%, 93%, and 47% respectively. The treated wastewater was used for irrigation in nearby black soil fields for Sunflower and Sugarcane with near normal yield.

Wanil. S. Pet al. (2016) investigated the performance of a field scale CW for treatment of wastewater from hundred village households in the Kothapally village of Telengana. The CW was vegetated with hybrid Napier. High removal efficiencies were observed for TSS, COD, SO_4, inorganic Nitrogen consistently such as- 85%, 88%, 62%, 69%. The pathogen removal efficiency was 87%. The revenue generated through treated wastewater as well the biomass produced validated the economic sustainability of this engineered ecosystem. As high skill and energy intensive wastewater treatment technologies are often unfeasible for small rural communities with

limited resources and power supply, so CW is a sustainable option for decentralized rural wastewater treatment.

Pelissari. C et al. (2016) studied a pilot scale hybrid constructed wetland located in Barcelona, Spain under NAWATECH project. The aim of the study was to assess the performance of the system when operating under various organic loading rate (OLR) and Different primary treatment. A simulation of monsoon was also conducted so as to test its potential to be applied in the context of peri-urban areas of India. They constructed a hybrid engineered wetland with two 1.5m^2 vertical sub-surface flow wetland alternated cycle of feed (3.5 days each), and were followed by a 2m^2 horizontal sub-surface flow and 2m^2 free water surface wetland in series. In between June 2012 to May 2013 the primary treatment was an imhoff reactor, and the system was operated under a flow rate of 200 L/d (OLR= 9.8 gm BOD m^2/d). In between may 2013 to May 2014 the system had a hydrolytic upflow sludge blanket (HUSB) reactor as primary treatment, and operated under a flow rate of 800 L/d (OLR= 103 gm BOD m^2/d). Results show that removal efficiency 76% COD, 92% BOD_5, 98% TSS for period 1 and 82% COD, 93% BOD_5 and 96% TSS in period 2. Conversely, the removal efficiency of NH_4-N was reduced to 75% in period 2 from 96% in period 1. This is due to high OLR of period 2 may have presumably limited the growth of autotrophic bacteria responsible for oxidation of NH_4-N due to limited oxygen transfer in bed. The imhoff tank (83% TSS removal) showed better performance than the HUSB reactor (30% TSS removal). Removal efficiencies achieved during the simulation of the monsoon did not vary significantly from the normal operation, showing a good buffer capacity to cope up with large fluctuations in flow and organic load. In general, the system proved to be robust system capable of handling large fluctuations in water quantity and quality, appropriate for the treatment of wastewater in peri-urban areas in India.

Sophia. J.D et al. (2016) assessed effective treatment and safe reuse of sugar industries effluent and its effect on aquatic and terrestrial ecosystem. This necessitates innovation of low cost treatment systems that shall be deployed at different scales. Therefore, Lakhsmipuram sugar industry located in Andhra Pradesh was selected for the WATER 4 CROPS project to develop bio-treatment of sugar industries effluent and reuse in agriculture. Vertical and horizontal sub- surface flow constructed wetland system comprising of 5 beds were constructed with the dimension of 21.85m x 11.10m x 1.0m covering an area of 242.53 m^2 and filled with various substrate. Water

quality analysis showed that removal efficiency of COD, BOD_3, PO_4, ranges between 83-92%, 73-80% and 61-68% respectively. Maximum reduction in BOD loading is observed in C3 which could be attributed to presence of emergent Macrophyte (Typha angustifolia) and other floating macrophytes like duckweeds and algae. Oxygen produced by algae in C3 bed increases D.O and decreases BOD. Vertical and horizontal flow constructed wetland system with 5 beds and varied substrates especially the beneficial macrophytes and algal consortium contributes in maximum removal efficiency and reduce BOD loading rate.

Hebbara. M et al. (2016) established a pilot scale constructed wetland with vertical flow and intermittent infusion of wastewater at University of Agriculture Sciences, Dharwad, Karnataka, with treatment capacity of $50m^3$/day. Macrophytes such as Typha latiofolia and Bracharia mutica planted in the CW were evaluated for their efficacy in improving the quality of domestic wastewater for a period of one year. The Typha latiofolia induced greater reduction of TS (35.8%), TSS (45.9%), TDS (30.5%), BOD (34.8%), COD (37.4%), Potassium (47.6%), Ca & Mg(36.3%), Na(35.3%). While, Bracharia mutica was efficient in reducing total nitrogen (39.3%), nitrate nitrogen (45.4%), ammonical nitrogen (40.8%), PO_4 (45.9%). Both Typha latiofolia and Bracharia mutica induced moderation of the quality of the sewage in respect of SAR, RSC and chloride content (3.8, 0.36, 3.2 and 4.2, 0.25, 3.9 respectively) as against raw sewage (4.8, 0.34, 5.1). Results indicate that use of combination of macrophytes is ideal for wetland planting for overall improvement in the quality of the domestic sewage and its reuse.

Munavalli. R et al. (2016) investigated the potential of hybrid constructed wetland (HCW) to treat domestic wastewater. HCW system consists of a vertical flow constructed wetland planted with Typha angustata, followed by two horizontal sub-surface flow constructed wetland planted with Typha angustata and Phragmites karka respectively. HCW system was assessed to remove COD, BOD for organic loading of 5.9gm COD/m^2/d. and hydraulic retention time of 2 day. The average removal efficiencies observed were COD (65%), BOD (81%), TSS (50%). Also growth of plants was observed during monitoring period. Average height of the plants was found to be 130 cm, with plant density 11 plants/m^2 Based on the results it can be concluded that the hybrid constructed wetland system can be effectively used as secondary treatment for onsite decentralized wastewater treatment.

Pophali. G.R et al. (2016) studied a 100m³/d capacity sewage treatment plant using natural treatment system in Nagpur. Natural treatment of sewage is enhanced by infusing improved anaerobic filter media in anaerobic reactor at primary stage for a substantial organic matter reduction, followed by a sub-surface horizontal flow constructed wetland for removal of nutrients and remaining organic matter. River bed filter media of different gradation 30-60 mm, 12 mm, 2-6 mm is provided in CW from bottom to top. Average sewage characteristics with respect to BOD, COD, TSS, TKN & TP considered in the design of STP are 150 mg/l, 300 mg/l, 300 mg/l, 25 mg/l, & 6mg/l respectively. The effluent collected after the anaerobic filter and constructed wetland has BOD, COD, TSS, TKN & TP in a range of 40-60 mg/l, 80-100 mg/l, 25-40 mg/l, 20-26 mg/l & 5-7 mg/l and 10-20 mg/l, 30-50 mg/l, 5-10 mg/l, 5-8 mg/l & 0.8-2 mg/l respectively. Treated effluent thus obtained is proposed to be further processed through pressure sand filter, activated carbon column and UV disinfection for polishing and reuse for non- potable purposes.

Patil. S et al. (2016) conveyed their study at hostel campus of collage of Engineering Pune where 2000 persons were staying. The basic aim of the study was to treat the sewage cost effectively for reuse. Three treatment systems were implemented there, a 40 m³/d for grey water treatment, and a 40m³/d for black water treatment and 100m³/d for mixed water treatment. Anaerobic settler, anaerobic baffled reactor, anaerobic filter and vertical flow constructed wetland were implemented at the site. The average hydraulic retention time for anaerobic treatment system was 2 days and for VFCW is 1 day. Black water was treated only by anaerobic treatment system; grey water is treated only by VFCW. Mixed water is treated by both of them. The removal efficiency on the basis of the following parameters BOD, COD & TSS are over 75% after anaerobic treatment System and over 90% after VECW. The outlet from VFCW was disinfected by UV disinfection unit and the final treated water was used for toilet flushing and gardening purposes. This was minimizing the total consumption of fresh water for hostel campus and also reduced the pollution load on environment.

2.2 Review of projects in India on Constructed Wetlands

SWINGS (SAFEGUADING WATER RESOURCES IN INDIA WITH GREEN AND SUSTAINABLE TECHNOLOGIES) started in September 2012 due to interest of implementing integrated and optimized solutions for wastewater reuse in different areas of INDIA.

A consortium of 10 partners form Europe and 11 partners from India , considering R&D ,NGO and local body organizations with complementary expertise to improve the water reuse and sanitation in developing regions in India using low cost, easy to adopt, sustainable and zero discharge methodology based on biological and natural systems. The project was supervised under the INDO- European Union Science & Technology Cooperation and the Department of Science and Technology (DST) , Govt. of India .The main objective of the project was to develop optimized schemes for low cost effective waste water management (Municipal Wastewater) in order to make full use of water resources (irrigation, cleaning, public or private demands, aquaculture farm feed) and to minimize energy demands as a treatment options for rural and energy scarce towns in India .Three pilot Plants with different waste water treatment technologies were set up in different parts of India, i.e Aligarh Muslim University(AMU, Aligarh), Kalyani University (KLY, Kalyani), Indira Gandhi National Tribal University (IGNTU, Amarkantak),

Technology used in AMU Plant in described below:

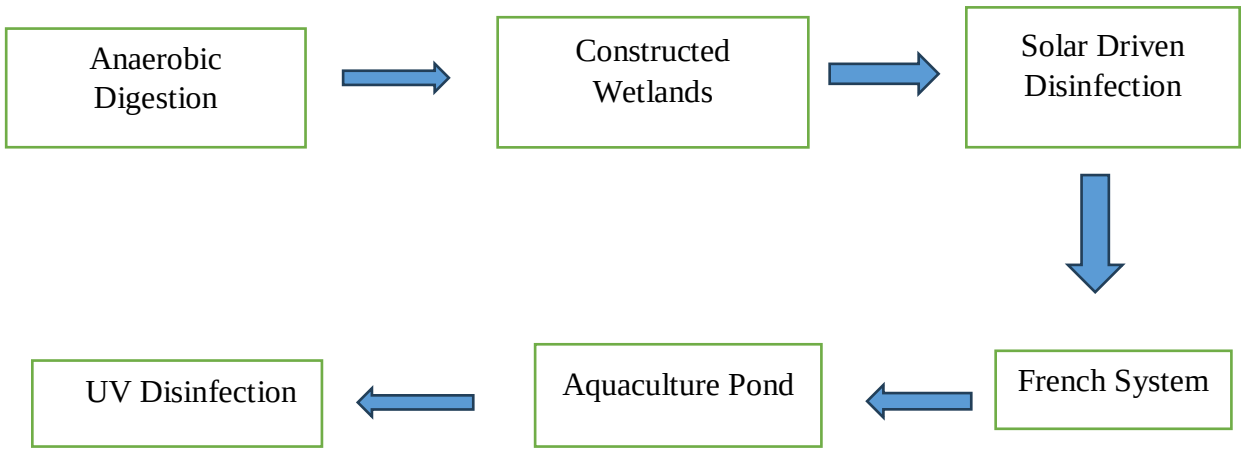


Fig.2.1. Flow Diagram of Sewage Treatment Process at AMU Plant

Technology used in Kalyani Plant is described below:



Fig.2.2. Flow Diagram of Sewage Treatment Process at KALYANI Plant

Technology used in IGNTU Plant is described below:



Fig.2.3. Flow Diagram of Sewage Treatment Process at IGNTU Plant

Results of AMU Plant clearly shows that Constructed Wetland is a well efficient system both as secondary and tertiary treatment technology with 77% COD, 85% BOD, 72% TSS removal Efficiency.

CHAPTER 3

3 WASTEWATER TREATMENT TECHNOLOGIES

3.1 Treatment of Sewage

The treatment of wastewater is divided into four phases according to their sequences in STP

- Preliminary Treatment
- Primary treatment
- Secondary treatment.
- Tertiary treatment.

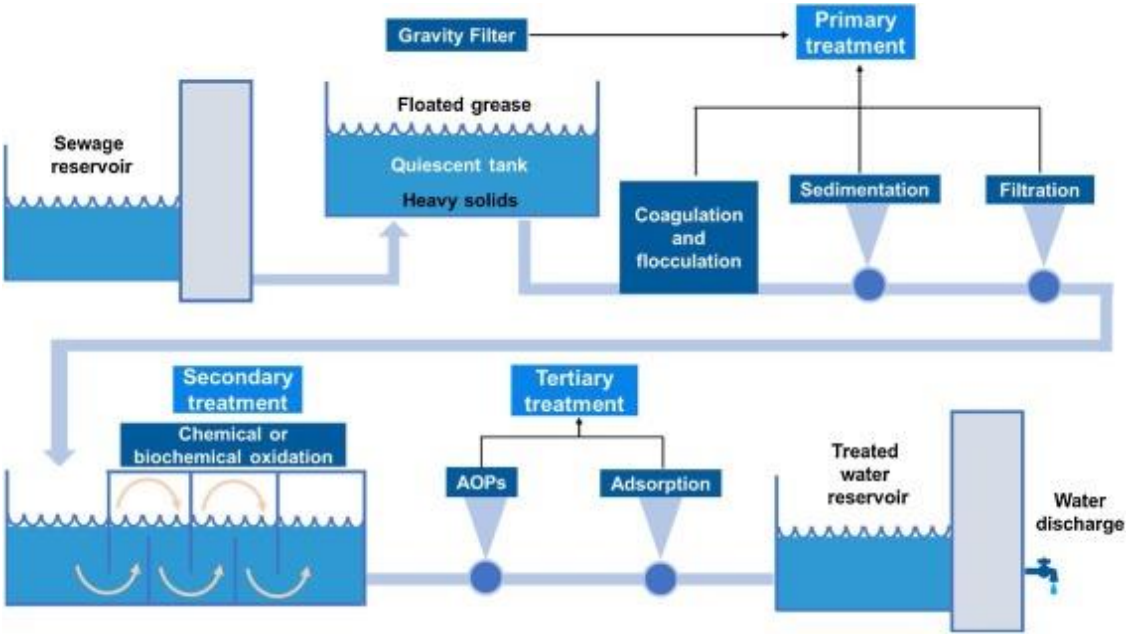


Fig.3.1. flow diagram for a typical large scale treatment plant

3.1.1 Preliminary Treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the O&M of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal, and, in some cases, communication of large objects.

3.1.2 **Primary Treatment**

In the primary sedimentation stage, sewage flows through large tanks, commonly called "pre-settling basins", "primary sedimentation tanks" or "primary clarifiers". The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities. Grease and oil from the floating material can sometimes be recovered for saponification (soap making) (Shewa et al. 2020). Primary treatment consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The settled and floating materials are removed and the remaining liquid may be discharged or subjected to secondary treatment. Some sewage treatment plants that are connected to a combined sewer system have a bypass arrangement after the primary treatment unit. This means that during very heavy rainfall events, the secondary and tertiary treatment systems can be bypassed to protect them from hydraulic overloading, and the mixture of sewage and storm water only receives primary treatment. Pre-treatment removes all materials that can be easily collected from the raw sewage before they damage or clog the pumps and sewage lines of primary treatment clarifiers. Objects commonly removed during pretreatment include trash, tree limbs, leaves, branches, and other large objects. Grit removal-Pretreatment may include a sand or grit channel or chamber, where the velocity of the incoming sewage is adjusted to allow the settlement of sand, grit, stones, and broken glass. These particles are removed because they may damage pumps and other equipment (Arashiro, 2019). Flow equalization-Clarifiers and mechanized secondary treatment are more efficient under uniform flow conditions. Equalization basins may be used for temporary storage of diurnal or wet-weather flow peaks. Basins provide a place to temporarily hold incoming sewage during plant maintenance and a means of diluting and distributing batch discharges of toxic or high- strength waste which might otherwise inhibit biological secondary treatment (including portable toilet waste, vehicle holding tanks, and septic tank pumpers). Fat and grease removal-In some larger plants, fat and grease are removed by passing the sewage through a small tank where skimmers collect the fat floating on the surface. Air blowers in the base of the tank may also be used to help recover the fat as a froth. Many plants, however, use primary clarifiers with mechanical surface skimmers for fat and grease removal (Sidwick, 1991).

3.1.3 Secondary Treatment

Secondary treatment removes dissolved and suspended biological matter. Secondary treatment is typically performed by indigenous, water-borne micro-organisms in a managed habitat. Secondary treatment may require a separation process to remove the micro- organisms from the treated water prior to discharge or tertiary treatment. Secondary treatment is designed to substantially degrade the biological content of the sewage which are derived from human waste, food waste, soaps and detergent. The majority of municipal plants treat the settled sewage liquor using aerobic biological processes. To be effective, the biota require bothoxygen and food to live. The bacteria and protozoa consume biodegradable soluble organic contaminants (e.g. sugars, fats, organic short- chain carbon molecules, etc.) and bind much of the less soluble fractions into Пос. Secondary treatment systems are classified as fixed-film or suspended-growth systems. Fixed-film or attached growth systems include trickling filters, bio-towers, and rotating biological contactors, where the biomass grows on media and the sewage passes over its surface. The fixed-film principle has further developed into Moving Bed Biofilm Reactors (MBBR) and Integrated Fixed-Film Activated Sludge (IFAS) processes. An MBBR system typically requires a smaller footprint than suspended-growth systems (Verlicchi et al. 2012). Suspended-growth systems include activated sludge, where the biomass is mixed with the sewage and can be operated in a smaller space than trickling filters that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems (Bunani, 2015).

3.1.4 Tertiary Treatment

Tertiary treatment is sometimes defined as anything more than primary and secondary treatment in order to allow rejection into a highly sensitive or fragile ecosystem (estuaries, low-flow rivers , coral reefs). Treated water is sometimes disinfected chemically or physically (for example, by lagoons and microfiltration) prior to discharge into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge or agricultural purposes (Talbot et al. 1993).

3.2 Treatment Process According to Their Treatment Mechanism

Technical Treatment process –

- Activated sludge
- Aerobic granulation
- Membrane bioreactor
- Rotating biological contactor
- Sequencing batch reactor
- Trickling filter

Natural Treatment Process-

- Aerated lagoon
- Waste Stabilization Ponds
- Oxidation Ponds
- Karnal Technology
- Duckweed ponds
- Soil Aquifer Treatment
- Constructed Wetland

3.2.1 Technical Treatment System

Activated sludge Process (ASP)-

In a sewage (or industrial wastewater) treatment plant, the activated sludge process is a biological process that can be used for one or several of the following purposes: oxidizing carbonaceous biological matter, oxidizing nitrogenous matter: mainly ammonium and nitrogen in biological matter, removing nutrients (nitrogen and phosphorus) (Mulas, 2006).

Aerobic Granulation-The biological treatment of wastewater in the sewage treatment plant is often accomplished using conventional activated sludge systems. These systems generally require large surface areas for treatment and biomass separation units due to the generally poor settling

properties of the sludge. In recent years, new technologies have been developed to improve settlability. The use of aerobic granular sludge technology is one of them (Sarma et al. 2017).

Membrane Bioreactor-Membrane bioreactor (MBR) is the combination of a membrane process like microfiltration or ultrafiltration with a suspended growth bioreactor, and is now widely used for municipal and industrial wastewater treatment with plant sizes up to 80,000 population equivalent (i.e. 48 million liters per day) (Melin et al. 2006).

Rotating Biological Contactor-A rotating biological contactor or RBC is a biological treatment process used in the treatment of wastewater following primary treatment. The primary treatment process removes the gritand other solids through a screening process followed by a period of settlement. The RBC process involves allowing the wastewater to come in contact with a biological medium in order to remove pollutants in the wastewater before discharge of the treated wastewater to the environment, usually a body of water (river, lake or ocean). A rotating biological contactor is a type of secondary treatment process. It consists of a series of closely spaced, parallel discs mounted on a rotating shaft which is supported just above the surface of the waste water. Microorganisms grow on the surface of the discs where biological degradation of the wastewater pollutants takes place (Fenu et al. 2010).

Sequencing batch reactor-Sequencing batch reactors (SBR) or sequential batch reactors are a type of activated sludge process for the treatment of wastewater. SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches. Oxygen is bubbled through the mixture of wastewater and activated sludge to reduce the organic matter (measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD)). The treated effluent may be suitable for discharge to surface waters or possibly for use on land (Dutta et al. 2015).

Trickling Filter-A trickling filter is a type of wastewater treatment system first used by Dibden and Clowes.

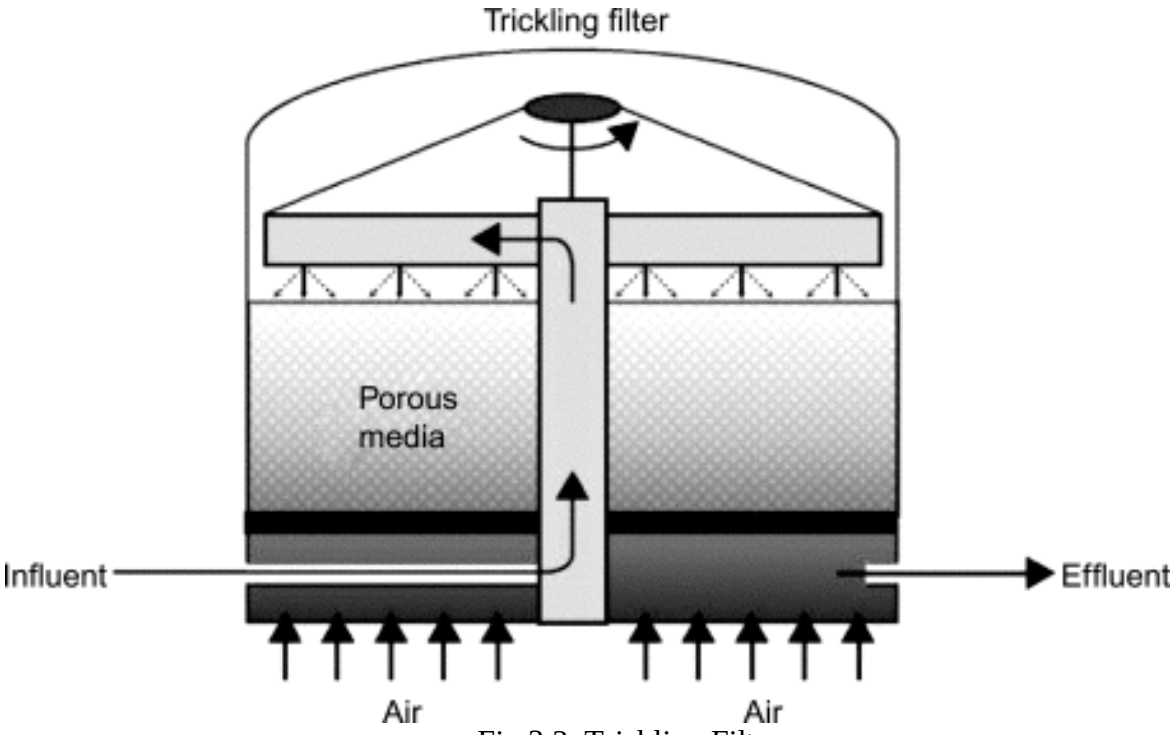


Fig.3.2. Trickling Filter

It consists of a fixed bed of rocks, lava, coke, gravel, slag, polyurethane foam, sphagnum peat moss, ceramic, or plastic media over which sewage or other wastewater flows downward and causes a layer of microbial slime (biofilm) to grow, covering the bed of media. Aerobic conditions are maintained by splashing, diffusion, and either by forced air flowing through the bed or natural convection of air if the filter medium is porous.

Aerated lagoon-An aerated lagoon or aerated basin is a holding and/or treatment pond provided with artificial aeration to promote the biological oxidation of wastewaters. There are many other biological processes for treatment of wastewaters, for example activated sludge, trickling filters, rotating biological contactors and biofilters. They all have in common the use of oxygen (or air) and microbial action to biotreat the pollutants in wastewaters (Shilton et al. 2012).

3.2.1 Natural Treatment System

Waste Stabilization Ponds-Waste stabilization pond technology is one of the most important natural methods for wastewater treatment. Waste stabilization ponds are mainly shallow man-made basins comprising a single or several series of anaerobic, facultative, or maturation ponds. The primary treatment takes place in the anaerobic pond, which is mainly designed to remove suspended solids, and some of the soluble elements of organic matter (BOD). During the secondary stage in the facultative pond most of the remaining BOD is removed through the coordinated activity of algae and heterotrophic bacteria. The main function of the tertiary treatment in the maturation pond is the removal of pathogens and nutrients (especially nitrogen). Waste stabilization pond technology is the most cost-effective wastewater treatment technology for the removal of pathogenic microorganisms. The treatment is achieved through natural disinfection mechanisms. It is particularly well suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors in the efficiency of the removal processes (Thirumurthi et al. 1974).

Anaerobic ponds-These units are the smallest of the series. Commonly they are 2-5 m deep and receive high organic loads equivalent to100g BOD/m^3 per day. These high organic loads produce strict anaerobic conditions (no dissolved oxygen) throughout the pond. In general terms, anaerobic pond functions much like open septic tank and work extremely well in warm climates. A properly designed anaerobic pond can achieve around 60 percent BOD removal at 20°c. One- day hydraulic retention time is sufficient for wastewater with a BOD of up to 300 mg/l and temperatures higher than 20°c. Designers have always been preoccupied by the possible odour that these tanks might cause. However, odour problems can be minimized in well-designed ponds, if the SO4 concentration in wastewater is less than 500 mg/l. The removal of organic matter in anacrobic ponds follows the same mechanisms that take place in any anaerobic reactor (Hassan et al. 2006).

Facultative Ponds-These ponds are of two types: primary facultative ponds receive raw wastewater, and secondary facultative ponds receive the settled wastewater from the first stage (usually the effluent from anaerobic ponds). Facultative ponds are designed for BOD removal on

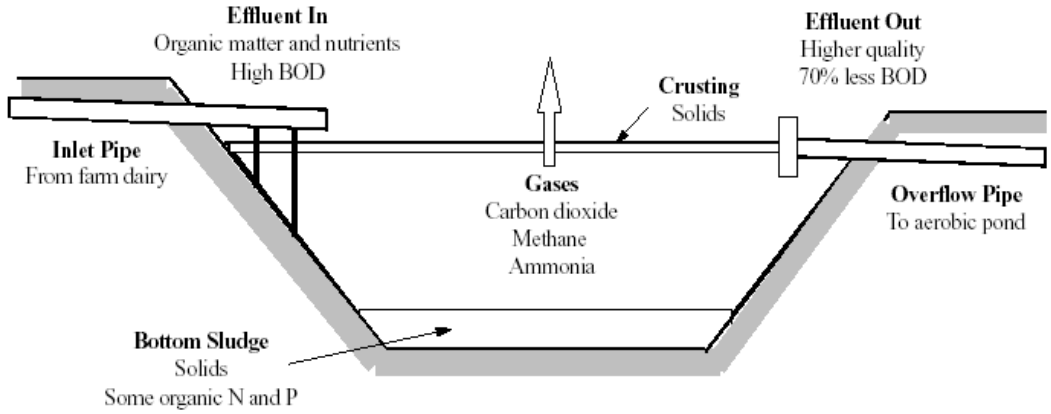


Fig.3.3. Facultative Pond

the basis of a low organic surface load to permit the development of an active algal population.

This way, algae generate the oxygen needed to remove soluble BOD. Healthy algae populations give the water a dark green colour but occasionally they can turn red or pink due to the presence of purple, sulphide-oxidizing photosynthetic activity. This ecological change occurs due to a slight overload. Thus, the change of colouring in facultative ponds is a qualitative indicator of an optimally performing removal process. The concentration of algae in an optimally performing facultative pond depends on organic load and temperature. The photosynthetic activity of the algae results in a diurnal variation in the concentration of dissolved oxygen and pH values. Variables such as wind velocity have an important effect on the behaviour of facultative ponds, as they generate the mixing of the pond liquid. Good degree of mixing ensures a uniform distribution of BOD, dissolved oxygen, bacteria, and algae, and hence better wastewater stabilization (von Sperling, 1996).

Maturation ponds-These ponds receive the effluent from a facultative pond and the size and number depend on the required bacteriological quality of the final effluent. Maturation ponds are shallow (1.0- 1.5 m) and show less vertical stratification, and their entire volume is well oxygenated throughout the day. Their algal population is much more diverse than that of facultative ponds. Thus, the algal diversity increases from pond to pond along the series. The main removal mechanisms especially of pathogens and fecal coliforms are ruled by algal activity in

synergy with photo-oxidation. On the other hand, maturation ponds achieve only a small removal of BOD, but their contribution to nitrogen and phosphorus removal is more significant (Garcia ,2000).

Oxidation ponds-Oxidation Ponds are also known as stabilization ponds or lagoons. They are used for simple secondary treatment of sewage effluents. Within an oxidation pond, heterotrophic bacteria degrade organic matter in the sewage to produce cellular material and minerals. The production of these supports the growth of algae in the oxidation pond. Growth of algal populations allows further decomposition of the organic matter by producing oxygen. The production of this oxygen replenishes the oxygen used by the heterotrophic bacteria.

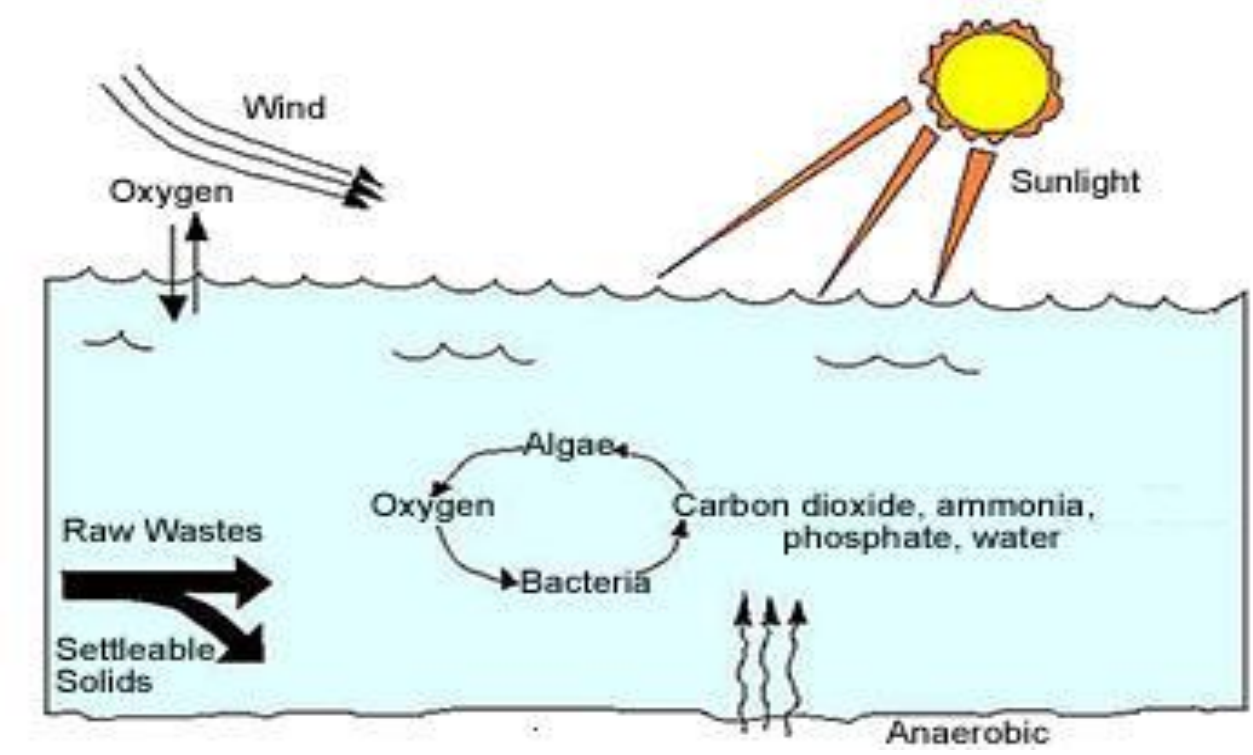


Fig.3.4. Oxidation Pond

Typically oxidation ponds need to be less than 10 feet deep in order to support the algal growth. In addition, the use of oxidation ponds is largely restricted to warmer climate regions because they are strongly influenced by seasonal temperature changes. Oxidation ponds also tend to fill, due to the settling of the bacterial and algal cells formed during the decomposition of the sewage. Overall, oxidation ponds tend to be inefficient and require large holding capacities and long retention times.

The degradation is relatively slow and the effluents containing the oxidized products need to be periodically removed from the ponds (Kaid et al.2022).

Soil Aquifer Treatment-The soil organisms bring about further microbial activity is polishing the wastewater and is a long term process. It is unique to soil conditions, climatology, precipitation and inundation that may bring in agricultural residues of insecticides and pesticides.

Constructed Wetland-A constructed wetland (CW) is an artificial wetland created for the purpose of treating anthropogenic discharge such as municipal or industrial wastewater, or storm water runoff. It may also be created for land reclamation after mining, refineries, or other ecological disturbances such as required mitigation for natural areas lost to land development. Constructed wetlands are engineered systems that use natural functions of vegetation, soil. And organisms to treat different water streams. Depending on the type of wastewater that has to be treated the system has to be adjusted accordingly which means that pre- or post- treatments might be necessary (Vymazal, 2011).



Fig.3.5.Constructed Wetland

CHAPTER 4

4 OVERVIEW OF CONSTRUCTED WETLAND SYSTEM

4.1 Constructed Wetland

A constructed wetland (CW) is an artificial wetland created for the purpose of treating municipal or industrial wastewater, greywater or stormwater runoff. It may also be created for land reclamation after mining, refineries, or other ecological disturbances such as required mitigation for natural areas lost to land development. Constructed wetlands are engineered systems that use natural functions of vegetation, soil, and organisms to treat different water streams. Depending on the type of wastewater that has to be treated the system has to be adjusted accordingly which means that pre- or post- treatments might be necessary. Constructed wetlands can be designed to emulate the features of natural wetlands, such as acting as a biofilter or removing sediments and pollutants such as heavy metals from the water. Some constructed wetlands may also serve as a habitat for native and migratory wildlife, although that is usually not their main purpose

4.2 Classification

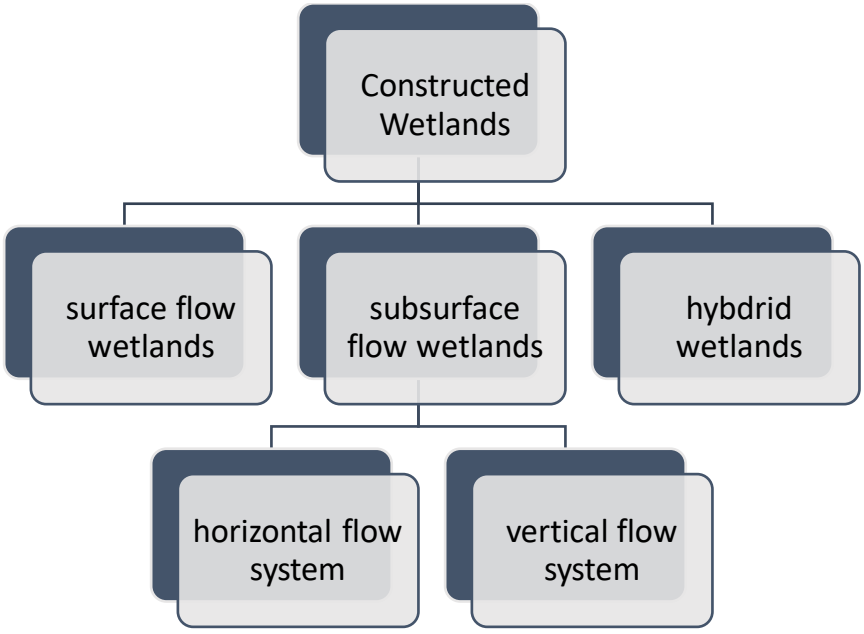


Fig.4.1. Classification of Constructed Wetlands

4.2.1 Free Surface Flow Constructed Wetland

Subsurface flow wetlands can be further classified as horizontal flow and vertical flow constructed wetlands. In the vertical flow constructed wetland, the effluent moves vertically from the planted layer down through the substrate and out (requiring air pumps to aerate the bed).

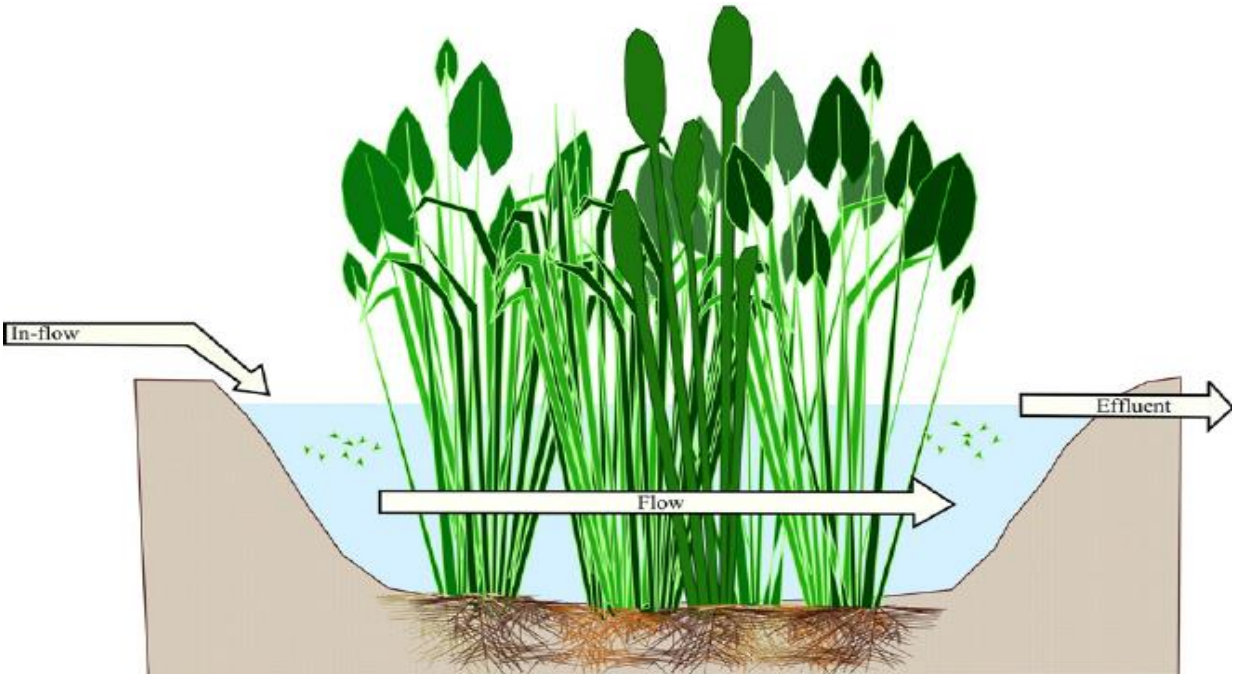


Fig.4.2. Free Surface Flow Constructed Wetland

In the horizontal flow CW the effluent moves horizontally via gravity. Parallel to the surface, with no surface water thus avoiding mosquito breeding. Vertical flow CWs are considered to be more efficient with less area required compared to horizontal flow CWs. However, they need to be interval-loaded and their design requires more know-how while horizontal flow CWs can receive wastewater continuously and are easier to build. Long retention times and an extensive surface area in contact with the flowing water provide for effective removal of particulate and organic matter. The sediment, plant biomass and plant litter surfaces are also where most of the microbial activity affecting water quality occurs, including oxidation of organic matter and transformation of nutrients. Biomass decay provides a carbon source for denitrification, but the same decay competes with nitrification for oxygen supply. Low winter temperatures enhance oxygen solubility in water, but slow microbial activity.

4.2.2 Sub-surface Flow Constructed Wetland

Surface flow wetlands, also known as free water surface constructed wetlands, can be used for tertiary treatment or polishing of effluent from wastewater treatment plants. They are also suitable to treat stormwater drainage. Pathogens are destroyed by natural decay, predation from higher organisms, sedimentation and UV irradiation since the water is exposed to direct sunlight. The soil layer below the water is anaerobic but the roots of the plants release oxygen around them, this allows complex biological and chemical reactions Surface flow wetlands can be supported by a wide variety of soil types including bay mud and other silty clays.Plants such as Water Hyacinth (Eichhornia crassipes) and Pontederia spp. Are used worldwide (although Typha and Phragmites are highly invasive). However, surface flow constructed wetlands may encourage mosquito breeding. They may also have high algae production that lowers the effluent quality and due to open water surface mosquitos and odours, it is more difficult to integrate them in an urban neighbourhood.

4.2.3 Horizontal Flow Constructed Wetland

Wetlands (CWs) using three different treatment media (gravel, pieces of plastic pipes, and shredded tire rubber chips) were investigated in Samaha village. Dakahliya, Egypt. The study focused on the wetland setup stage during the first months of its operation (setup stage). In this stage media porosity, bacterial biofilm, and plant roots growth were in progress and it was prior to the operational steady state stage. Objectives of this paper are to study the change in media porosity of HSSF wetland cells in order to estimate duration of wetland setup stage, and to evaluate the use of different bed media on biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) treatment. The results showed that after 180 days of operation, the wetland cells had reached steady porosity and had started stable treatment. Also performance of plastic media bed in pollutants reduction was better than gravel and rubber beds and gravel media was in advanced than rubber media.

4.2.4 Vertical Flow Constructed Wetland

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. One of the major threats of good performance of VFS is clogging of the filtration substrate. Therefore, it is important to properly select the filtration material, hydraulic loading rate and distribute the water evenly across the bed surface in order to avoid overloading of certain parts of the surface. Given their reliance on a well-functioning pressure distribution, they are more adapted to locations where natural gradients can be used. Thus enabling the filter by gravity. Since flat areas require the use of pumps, they are thus dependent on a reliable power supply and frequent maintenance.

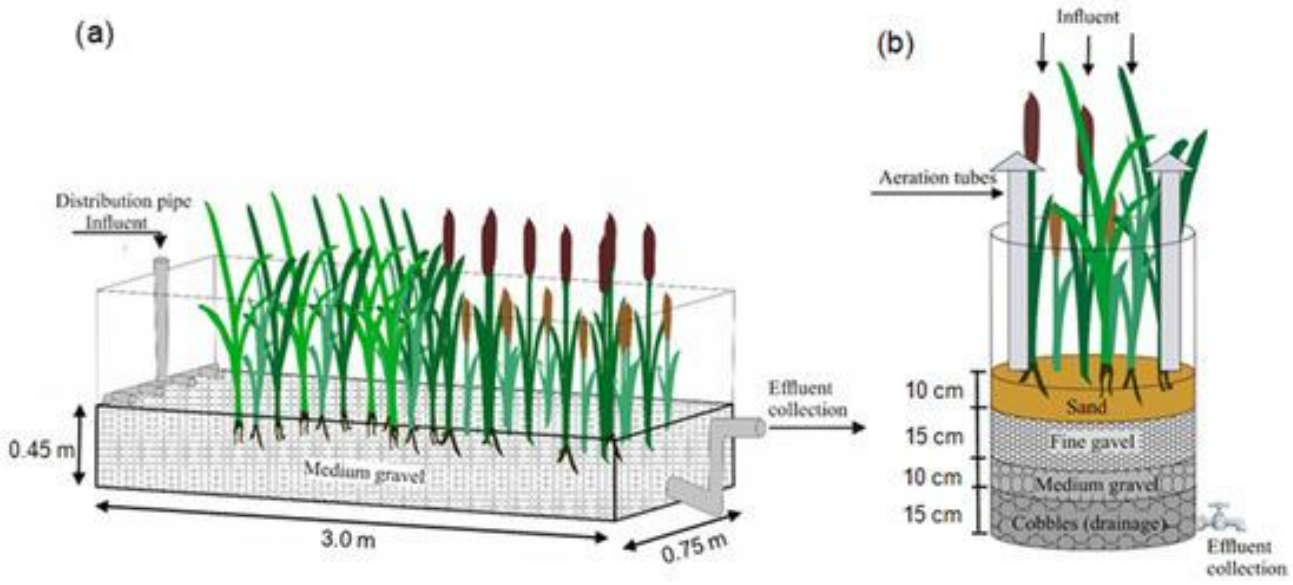


Fig.4.3.Horizontal and Vertical Subsurface Flow

4.2.5 Hybrid Constructed Wetland

Various types of CW may be combined in order to achieve higher treatment effect, especially for nitrogen. In these systems, the advantages of the HSF and VF systems can be combined to complement each other. Therefore, there has been a growing interest in hybrid systems (also sometimes called combined systems). Hybrid systems used to comprise most frequently VFS and HFS arranged in a staged manner, however, all types of CW could be combined. In hybrid systems, the advantages of various systems can be combined to complement each other. It is possible to produce an effluent low in BOD, which is fully- nitrified and partly denitrified and hence has much lower total-N concentrations.

The design consists of two stages of several parallel VF beds (filtration beds) followed by 2 or 3 HF beds (elimination beds) in series. The results Indicate very good. Removal for organics (BODs and COD) and TSS while removal of nitrogen is enhanced with nitrate increase at the outflow.

4.3 Component and Design Criteria of Constructed Wetland

Constructed wetland comprises of the following five major components:

Basin- Systems have been designed with bed slopes of as 1 to 3 percent 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.

For dimensioning CW basin for domestic wastewater the following inflow characteristics have to be considered:

- BOD, 27° C. in mg/day.
- Quantity of wastewater, in lit /day.

The BOD criteria (organic loading) ranges for dimensioning are:

- For horizontal flow 10-30 g/BOD/m^2/day
- For vertical flow 20-40 g/BOD/m^2/day

For industrial effluents specific recommendation according to type of industry are required. Parts near the lateral sides and the infiltration and drainage areas may not be included in the surface calculations.

The hydraulic load criteria range for dimensioning are:

- For horizontal flow 40-100L/m^2/day
- For vertical flow 50-130 L/m^2/day

A freeboard of at least 20 cm is to be provided.

Subtrate- Many different media sizes have been tried for the bed, but gravel less than 4 cm diameter seems to work best. Larger diameters increase the flow rate, but result in turbulent flow.

Smaller media gives a reduced hydraulic conductivity, but has the advantage of more surface area for microbial activity and adsorption. Soil is sometimes used to remove certain materials due to the ability of reactive clays to adsorb heavy metals, phosphates, etc.

The filter media effective for the biological treatment must consist of sand / gravel, a carefully mixed soil or a comparable media. The design of the correct filter media according to the available material is the most important step in the design process. If the material is too coarse the wastewater will flow too fast; if it is too fine clogging and overflow will occur. Both cases cause poor treatment efficiency.

Sand and gravel with rounded grains are ideal. Large and sharp edged particles can lead to damage of the liner. Media of relatively similar grain size, like river sand or sieved materials are best. The following filter bed parameter should be met:

- Permeability (k) = 1010 m/s for of domestic effluents, 10 10 m/s for industrial effluents.
- Uniformity coefficient (U) = d/ do ≤ 5%; (ratio of grain sizes which contain 60% and 10% of the total weight)
- Effective grain size (d10) = should be≥ 0.2 mm
- Content of silt or bonded admixtures = should be < 5% (if at all)

The recommended depth of the filter media is:

- For horizontal filters: 50-100 cm
- For vertical filters: 60-120 cm

If a horizontal system is used, increasing the depth up to more than one meter is not useful, because of the limited root growth of the plants which is the only oxygenating factor. In vertical systems an increase in depth of more than 120 cm will enhance the treatment efficiency further, but this is normally limited due to increased cost of filter material.

Vegetation-Role of vegetation in Constructed Wetland

- Protection and stabilization of the surface of the filter material.
- Formation of a suitable environment for microorganisms present in the filter material.
- Partially protection against clogging of the filter material.

- Oxygen supply to the area close to the roots of macrophytes formation of aerobic and anoxic zones in the immediate vicinity.
- Enhance the aesthetic effect and allow positive integration into the landscape.
- Improve the microclimate properties by high transpiration.
- Reduction of runoff of treated wastewater to the opportunity to design drain less systems.
- Nutrient depletion and vice versa supply of carbon from decomposing organic residues.

The following requirements of plants should be considered for use in constructed wetland-

- Ecological adaptability (no disease or weed risk to the surrounding natural ecosystems).
- Tolerance of local conditions in terms of climate, pests and disease.
- Tolerance of pollutants and hypertrophic waterlogged conditions.
- Ready propagation, rapid establishment, spread and growth.
- High pollutant removal capacity, through direct assimilation or indirect enhancement of Nitrification, denitrification and other microbial processes.
- Have rich belowground organs (i.e. roots and rhizomes) in order to provide substrate for attached bacteria and oxygenation (even very limited) of areas adjacent to roots and rhizomes.
- Have high aboveground biomass for winter insulation in cold and temperate regions and nutrient removal via harvesting.

With the available experience the following species can be given

Phragmites australis(common reed)- formerly known as Phragmite. Communes (Norfolk reed), is a member of the large family Poaceae (roughly 8000 species within 785 genera). It may be found in permanently flooded soils of still or slowly flowing water. This emergent plant is usually firmly rooted in wet sediment but may form lightly anchored rafts of 'hover reed'.

Reproduction in closed stands of this species is mainly by vegetative spread, although seed germination enables the colonization of open habitats.

Common reed or Norfolk Reed is most common in nutrient-rich sites and absent from the most oligotrophic zones. However, the stems of this species may be weakened by nitrogen rich water

and are subsequently more prone to wind and wave damage, leading to an apparent reduction in density of this species in Norfolk (England) and elsewhere in Europe.

Phragmites karka (reed)- is a perennial reed with long rhizomes and robust, erect culms to 3 m. The leaves are 15-30 cm long and nearly 2.5 cm broad; inflorescence is a large plumelike panicle with capillary branches and small, slender spikelets. It is leafy up the panicle. In New Guinea the reed occurs from near sea-level to at least 2 000 m. It thrives in a rainfall regime from 200 to 5 000 mm in swamps (India). It grows in standing water and is therefore tolerant of flooding. It found along streams, in wet grassland and in swamps in Africa, India. New Guinea and northern Australia.

Arundo donax (mediteranean reed)- is native to eastern and southern Asia, and probably also parts of Africa and the southern Arabian Peninsula and from Poaceae family. It forms dense stands on disturbed sites, in wetlands and in riparian zones (banks of watercourses). Arundo donax is a grass that generally grows to 6 m high, in ideal conditions it can exceed 10 m, with hollow stems 2-3 cm diameter. The leaves are alternate, 30-60 cm long and 2-6 cm wide with a tapered tip, grey-green, and have a hairy tuft at the base. Overall, A. donax flowers bear upright, feathery plumes 40-60 cm long, but the seeds are rarely fertile.

Typha latifolia (cattail)- is a species belonging to the small family Typhaceae. This species is widespread in temperate parts of the northern hemisphere but extends to South Africa, Madagascar, Central America and the West Indies and is naturalized in Asia. A Typha latifolia is typically found in shallow water or on exposed mud at the edge of lakes, ponds, canals and ditches and less frequently near fast flowing water. This species rarely grows at water depths below 0.3 m, where it is frequently replaced by P. australis. Cattail is a shallow- rooted perennial producing shoots throughout the growing season, which subsequently die in autumn. Colonies of this species expand by rhizomatous growth at rates of 4 m/a, while detached portions of rhizome may float and establish new colonies.

Typha angustifolia (cattail) - is a narrow-leaved cattail and typically three to five feet tall. With long, stiff leaves ¼ to ½ inch in wide. Flowers form a dense cylindrical “spike” at the top of the plant and typically the male and female flowers are separated. This species quickly spreads in open, wet mineral soils and can quickly out-compete native plants in aquatic, wetland habitats. This species prefers wet meadows, shores, marshes and ditches often in calcareous habitats.

Juncus effusus (bulrush) - is a rhizomatous, perennial herb with a large, tufted, cespitose growth form. Juncus effusus stems are stout but soft, 5-15 m tall and 1.5-3 mm wide. The leaves are dull chocolate brown or chestnut-colored at the base, the inner sheaths dark toward the summit. The inflorescence is a many-flowered, loosely clustered panicle, 2-10 cm long.

Iris pseudacorus -show good treatment and nutrient uptake.it is invasive and once established, hard to remove. It can survive over 12 inches of flooding for months.

Schoenoplectus lacustris (bulrush) - grows up to 3.5 meters tall, with stems 5-15 millimeters thick. Most of the leaves of S. lacustris are reduced to bladeless sheaths around the stem, but leaf blades up to 100 centimeters long can be formed under water. The inflorescence appears at the top of the stem, and comprises 3-10 branches, each of which is up to 10 cm long and may be again divided into shorter branches. The flowers are in the form of spikelets, each of which is 6-15 millimeters long by 3-5 mm wide. It may go dormant in summer, but will green up in winter. They never grow so densely that they seriously block air to water or shade other plants. They Colonizes slowly, especially in rock media.

Planting Techniques-

- Reeds can be planted as rhizomes, seedlings or planted clumps.
- Clumps can be planted during all seasons. ($2/m^2$).
- Rhizomes grow best when planted in Pre-Monsoon. ($4\text{-}6/m^2$).
- Seedlings should be planted in Pre-Monsoon ($3\text{-}5/m^2$).

Liner- The liner goes under the entire system and can be a manufactured liner or clay. This prevents the wastewater from infiltrating into the ground before it is treated. A berm around the system prevents runoff from entering the system.Lining can be done in CW by the following way:

- Using concrete or plastic tank.
- Providing plastic liner, UV resistant, if exposed to the sun, thickness > 1 mm, root resistant, preferably from polyethylene or equivalent material. The liner has to be protected against damages caused by rocks of the existing soil and by sharp edged gravel of the drainage layer. Geotextiles may be used for prevention of such damages.
- Providing clay sealing with a verified thickness of 30 cm. It has to be compacted properly.

- Improvement of existing soil by admixture of bentonite or very fine clay (two layers of 20 cm each, mixed and compacted separately).

After finishing the sealing a leakage test should be carried out by filling the bed with water. If the loss is less than 2mm overnight, the sealing is to be considered as satisfactory.

Inlet- The inlet can be a manifold pipe arrangement, an open trench perpendicular to the flow, or weir box. The manifold arrangement can be a pipe with several valve outlets or a simple perforated pipe. Coarse gravel allows rapid infiltration of the water. The inlet purpose is to spread the wastewater evenly across the treatment bed for effective treatment.

Outlet- The outlet structures used are similar to the inlet structures. One preferred addition is making the outlet adjustable to allow the control of water level. The level could be lowered when a large amount of rainfall is expected or raised for maximum cross-sectional use of the media.

4.4 Hydrology of Constructed Wetland

A. 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.

B. 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 hydro period of a wetland will be strongly affected by seasonal differences in precipitation and evapotranspiration

C. Hydraulic Residence Time-the period of time that wastewater is retained within the wetland is critical to the various treatment processes that occur. Required Detention Times 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 wastewater treatment processes depends amongst other factors on the detention time. The following equation gives an

approximate estimate of detention time.

$$t = (P * V\text{bed})/Fav$$

Where, t is the average detention time,

P is the porosity or void ratio of reed bed substrate,

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

F_{av} is the average discharge (m^3/day).

D. 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=F/A Where, A is Reed Bed wetland surface area (m^2).

E. 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.

F. 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, hydro period 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 storm water inflow.

R= contribution from rainfall ,I= net infiltration (infiltration less exfiltration)

O= surface outflow, ET= loss due to evapotranspiration

4.5 Contaminant Removal Mechanism

A constructed wetland is a complex assemblage of wastewater, substrate, vegetation and an array of microorganisms (most importantly bacteria). Vegetation plays a vital role in the wetlands as they provide surfaces and a suitable environment for microbial growth and filtration. Pollutants are removed within the wetlands by several complex physical (sedimentation, filtration, adsorption and volatisation) chemical (precipitation, adsorption hydrolysis, oxidation /reduction) and biological (bacterial metabolism, plant metabolism, plant absorption, natural die-off processes as depicted in

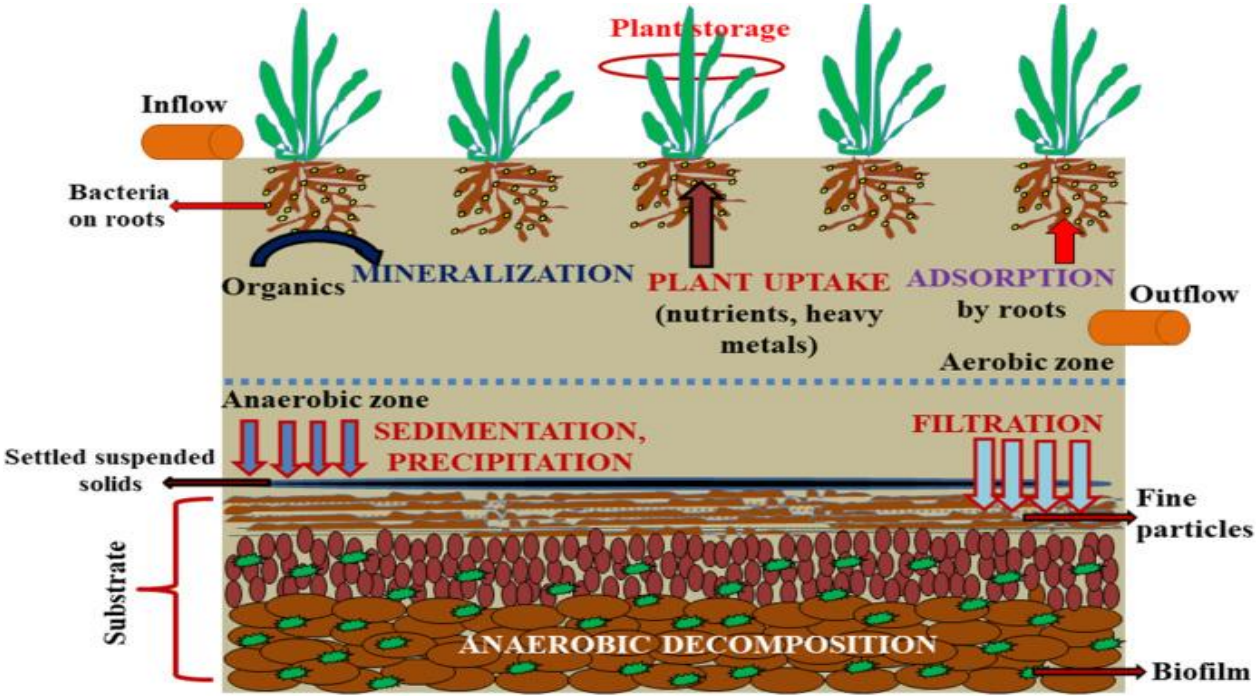


Fig.4.4. Contaminant Removal Mechanism in Constructed Wetland

4.5.1 Suspended Solids Removal

Wastewater suspended solids consists of a range of organic and inorganic materials but is typically dominated by fecal organic matter and organic particles like bacteria. The density and size of particles can vary considerably. Suspended solids removal in wastewater treatment wetlands is a fairly rapid physical process. The major removal mechanisms are sedimentation, filtration and surface adhesion

4.5.2 BOD Removal

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

4.5.3 Nitrogen Removal

There are sufficient studies to indicate some roles being played by wetland plants in Nitrogen removal but the significance of plant uptake vis-à-vis nitrification/denitrification is still being questioned. Nitrogen (N) can exist in various forms, namely Ammoniacal Nitrogen (NH, and NH), organic Nitrogen and oxidized Nitrogen (NO, and NOx). The removal of Nitrogen is achieved through nitrification/denitrification, volatilization of Ammonia (NH,) storage in detritus and sediment, and uptake by wetland plants and storage in plant biomass. A majority of Nitrogen removal occurs through either plant uptake or denitrification. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system. At the root-soil interface, atmospheric oxygen diffuses into the rhizosphere through the leaves, stems, rhizomes and roots of the wetland plants thus creating an aerobic layer similar to those that exists in the media-water or media-air interface. Nitrogen transformation takes place in the oxidized and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonification takes place where Organic N is mineralized to NH_4+-N in both oxidized and reduced layers. The oxidized layer and the submerged portions of plants are important sites for nitrification in which Ammoniacal Nitrogen is converted to nitrite (NO_2-N) by the Nitrosomonas bacteria and eventually to nitrate (NO_3-N) by the Nitrobacter bacteria which is either taken up the plants or diffuses into the reduced zone where it is converted to N_2 and N_2O by the denitrification process. Denitrification is the permanent removal of Nitrogen from the system; however the process is limited by a number of factors, such as temperature, pH, redox potential, carbon availability and nitrate availability. The annual denitrification rate of a surface-flow wetland could be determined using a Nitrogen mass-balance approach, accounting for measured influx and efflux of Nitrogen, measured uptake of Nitrogen by plants, and sediment, and estimated NH_3 volatilization.

4.6 Advantages of Constructed Wetland

- Constructed Wetlands can be less expensive to build than other treatment processes.
- It utilize natural processes .
- Simple in Construction .
- Simple operation and maintenance, (Simple enough to be operated by the local community while also providing employment opportunities)
- Cost effectiveness as it has low construction and operation costs,
- Process stability. (Adjust to fluctuations in flow).
- Low energy demand. (Does not require electricity).
- Positive environmental impact. (Serve as habitat for plant and animal species, Can be Integrated into sustainable landscape design).
- Treated wastewater has the potential to increase farm productivity and profitability. Can be a potential source for reliable irrigation water supply for farmers.
- Such approaches have the potential to meet the rural sanitation goals.
- Also widely applicable for small townships, institutional campuses, small industries,etc.

4.7 Limitations of Constructed Wetland

- Large area requirement.
- Construction wetland treatment may be economical relative to other options only where land is available and affordable.
- CW are based on filtration mechanism, therefore, they are sensitive against clogging. Higher concentrations of settleable matter, oil and grease, especially mineral oil in the wastewater higher the tendency to surface clogging as well as internal clogging. Overloading of CW with organic matter can also cause clogging due to increased growth of bacteria within the filter matrix. These problems can be avoided by appropriate pretreatment of wastewater, design of the filter bed and proper operation of the system.

- In very hot and dry climate the evaporation in CW can be so high that the wastewater is concentrated substantially. CW with smaller specific surface, for example vertical systems have to be used in cases where increase of TDS is undesirable.
- It is a breeding place of mosquito and vector.

CHAPTER 5

5 OBJECTIVE AND SCOPE OF RESEARCH WORK

5.1 Objectives of the Study

- To develop a constructed wetland that is energy-efficient for the in-situ treatment of wastewater that flows through Jadavpur University's manhole.
- To study various treatment unit parameters and characteristics in order to determine design guidelines.

5.2 Scope of Work

- To conduct a treatability study for wastewater treatment at the bench scale using both biological and physico-chemical processes.
- Design a vertical and horizontal constructed wetland system.
- Regularly collect and examine samples from the inlet and outflow of the bench scale model.

To study various treatment unit characteristics and criteria in order to develop design guidelines.

5.3 Study Area

Raw sewage samples were collected from Jadavpur University, Jadavpur, Kolkata 700032.

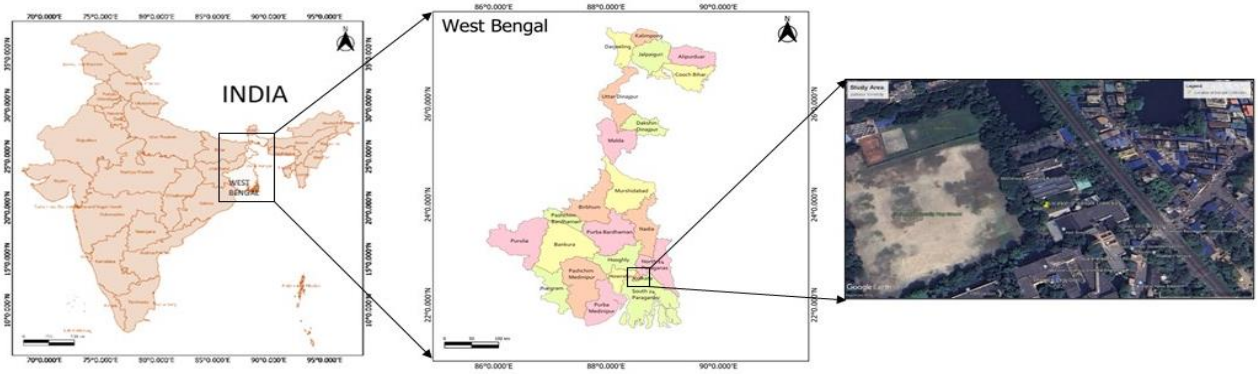


Fig.5.1. Map of Study Area

5.4 Experimental Setup & Methodology

In order to conduct a bench scale model study of a constructed wetland, a glass rectangular tank measuring 300 mm by 180 mm by 180 mm was constructed. It was installed on the roof of the Regional Centre, SWRE, and JU at a 1% slope. After that, the tank (CW) was filled with vertical layers of gravel ranging in size in 1st column and 3rd column - 10mm, and 2nd column -3 to 5mm. Next, for a week, raw sewage was added to the setup to encourage the growth of microorganisms

in the tank. ***Canna indica*** plants were added to the setup after two days of operation in order to improve the model's effectiveness. The plants were taken from Jadavpur University campus. Total 350 L wastewater (Raw Water) was collected from Jadavpur University Campus. Tap with freeboard of 30mm in CW the different flow rates with variable time were maintained by adjusting the tap. After different designed retention time, the outlet discharged (final treated) water was collected for laboratory analysis of different wastewater quality parameter such as BOD, COD, DO, pH, Turbidity, TSS, Phosphate, TKN, Nitrate, Nitrite, TC, FC. The growth rate of the plant was measured and managed it periodically.

5.5 Flow Diagram of Treatment Process

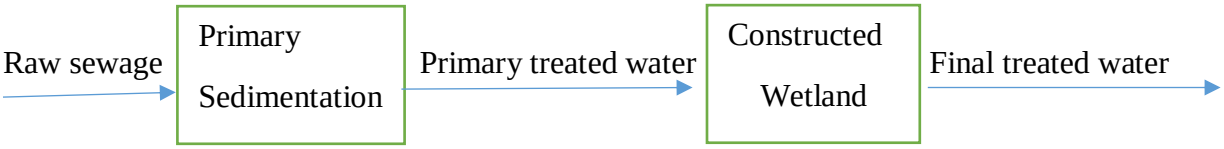


Fig.5.2.Flow Diagram of Treatment Process

5.6 Design of Experimental Setup of Costructed Wetland

Length of the Tank = 30cm

Outer Width = 18cm

Inner Width = 15cm

Height of tank = 18cm

Free Board = 3cm

Total Cross-Sectional Area of tank = 0.0324 m2

Total Volume of Bed (empty) = 0.00972 m3 = 9.72 Ltr

Volume of Void with Gravel in Bed = 6.5 Ltr

Porosity of Bed = 0.66

Hydraulic Loading Rate:

$$HLR = \frac{Q}{A}$$

Where, Q = Wastewater flow rate; A = Area

HLR= 925.92 m3/ha/d

Organic Loading Rate:

$$OLR = \frac{C_o \times Q}{V}$$

Where, Co = Influent BOD; Q = Wastewater flow rate; V = Volume

$$OLR = \frac{0.1 kg/m^3 \times 0.003 m^3/d}{0.00972\, m^3}$$

OLR = 0.03086 $kg/m^3/d$

The gravels are found to be uniformly graded. The Uniformity of Co-efficient is 1.54.

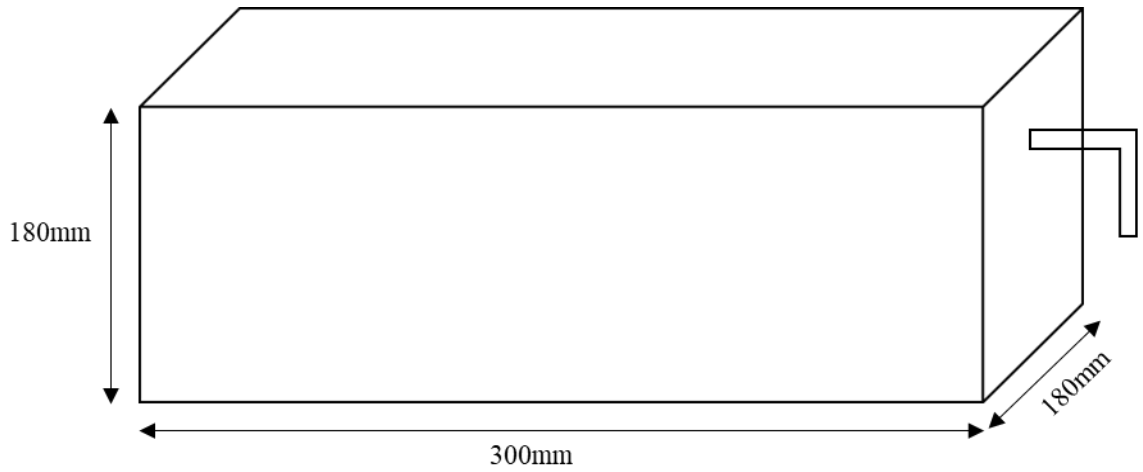


Fig.5.3. Model of Horizontal Constructed Wetland

CHAPTER 6

6 MATERIAL AND METHODOLOGY

The main purpose of the whole study was the collection of the samples and testing their water quality parameters before and after treatment. For the water quality test, following samples were collected in clean plastic container,

- Raw sewage collected from nearby canal.
- Primary Treatment Effluent.
- Final Treated effluent outlet of CW.

The samples were analysed using the "standard methods for examination of water and waste water" specified by "American Public Health Association (APHA), 2000". The following tests have done in this study are:

1. 3-day Biochemical Oxygen Demand (BOD_3)
2. Chemical Oxygen Demand (COD)
3. Dissolved Oxygen (DO)
4. pH
5. Total Suspended Solids (TSS)
6. Ammonia Nitrogen
7. Total Kjeldahl Nitrogen
8. Nitrate Nitrogen
9. Total Phosphate.
10. Total coliform (TC) & Fecal coliform (FC)

6.1 pH

It is the logarithm of the reciprocal of the hydrogen ion activity in moles per litre. The practical pH scale extends from 0 to 14 with the middle value (pH =7) corresponding to exact neutrality at 25ºC. Whereas 'alkalinity' and 'acidity' express the total reserve or buffering capacity of a sample,

the pH value represents the instantaneous hydrogen ion activity. This determination is useful in calculation of carbonate, bicarbonate, hydroxyl and carbon dioxide and in calculation of the extend of corrosion or stability index and in controlling the water treatment process, especially during coagulation and disinfection and water softening.

Determination of pH plays an important role in the wastewater treatment process. Extreme pH levels, presence of particulate matters, accumulation of toxic chemicals and increasing alkalinity levels are common problems in wastewater. This becomes a serious environmental concern in recent years and hence municipal and industrial wastewater treatments are critical before it enters to lakes, rivers, canals and other water bodies. The pH analyses are important for neutralization, precipitation, coagulation and other biological treatment process. pH analyses are probably the most recommended method for wastewater treatment.

6.1.1 Methods Available

There are two methods in determination oh pH values, these are

- Colorimetric Methods: This method requires less expensive equipment but suffers from source interference contributed by color, turbidity, high saline content, colloidal matter, free chlorine and various oxidants and reluctant. It is only suitable for rough estimation.
- Electrometric Method: The electrometric method which is considered standard is given by a glass electrode method. The glass electrode method is relatively immune to the interference from color, turbidity and other previously mentioned factor. It is suitable for very exact estimation (+/-0.1 pH unit).

Pure water undergoes dissociation in the following way:

$H_2O=H^+ + OH^-$

When this reaction reaches the equilibrium condition we can write

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

$[H_2O] = K_{ion}$ [At 25°C temperature $K_{ion} = 1.82*10^{-16}$]

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

No. 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 is k_{ion} $[H_2O] = k_w$ is called ion product constant of water]

Taking common logarithm on both side

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

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

By definition in electro natural condition

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

pH-pOH=7

6.1.2 Apparatus Used

- Beaker
- pH meter.

Ph Meter: pH is measured using pH meter, which comprises a detecting unit consisting of a glass electrode, reference electrode, usually a calomel electrode connected by KCI to the pH sensitive glass electrode and an indicating unit which indicates the pH corresponding to the electromotive force is then detected. Before measurement, pH meter should be calibrated by using at least two buffers. Also it is recommended to use hydrated silica gel for the glass electrode, and the electrodes must be soaked with water or in suitable buffer followed by rinsing in water Electrode tips should be cleaned after use of wiping with tissue paper to remove adhering substances. Potassium level in the calomel electrode is maintained and the cap should be removed during measurement. For the accurate measurement of pH, the temperature of the buffer should be maintained for standardization of pH meter is same.

6.1.3 Procedure

a) The test cell is filled with KCL solution

b) The temperature is adjusted to the test temperature 25° C

c) Standard buffer solution is taken. If there is any discrepancy between the actual pH value and the pH value obtained in the scale we have to adjust it and bring it to the actual value by operating

the buffer switch. We have to standardize the entire pH meter between the range (4.01 to 7.0) or (7.0 to 9.2)

e) After this standardization process we should take the water sample in the glass bucket and measure its pH value from the scale.

6.2 TOTAL SUSPENDED SOLIDS (TSS)

Solids can be dispersed in water in both suspended and dissolved forms. Although some dissolved solids may be perceived by physical senses, they fall more appropriately under the category of chemical parameters.

Solids suspended in water may consist of inorganic particles. Inorganic solids such as clay, slit and other soil constituents are common in surface water. Organic material such as plants, fibers a biological solids (algal cell, bacteria etc.) are common constituents of surface waters. Other suspended material may result from human use of water. Domestic wastewater usually contains large quantities of suspended solids that are mostly organic in nature.

Suspended material may be objectionable in water for several reasons. It is aesthetically displeasing and provides adsorption sites for chemical and biological agents. Suspended organic solids may be degraded biologically, resulting in objectionable by - products.

Total suspended solids means the portion of solids that retained by a filter. The estimation of suspended solids depends, upon the nature of filter paper and the particle size of the suspended solids. A well-mixed sample is filtered through a weighted standard glass fiber paper and the residue retained on the filter is dried to a constant weight at 103℃ to 105℃.The increases in weight of the filter represents the total suspended solids.

Now, TSS (mg/l) = $(W_2-W_1) \times 1000$/ Volume of sample

Where,

W_1 = weight of filter paper before passing sample.

W_2= weight of filter paper after passing sample.

6.2.1 Apparatus Used

- 100ml measuring cylinder

- Whatman grade 42 glass fibre
- Beaker
- Filter paper
- Filtering apparatus.
- Conical flasks
- Hot air oven
- Digital weight machine
- Dessicator

6.2.2 **Procedure**

a) The filter paper was taken in the hot air oven at 105°C for 1hour and then it was kept in the desiccators (contains CaO) for 30 minutes.

b) Then the filter paper is weighted.

c) The 100 ml sample was collected & then it was filter within the filter paper.

d) Then the filter paper is heated to dry in the hot air oven in 105° c by evaporating the water for Around 1 hour.

e) Then these were kept in the desiccators (contains CaO) for 30 minutes as it comes to room temperature.

f) Then filter paper is weighted.

6.3 BIOCHEMICAL OXYGEN DEMAND (BOD3, 27° C)

The biochemical oxygen demand determination is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic organisms in a water body to break the organic materials present in the given water sample at certain temperature over a specific period of time.

Biochemical oxygen demand of water or polluted water is the amount of oxygen required for the biological decomposition of dissolved organic matter to occur under standard condition at a standardized time and temperature. Usually the time is taken as 5 days and the temperature is 20°C.

The test measured the molecular oxygen utilized during a specified incubation period for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as sulphides and ferrous ion. It also may measure the amount of oxygen used to oxidize reducing form of nitrogen (nitrogenous demand

6.3.1 Principle

The sample is filled in an airtight bottle and incubated at specified temperature for 3 days. The dissolved oxygen (DO) content of the sample is determined before and after three days of incubation at 27°C and the biochemical oxygen demand is calculated from the difference between initial and final dissolved oxygen.

The initial dissolved oxygen is determined shortly after the dilution is made; all oxygen uptakes occurring after this measurement is included in the biochemical oxygen demand measurement.

6.3.2 Available Methods

Basically biochemical oxygen demand determination involves determination of dissolved oxygen at a particular interval and at specified temperature; biochemical oxygen demand measurement is usually done by any of following two methods depending upon dissolved oxygen depletion:

- Direct Method: - This method is suitable for those biochemical oxygen demand, does not exceed 7 mg/liter provided that they are aerated to bring the dissolved oxygen level nearly to the saturation at the start of the test. This method does not involve any modification of the sample.
- Dilution Method: This method is suitable for those wastes which posses' high biochemical oxygen demand value involves high dissolved oxygen depletion if measured directly. Here the sample is diluted to desired degree to have safe dissolved oxygen depletion value. This method can be performed in two ways:
- With Seed: This is performed when the wastewater sample dose not contains sufficient amount of microorganism. Seed sample containing necessary microorganism are added to the original sample.
- Without Seed: This test is usually performed where the wastewater contains sufficient amount of microorganism.

In our biochemical oxygen demand determination test the dissolved oxygen concentration with the modified Winkler Method with and also without seed was employed.

6.3.3 Reagents Used

- Calcium Chloride
- Magnesium Sulphate
- Ferric Chloride
- Di Potassium Hydrogen Phosphate
- Potassium Di Hydrogen Phosphate Di Sodium Hydrogen Phosphate
- Ammonium Chloride
- Manganous Sulphate
- Potassium Iodide
- Sodium Azide
- Concentrated Sulfuric Acid
- Sodium Thiosulphate
- Double Distilled Water

6.3.4 Reagent Preparation

(1) Nutrients Preparation: Nutrients are required beside the bio-degradable dissolved organic matter for the proper growth of the microorganisms. The following nutrients are added in stipulated quantity within the waste sample.

(2) Phosphate Buffer Solution: It is added in order to maintain a moderately constant pH value. Beside this it also acts as a source of nitrogen and phosphate required as nutrients.

In this case we have dissolved following chemicals-

- 8.5 gm potassium di-hydrogen phosphate.
- 21.75gm di-potassium hydrogen phosphate.
- 33.4gm dissolve hydrogen phosphate hecta-hydrate or 2.205gm (Na_2HPO_4, $2H_2O$)
- 1.7 gm Ammonium chloride in about 500 ml distilled water Dilute it to llitre.

(3) $MnSO_4$ Solution :- In this case we have to dissolve 480 gm. Manganus Sulphate tetra hydrate ($MnSO_4$, + H_2O) in boiled distilled water, filter it and dilute to 1 liter.

(4) $CaCl_2$ solution:- Dissolve 2.75 gm anhydrous $CaCl_2$ in 100 ml distilled water

(5) $FeCl_3$ Solution:- Dissolve 0.025 gm, $FeCl_3$,$6H_2O$ in distilled water and dilute it to 100 ml.

(6) Alkali Azide Solution: In this case we have to dissolve 500 gm. Sodium Hydroxide (NaOH) and 135 gm. Of Sodium Iodide (Nal) in distilled water, filter it and dilute to 1 liter.

(7) Starch solution: In this case we have to add 1 gm. Starch in 50 ml. distilled water and then heat the solution so that all the starch dissolves in water and clearance will ppear in upper position.

(8) $MgSO_4$, Solutionistilled m. of Magnesium Sulphate Hepta Hydrate

9$MgSO_4$ 7 H_2O) has to be added to distilled water and to be diluted to 1 liter

(9) Sulphate solution: 6.205 gm. Of sodium thio sulphate penta hydrate (Na_2S_2 O_3, 7 H_2O) has to be dissolved in distilled water and 0.4 gm. Of solid Sodium (NaOH) has to be added to it and the entire solution have to be diluted to 1 liter.

6.3.5 Apparatus Used

- Aerator, 300ml BOD bottles
- 1000ml conical flask
- BOD incubator
- 10ml measuring pipettes
- 250ml measuring cylinders
- Flasks
- Burette
- Burette stand

6.3.6 Procedure

1. Take 1 ltr aerated D/D water.

2. The nozzle of the aerator should be cleaned and the distilled water have to be aerated by means of a compression for about 45 min in order to raise the initial DO.

3. Add 1 ml each

a. Phosphate buffer solution. b. $MgSO_4$ solution

c. $CaCl_2$ solution d. $FeCl_3$ solution

4. Take required amount of sample with suitable dilution factor and rest of ml D/D water in 1 ltr. measuring cylinder.

5. This mixture has to be kept in three nos. of 300ml BOD bottle.

6. Keep 2 BOD bottle bottle in incubator at 27°C and remaining 1 is used for the test as '0'day BOD.

- PROCEDURE FOR '0' DAY DO MEASURING

a) Add 2 ml Azide solution + 2 ml $MnSO_4$ solution

b) 15 time shake it, keep it for few minutes and flock will appear.

c) Add 2 ml H_2SO_4 conc. When 1/3 rd flock is cleared. Shake it and iodish color will be seen.

d) Take 203 ml this solution in a conical flask.

e) Titrate it with $Na_2S_2O_3$ solution and stop it when light yellow colour will be seen.

f) Then add 2 ml starch solution. Deep blue colour will be seen. Again titrate with $Na_2S_2O_3$. Stop when it becomes colourless.

The same procedure was repeated for rest 2 sample after 3 days.

BOD (mg/L) = $[(S_3 - S_0) - (C_3 - C_0)]$ * Dilution factor

Where, S_0 and S_3 are the initial and 3-day DO of the sample.

C_0 and C_3 are the initial and final DO of the blank.

Dilution factor = 100 / f. where f is % of dilution.

6.4 DISSOLVED OXYGEN (DO)

The low solubility of oxygen is the major factor that limits the purification capacity of natural water and necessitates waste water treatment to remove polluted matters capacity of receiving streams. The aerobic biological treatment processes, the limited solubility of oxygen is of great importance because it governs the rate at which oxygen will be absorbed by the medium. In liquid wastes, dissolved oxygen is the factor that determines whether the biological changes are brought about by aerobic or non-aerobic organism. The former uses free oxygen for oxidation of organic and inorganic matters and produce end products, whereas the latter brings about such oxidation through the reduction of certain inorganic salts such as sulphates and the end products are often very obnoxious. Thus the dissolve oxygen measurement is vital for maintaining aerobic conditions in natural water that receive polluted matter and in aerobic treatment process intended to purify domestic and industrial waste water. It Is one of the most important single tests that the environmental engineers uses to maintain conditions favourable for the growth and reproduction of a normal population of fish and other aquatic organism by maintaining the dissolved oxygen level to support the desired aquatic life in a healthy condition at all times. Determination of dissolved oxygen serve as the basis of B.O.D. test thus to evaluate the pollution strength of wastes and the rate of biochemical oxidation. Oxygen plays a significant factor in the corrosion of iron and steel, particularly in water distribution systems and steam boilers. Removal of oxygen from boiler feed water by physical and chemical means is a common practice in the power industry.

6.4.1 Available Methods

More commonly used procedures are

1. Azide modification →Effectively removes the interferences caused by nitrite, which is the most common interference in biologically treated effluents and incubated BOD samples.

2. Permanganate modification → Used in the presence of ferrous iron.

3. Alum flocculation →interference. Used in the presence of suspended solids, which cause

4. Copper Sulphate →Sulfuric acid flocculation modification used in activated- sludge mixed liquors.

5. DO Meter → Used digital techniques.

6.4.2 Procedure (Azide Modification)

6.4.3 Reagents Preparation

(a) Manganese sulphate solution: - Dissolve 480g $MnSO_4$, 4H:O; or 400g $MnSO_4$, 2 H_2O of 364g $MnSO_4$, H_2O in distilled water, filter, and dilute to 1 liter. The manganese sulphate solution should not give a colour with starch when added to an acidified solution of potassium iodide.

(b) Alkali – lodide - Azide reagent: - The reagent may be prepared in the traditional way, Dissolved 500g Sodium hydroxide, NaOH (or 700g KOH) and 135g of NaCl (150g KI) in Distilled water and dilute to 1 liter. To this solution add 10g Sodium azide, (NaN_3) dissolved in 40ml-distilled water. Potassium and sodium salts may be used interchangeably. This reagent should not give a colour with starch solution when diluted and acidified.

(c) Sulfuric Acid, conc.:- The strength of this acid is about 36N, Hence 1ml is equivalent to about 3ml of the alkali – iodide – azide reagent.

(d) Starch: - Either the aqueous solution or soluble Starch Powder mixtures may be used. Prepare the aqueous solution by adding a cold water suspension of 5g arrowroot or soluble starch to approximately 800ml of boiling Water, with stirring, Dilute to 1 liter, allow boiling a few minutes and let settle overnight. Use the clear separate.

(e)Sodium thiosulfate stock solution, (0.10N):- Dissolve 24.82g Na:S:Os, $5H_2O$ in boiled and cooled distilled water and dilute to I liter. Pressure by adding 5ml chloroform or ig NaOH per liter.

(f) Standard Sodium Thiosulfate Titrant, (0.0250N):- Prepare either by diluting 250.0 ml Sodium thiosulphate stock Solution to 1000ml or by dissolving 6.205g $Na_2S_2O_3$, $5H_2O$ in freshly boiled and cooled distilled water and diluting to 1000ml. Standard Sodium thiosulphate solution, exactly 0.0250N is equivalent to 200µg DO per 1.00ml.

(g) Standard Potassium Dichromate Solution, (0.0250N): A solution equivalent to 0.0250N sodium thiosulfate contains 1.226 g/l $K_2Cr_2O_7$. The $K_2Cr_2O_7$ should be previously dried at 103°c for 2hr. The solution should be prepared in a volumetric flask.

6.4.4 Standardization

Dissolved approximately 2g K1, free from iodide, in an Erlenmeyer flask with 100 to 150ml distilled water; add 10 ml 10 H_2SO_4, followed by exactly 20.0 ml standard potassium dichromate

solution. Dilute to approximately 400 ml and titrate the liberated iodine with the thiosulfate titrate, adding starch towards the end of the titration, when a pale straw colour is reached.

6.4.5 Calculation

Because 1 ml 0.0250N Sodium thiosulfate titrant is equivalent to 0.200mg DO, each mm. of sodium thiosulfate titrant used is equivalent to 1 mg/l DO when a volume equal to 200 ml of original sample is titrated. Because 1 ml 0.0250 Sodium thiosulfate titrant is equivalent to 0.200mg DO, each mm. of Sodium thiosulfate titrant used is equivalent to 1 mg/l DO when a volume equal to 200 ml of original sample is titrated.

6.5 CHEMICAL OXYGEN DEMAND (COD)

Chemical Oxygen Demand (COD) may be defined as the oxygen required for stabilizing both biodegradable & non-biodegradable dissolved organic matter under aerobic condition at a standard time and temperature. This test is widely used as a means of measuring the pollution strength of domestic and industrial waste. This test allows measurement of a waste in terms of the total quantity of oxygen required for oxidation to CO2 and water. It is based upon the fact that all organic compounds, with a few exceptions, can be oxidized by the action of strong oxidizing agents under acidic condition. The COD test is used extensively in the analysis of industrial wastes. It is particularly valuable in surveys designed to determine and control losses to sewer system. In conjunction with the BOD test the COD test is helpful in indicating toxic condition and the pressure of biologically resistant organic substances.

6.5.1 Available Methods

There are number of methods available for the COD test. Among these the following are important from the subject point of view

i. Open Reflux Method
ii. Closed Reflux, Titrimetric Method
iii. Closed Reflux, Colorimetric Method

These methods are discussed below

- Open Reflux Method: This is the method we have followed and discussed afterward.
- Closed Reflux, Titrimetric Method: Most types of organic matter are oxidized by a boiling

mixture of Chromic and Sulfuric acid. A sample is refluxed in strongly acid solution with a known excess of Potassium Di Chromate ($K_2Cr_2O_7$) After digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with Ferrous Ammonium Sulphate to determine the amount of $K_2Cr_2O_7$ consumed and oxidizable matter is calculated in terms of Oxygen equivalent The ratios of reagent weights, volumes and strengths should be kept constant when sample volumes other than 50 ml. are used.

- Closed Reflux, Colorimetric Method: When a sample is digested, the dichromate ion oxidizes COD material in the sample. This results in the change of chromium from the hexavalent (VI) state to the trivalent (III) state. Both of these chromium species are coloured and absorb in the visible region of the spectrum. The dichromate ion ($Cr_2O_7^{2-}$) absorbs strongly in the 400 mm region, where the chromic ion (Cr^{3+}) absorption is much less The chromic ion absorbs strongly in the 600 mm. region where the dichromate has nearly zero absorption In 9(M) of Sulfuric Acid solution the approximate molar extinction coefficients for these chromium species are as follows: Cr^{3+} lit/mole cm. at 604 nm. $Cr_2O_2^{2-}$ 380 lit/mole cm. at 444 lit/mole cm. at 426 nm The C r^{3+} has a minimum in the region of 400 nm.

6.5.2 Principle

The organic the presence of sample gets oxidized completely by potassium dichromate (KCO- presence of sulphuric acid (H_2SO_4) silver sulphate ($AgSO_4$) and mercury sulphate ($HgSO_4$) to produce carbon dioxide (CO_2) and water (H_2O) is refluxed with a known amount of potassium dichromate ($K_2Cr_2O_7$) in the sulphuric acid medium and the excess potassium dichromate ($K_2Cr_2O_7$) is determines by titration against ferrous ammonium sulphate, using ferrous as a indicator. The dichromate consumed by the sample is equivalent to amount of oxygen (O_2) required to oxidize organic matter.

Oxidizes the various types of organic substances into CO_2 and H_2O

$C_aH_aO_b + cCr_2O_{7-} + 8eH^+ \rightarrow nCO_2 + a + 8e\ H_2O + 2cCr^{+3}$ Where,

$C = 2/3\ n + a/6 - b/3$

As a result of this reaction chromium is reduced from a state of valance six to that of three.

6.5.3 Apparatus Used

- Glass beads
- COD digester
- 250ml flasks
- Burette
- 10ml pipettes
- Burette stand

6.5.4 Reagents Used

- Potassium Dichromate
- Sulfuric Acid
- Ferrous Ammonium Sulphate
- Silver Sulphate Mercury Sulphate
- Ferrous Indicator
- Doubled Distilled Water

6.5.5 Reagent Preparation

1) Standard Potassium Dichromate Solution (0.25 N): Appropriately 15gm of $K_2Cr_2O_7$was dried at 103°C for 2hr. Exactly 12.259gm of specially dried orange crystal was dissolved in double distilled water (D.D) and dilute to exactly I litre.

2) Ferrous Ammonium Sulphate Solution (FAS) (0.25 N): 98gm of $Fe(NH_4)_2SO_4$, $6H_2O$ was dissolved appropriately in 600 ml D.D. 20 ml of concentrated H_2SO_4 was then added and allowed to cool and diluted to 1 litre with D.D water.

3) Mercuric Sulphate: Powdered $HgSO_4$.

4) Ferrous indicator Solution: 1.485gm 1, 10 Phenolthroline Mono Hydrate was dissolved together with 0.695gm $FeSO_4$, 7 H_2O in distilled water and diluted to 100 ml.

5) Sulphuric Acid reagent: 4.4gm Ag_2SO_4 was taken in 500 ml H_2SO_4 bottle.

6) Glass Beads

7) Standardisation: 10 ml distilled water was added to 10 ml of 0.25 (N) $K_2C_2O_7$ solution with further addition of 20 ml of concentrated H_2SO_4 and then allowed to cool. Then it was titrated with F.A.S. using 1-2 drops of ferrous indicator. The colour change is very sharp, going from blue green to reddish brown.

F.A.S. Normality= $\frac{(\text{volume of } K_2Cr_2O) \text{ x } (K_2Cr_2O7 \text{ in Normality})}{\text{Volume of FAS used}}$

6.5.6 Standardization

Volume of titrant (in burette), $Fe(NH_4)_2SO_4, 6H_2O = V_1 = 10ml$

Volume of $K_2Cr_2O_7$ solution $V_2=10ml$

Strength of $K_2Cr_2O_7 = S_2 = 0.25(N)$

We know that: $V_1S_1 = V_2S_2$

6.5.7 Procedure

1. 25 ml of 0.25N $K_2Cr_2O_7$.1gm $HgSO_4$.5.0 ml concentrated H_2SO_4 25 ml sample and 30 ml H_2SO_4, solution (Ag_2SO_4) was mixed in a conical flask.

2 About 5 pieces of glass beads was taken in the flask.

3. Then all flask were heated and refluxed for 2 hrs. (30°C for 1hr and 60°C for next

hr).

4. All the flask were then allowed to cool and the condenser was washed down with about 25-ml of distilled water.

5. The acid solution was then diluted to about 200-ml with double distilled water and the solution was then allowed to cool to room temperature.

6. 3 drops of ferrous indicator was then added to the flask.

7. The excess dichromate was then titrated with 0.25N $F(NH_4)_2SO_4$ solution.

8. The titration should be stopped when colour changes from blue green to reddish.

6.5.8 Calculation

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

A=1 ml of Fe $(NH_4)_2SO_4$ solution required for the titration of the blank = 25.8 ml.

B = 1 of Fe $(NH_4)_2SO_4$ solution required for the titration of the sample N = of the Fc (NH_4) $2SO_4$ solution = 0.25(N) S = n of sample used for the titration = 25ml

6.6 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 in the test for total coliform bacteria. Total coliform counts give 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 faces of warm-blooded animals. Because the origin of the Fecal coliform are most specific 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. Coliform bacteria can also be found in soil, other animals, insects etc. 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 "potability", suitability for consumption, of drinking water. In measures the concentration of total coliform bacteria associate with the possible presence of disease causing organism. Fecal coliform bacteria indicate the presence of the sewage contamination of a water way and the possible presence pathogenic organism.

6.6.1 Available Method

i. Membrane Filter Method: Used for only good quality water.

ii. Multiple Tube Method: Used for any type of water.

6.6.2 Membrane Filter Method

This method is applicable for the good quality of water. This method is a fast way to estimate bacterial population in water. In the initial steps, an appropriate sample volume passes through a membrane filter with pore size small enough (0.45 micron) to retain the bacteria present. The filter is placed on an absorbent pad (in a petri dish) saturated with a culture medium that is selective for coliform growth. The petri dish containing the filter and pad is incubated, upside down, for 24 hours at the appropriate temperature. After incubation, the colonies that have grown are identified and counted using a low power microscope.

6.6.3 Multiple Tube Method (MPN)

Water receives its bacterial population from air, soil, swage, organic wastes, that plants and animals etc. These bacteria in water may be harmless or harmful for both to human consumers. Therefore, bacterial examination of water is necessary first and for most to disclose the presence of microorganisms, specially that might constitute a health hazard. It is universally recognized that the excreta of man, mammals and birds contain enormous number of coliform bacteria. The coliform group comprises all the facultative and aerobic gram- negative, non-spore forming rod shaped bacteria that ferment lactose with gas formation within 48 hrs at 37°C. Thus, presence of this organism in water undoubtedly indicates the fecal contamination of water. The presence of other coliform bacteria which are non-fecal and widely distributed in nature may therefore, be of little epidemiological significance

Generally, this type of tests is carried out to determine the occurrence of coliform hacteria in walt

A. Apparatus Used

- Test tubes
- Test tubes stands
- Digital weight machine
- Autoclave
- Durham's tubes
- Non-Absorbent Cotton
- 1ml pipettes

- 10ml pipettes
- 2000ml beaker
- Biological incubator
- Platinum loop
- Water bath

B. Reagents

i. Macconkey Broth

ii. EC Broth

iii. Brilliant Green Bile Broth

C. Preparation of Media

- Preparation of Macconkey Broth for presumptive coliform test.
    - Macconkey Broth powder– 80 gm
    - Double Distilled Water (D/D) – 1000 ml
    - If required, heat the solution to dissolved completely. This is double strength (DS) Macconkey Broth.
- Preparation of Brilliant Green Bile Broth for total coliform confirmatory test
    - Brilliant Green Bile Broth powder – 4 gm
    - D/D water – 100ml
    - If require, heat the solution to dissolve completely
- Preparation of E.C. broth for faecal coliform
    - EC broth– 3.7gm
    - D/D water– 80 ml
    - If required, heat the solution to dissolved completely.

1. Plug all tube (for 1 sample 15 tubes) tightly with known absorbent cotton cool. Place all the tube in a wire mesh cage with either brown paper or aluminum foil.

2. Put 10 ml Macon D.S. in each tube 3. Among them add 9 ml D/D to 5 tubes

4. Add 9.9 ml D/D to another 5 tubes

5. Sterilize all the tubes in autoclave

6. Keep the tubes in autoclaves for 15 min at a pressure 15 lb/inch

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

D. Total Coliform Test

i. Here number of tubes to be taken depends on the number of tubes showing positive result in the presumptive test. One tube for TC test should be taken against each positive tube of presumptive test.

ii. 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 Brilliant Green Bile Broth both after inoculation at 37°C in incubation for 48 hrs.

E. Fecal Coliform Confirmatory Test

i. Here also number of tubes to be taken depends upon in the number of tubes showing the positive result in the pre-test. One tube for FC should be taken against positive of pre- test.

ii. Take 5 ml of EC Broth. Then inoculate it in autoclave.

iii. With a help of a platinum loop add a little amount of solution (which is test for presumptive test).

iv. Keep the tubes containing FC Broth after inoculation in 44°C on water both for 24 hrs.

v. The number of positive test tubes, where formation of gases takes place has been noted.

6.7 TOTAL PHOSPHATE

Take 10 ml Sample then mix 1 ml H_2SO_4 (Conc.) and 5 ml HNO, (Conc.) with it. Then boil the mixture and reduce the volume of the sample to 1 ml. Then cool it at room temperature. Now add 20 ml D/D water to It. Then add I drop Phenonthraeline indicator. After that add I N NaOH till the color of the sample changes to pink. Then add 1 tea spoon Charcoal. Then the color of the solution

changes to white. Now filter it and collect the filtrate. Mix D/D water with the filtrate to make the solution 100 ml. Then pour the solution into a clean and dry Spectrophotometric cell and measure absorbance at 720 nm.

6.8 TOTAL KJELDAHL NITROGEN (TKN)

The kjeldahl method determines nitrogen in tri-negative states. It fails to account for nitrogen in the form of Azide, Azine, Azo, Hydrazone, nitrate, nitrite and semi-Carbazone. In presence of H_2SO_4 potassium sulphate and mercuric sulphate catalyst, amino nitrogen of many organic materialsis converted to ammonium sulphate. Free ammonia and ammonical nitrogen also are converted to ammonium sulphate. If free ammonia and ammonical nitrogen is removed, organic nitrogen can be obtained. During sample digestion a mercury ammonium complex is formed and then decomposed by Sodium Thiosulphate. After decomposition the ammonia is distilled from an alkaline medium and absorbed in boric acid. The ammonia is then determined by titrimetric method

6.8.1 Apparatus Used

- Distillation assembly
- Digestion apparatus
- Beaker
- Burette
- Pipette
- Measuring cylinder

6.8.2 Reagent Preparation

1) Digestion reagent: dissolve 134gm K_2SO_4 and 7.3gm $CuSO_4$, in about 800 ml water. Carefully add 134 ml conc. H_2SO_4, when it has cooled to room temperature, dilute the soln. to 1 litre with D.D water. Keep it at 200 C.

2) Sodium Hydroxide- Sodium Thiosulphate reagent: Dissolve 500gm NaOH and 25gm $Na_2S_2O_3$), $5H_2O$ in water and dilute it to 1 litre.

3) Borate buffer soln- Add 88ml of 0.1(N) NaOH to 500ml (0.025M) Na_2 B_4O_7, solution and dilute it to 1 litre.

4) Mixed indicator solution Dissolve 200 mg of methyl red indicator in 100 ml of 95 percent ethyl or isopropyl alcohol. Dissolve 100mg of methylene blue in 50 ml of 95 percent ethyl or isopropyl alcohol. Combine these two. Prepare monthly.

5) Indicating boric acid solution - Dissolve 20g of hydroboric acid in ammonia free water, add 10 ml of mixed indicator solution and dilute to 1 litre.

6) Standard sulphuric acid titrant -0.02 N(1ml-280 pg of nitrogen).

6.8.3 Procedure

1. Place a measured volume of sample in an 800 ml kjeldahl flask. Select sample size from the following table.

Table: 5. Limit of Total Kjeldahl Nitrogen (TKN)

TKN in Sample, mg/l	Sample Volume, ml
0-1	500
5.10	250
10-20	100
20-50	50
50-100	25

2. Ammonia removal - Add 25 ml borate buffer and then 6 (N) sodium hydroxide until pH 9.5 is reached. Add a few glass beads or boiling chips and boil off 300 ml. If desired, distil this fraction and determine ammoniacal nitrogen. Alternatively, if ammonia has been determined by the distillation method, use residue in distilling flask for organic nitrogen determination.

3. Digestion Cool and add carefully 50 ml of digestion reagent to distillation flask. Add a few glass beads and after mixing, heat under a hood or with suitable ejection equipment to remove acid fumes. Boil briskly until the volume is greatly reduced and copious white fumes are observed. Then continue digestion for additional 30 minutes. As digestion continues, coloured or turbid samples will turn clear or straw coloured. After digestion, let flask and contents cool, dilute to 300 ml with water and mix. Tilt flask and carefully add 50 ml of hydroxide thiosulphate to form an alkaline layer at flask bottom. Connect flask to steamed-out distillation apparatus and shake flask

to insure complete mixing. A black precipitate of mercuric sulphide will form and the pH should exceed 11.0.

4. Distillation Distil and collect 200 ml of distillate below surface of 50 ml absorbent solution. Use 50 ml indicating boric acid for titrimetric finish. Extend tip of condenser well below the level of absorbent solution and do not let temperature in condenser rise above 29°C. Lower collected distillate free of contact with delivery tube and continue during last 1 or 2 minutes to cleanse condenser.

6.8.4 Calculation

(A-B) X 280

Total kjeldahl nitrogen, mg/l = $\frac{(A-B)\ X\ 280}{V}$

Where,

V =volume in ml of sulphuric acid used for sample,

A=volume in ml of sulphuric acid used for blank, and

B=volume in ml of sample taken for test.

6.9 NITRATE NITROGEN

6.9.1 Available Methods

a) Cadmium reduction method,

b) Chromotropic acid method, and

c) Devarda's alloy reduction method

6.9.2 Cadmium Reduction Method

Nitrate is reduced to nitrite in presence of cadmium. The nitrite produced is determined by diazotizing with sulphanilamide and coupling with N-(1 naphthyl) ethylenediamine to form a highly coloured azo dye which is measured calorimetrically.

1) Apparatus Used

- Reduction column commercially available one or construct the column from a 100 ml

volumetric pipette by removing the top portion. The column can also be constructed by two pieces of tubing joined end to end join a 10 cm length of 3 cm internal diameter (ID) tubing to a 25 cm length of 3'5 cm ID tubing

- Spectrophotometer for use near 543 nm with a light path of 1gm or longer.

2) Reagent Preparation

1. Nitrate free water - The absorbance of a reagent blank prepared with this water should not exceed 0.01. Use for all solutions and dilution.

2. Copper-cadmium granules Wash 25 g of 40-60 mesh cadmium granules with 6 N hydrochloric acid and rinse with water. Swirl cadmium with 100 ml of 2 percent copper sulphate solution for 5 minutes or until blue colour partially fades. Decant and repeat with fresh copper sulphate until a brown colloidal precipitate develops times) to remove all precipitated copper. Wash copper-cadmium copiously with water (at least 10 times) to remove all precipitated copper.

3. Sulphanilamide reagent Dissolve 5 g of sulphanilamide in a mixture of 50 ml concentrated hydrochloric acid and 300 ml of water many months.

4. Al-(1-naphthyl) - ethylenediamine dihydrochloride (NED dihydrochloride) solution. 5. Dissolve 500 mg of NED &hydrochloride in 500 ml of water. Store in dark coloured bottle. Replace as soon as a brown colour develops.

6. Ammonium chloride EDTA solution - Dissolve 13 g .of ammonium chloride and 1.7 g of disodium ethylenediamine tetraacetate in 900 ml of water. Adjust pH to 8'5 with liquor ammonia and dilute to 1 litre. Dilute 300 ml of the above solution to 500 mi with water to get a dilute solution.

7. Hydrochloric acid-6 N.

8. Copper sulphate solution - 2 percent (m/v).

9. Stock nitrate solution - Dissolve 0.721 8 g of dry potassium nitrate in water and dilute to 1000 ml. Preserve with 2 ml of chloroform per litre (1ml 100 µg of nitrate nitrogen). Dilute 50 ml of stock nitrate solution to 500 ml with water to get standard solution 1.00 ml equal to 10.0 µg nitrate nitrogen.

10. Stock nitrite solution Dissolve 0.6072 gm of dried potassium nitrite in nitrite free water and make up to 1000 ml (1'00 ml 100 µg nitrite nitrogen). Preserve with 2 ml of chloroform and keep in a refrigerator. The solution is stable for 3 months. Dilute 50'0 ml of above stock nitrite solution to 500 ml with nitrite free water. (1.00 ml 10'0 µg of nitrite nitrogen).

3) Procedure

1. Preparation of reduction column Insert a glass wool plug into the bottom of reduction column and fill with water. Add sufficient copper-cadmium granules to produce a column 18.5 cm long. Maintain water level above Cu-Cd granules to prevent entrapment of air. Wash column with 200 ml dilute ammonium chloride EDTA solution. Activate column by passing through it, at 7 to 10 ml/minute, 100 ml of a solution comprising 25 ml of a 1.0 mg nitrogen (nitrate) per litre standard and 75 ml of ammonium chloride EDTA solution.

2. Treatment of sample - If turbidity or suspended solids are present, remove by filtering through a 0.45 mm pore diameter membrane or glass fibre filter. Adjust pH to between 7 and 9 as necessary. To 25.0 ml sample or a portion diluted to 25.0 ml, add75 ml of ammonium chloride EDTA solution and mix. Pour fixed sample into column and collect at the rate of 7 to 10 ml/minute. Discard first 25 ml. Collect the rest in original sample flask. There is no need to wash the column between samples but if columns are not to be reused for several hours or longer pour 50 ml dilute ammonium chloride - EDTA solution on to the top and let it pass through the system. Store Cu-Cd column in this solution and never allow it to dry.

3. As soon as possible and not more than 15 minutes after reduction, add 2.0 ml sulphanilamide reagent to 50 ml of sample. Let the reagent react for 2 to 8 minutes. Add 2 ml of NED dihydrochloric acid solution and mix immediately. Between 10 min and 2 h afterwards, measure absorbance at 540 nm against-a distilled water reagent blank. Using the standard nitrate nitrogen solution, prepare standards in the range of 0.05 to 1.0 mg of nitrate nitrogen per litre by diluting the following volumes of standards to 100 ml in volumetric flasks: 0.5, 1.0, 2.0, 5.0 and 10.0 ml. Carry out reduction of standards exactly as described for samples. Compare at least one nitrite standard to a reduced nitrate standard at the same concentration to verify reduction column efficiency. Reactivate copper cadmium granules when reduction efficiency falls below 75 percent.

4) Calculation

Obtain a standard curve by plotting absorbance of standards against nitrate nitrogen concentration. Compute sample concentration directly from standard curve. Report as milligrams of oxidized nitrogen per litre (sum of nitrate nitrogen plus nitrite nitrogen).

6.10 NITRITE NITROGEN

Nitrite is determined through formation of a reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulphanalic acid with N-(1 naphthyl)-ethylene diamine dihydr. Ochloride (NED dihydrochloride). The colour obeys Beers' law up to 180 pg/1 with 1 cm path length at 543 nm.

6.10.1 Apparatus Used

- Colorimeter or spectro-photometer that can be operated at 543nm.
- Nessler tubes or 100mL, capacity volumetric flask.

6.10.2 Reagent Preparation

1. Nitrite-free water - If the distilled water is not nitrite free, prepare as follows: Add to 1 litre of distilled water, a small crystal each of potassium permanganate and barium hydroxide or calcium hydroxide. Redistil in an all borosilicate glass bottle. Add 1 ml of concentrated sulphuric acid and 0.2 ml of manganese stilphate (36.48 g MnSO, H,O/100 ml) solution to each 1 litre of distilled water and make pink with 1 to3 ml of potassium permanganate solution (400 mg/l). Redistil in an all borosilicate glass bottle. Use this water in making all reagents and dilutions.

2. Sulphanilamide reagent Dissolve 5 g of the material in a mixture of 50 ml of concentrated hydrochloric acid and 300 ml of water. Dilute to 500 ml with water. The reagent is stable for several months.

3. NED dihydrochloride - Dissolve 500 mg of the material in 500 ml of water. Store in coloured bottle in dark. Replace monthly or when it turn dark brown in colour.

4. Hydrochloric acid-1:3.

5. Sodium oxalate 0.05 N. Dissolve 3.350 g of sodium oxalate (primary standard grade) in 1000 ml of water.

6. Ferrous ammonium solphate 0.05 N. Dissolve 19.607 g of ferrous ammonium sulphate in 20 ml of concentrated sulphuric acid and water and dilute to 1 litre. Standardize with standard dichromate.

7. Stocknitrite solution Dissolve 1.232 g of sodium nitrite in water and dilute to 1000 ml (1 ml 250 µg of N). Preserve with 1 ml of chloroform. Standardize using sodium oxalate and standard potsssium permanganate solution.

8. Interinediate nitrite solution Calculate the volume, G, of stock nitrite solution required for intermediate nitrite solution from G 12.5/A, where A is the stock solution in mg/l. Dilute the volume G to 250 ml with water (1.00 ml 50.0 µg N).

9. Standard nitrite solution Dilute 10.00 ml of intermediate nitrite solution to 1000 ml with water (1.00 ml = 0.500 µg N).

6.10.3 Procedure

1. If sample contains suspended solids, filter through a 0.45 mm pore diameter membrane filter.

2. To 50mL clear sample neutralized to pH 7 or to a portion diluted to 50ml, add 1ml sulfanilamide solution. Let reagent react for 2 to 8 min.

3. Add 1.0ml. NED dihydrochloride solution and mix immediately. Measure absorbance after 10 min but before 2 hrs at 543 nm.

4. Prepare blank in the same way substituting water for the sample.

6.11 PHOSPHATE

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

6.11.1 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 soluble orthophosphate.
- UV-Visible Spectro- Photometer.

6.11.2 Colorimetric Method

a. Vanadomelybdic acid method.

b. Stannous chloride method.

c. Asoorbia acid method.

1) Vanadomelybdic Acid Method

Different forms of phosphate are classified into orthophosphates, condensed phosphate(pyro, meta and polyphosphates) and organically bound phosphate. These forms of phosphates may occur in the soluble form or in the bodies of aquatic organism.

The chemistry involved in this method is essentially as follows:

Phosphate ion combines with Ammonium molybdate under acid condition to form a complex compound known as ammonium phosphomolybdate.

PO+1.2 (NH) MoO, +24 H (NH4)PO +1.2 MoO) +21 NH +12H_2O

At lower concentration of phosphate, a yellow colloidal solution is formed which is not discernible for phosphate concentration less than 30 mg/l. For that reason, in order to develop color vanadium is added and forms a vanadomolydophosphoric acid complex which yields a much more intense yellow color.

The molybdenum contained in ammonium phosphomolybdate is also readily reduced to produce a blue color solution that is proportional to the amount of phosphate present.

2) Apparatus Used:

- Volumetric flasks
- Reagent bottles
- Conical flasks
- Beakers
- Pipettes

- Spectrophotometer to measure at 720nm.

3) Reagent Preparation

- Phenolphthalein indicator solution.
- Concentrated HCL.
- Vandate-molybdate reagent - Add 12.5 gm Ammonium Molybdate [$(NH_4)6Mo_7 O_{24,} H_2O$] to150 ml D/D water. Add 0.625 gm Ammonium Meta-Vandate (NH_4Vo_3) to 150 ml D/D water. Now boil it for 20 min. and then cool it at room temperature. Then mix 165 ml HCl (conc.) with it.

4) Procedure:

Total Phosphate-Take 10 ml Sample then mix 1 ml H_2SO_4 (Conc.) and 5 ml HNO_3 (Conc.) with it. Then boil the mixture and reduce the volume of the sample to 1 ml. Then cool it at room temperature. Now add 20 ml D/D water to it. Then add I drop Phenonthraeline indicator. After that add 1 N NaOH till the color of the sample changes to pink. Then add 1 tea spoon Charcoal. Then the color of the solution changes to white. Now filter it and collect the filtrate. Mix D/D water with the filtrate to make the solution 100 ml. Then pour the solution into a clean and dry Spectrophotometric cell and measure absorbance at 720 nm. Ortho Phosphate-Take 5 ml Sample, now mix 5 drops of Vandate-molybdate reagent, leave the mixture to stand for 5 minutes. Then pour the solution into a clean and dry Spectrophotometric cell and measure absorbance at 720 nm.

CHAPTER 7

7 RESULT AND DISCUSSIONS

During the experimental period which started in the month of April 2024, samples were collected from CW system and analyzed for each of the various physical, chemical and microbiological parameters. Table presents the wastewater sample from inlet and outlet from chamber of each monitored parameter.

7.1 Tabulated Results Week-1

Sampling date → 23/04/2024 Flow rate →3 lit/day Condition→ Without Plant

Table: 5. Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	**Raw Water**	**Final Output**	**Removal Efficiency** (%)
pH	7.23	7.02	2.90
Turbidity (NTU)	4.88	3.2	34.43
TSS (mg/L)	80	24	70.00
Nitrate (mg/L)	3.5	1.2	65.71
Nitrite (mg/L)	0.061	0.047	22.95
Phosphate (mg/L)	2.25	0.67	70.22
DO (mg/L)	7	5.1	27.14
BOD (mg/L)	102	28	72.55
COD (mg/L)	214.2	58.8	72.53
TC (MPN/100 ml)	1700	700	58.82
FC (MPN/100 ml)	1050	500	52.38
TKN	18.7	5.6	70.05

7.2 Tabulated Results Week-2

Sampling date→03/05/2024 Flow rate→3 lit/day Condition→Without Plant

Table: 6. Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	**Raw Water**	**Final Output**	**Removal Efficiency** (%)
pH	7.24	6.86	5.25
Turbidity (NTU)	5.32	2.74	48.50
TSS (mg/L)	74	26	64.86
Nitrate (mg/L)	3.4	4.1	-
Nitrite (mg/L)	0.056	0.045	19.64
Phosphate (mg/L)	1.26	1.6	-
DO (mg/L)	6.6	5.1	22.73
BOD (mg/L)	85	18	78.82
COD (mg/L)	171.6	39.6	76.92
TC (MPN/100 ml)	1035	420	59.42
FC (MPN/100 ml)	700	550	21.43
TKN	20.3	3.9	80.79

7.3 Tabulated Results Week-3

Sampling date →13/05/2024 Flow rate → 3 lit/day Condition→Without Plant

Table :7. Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	Raw Water	Final Output	Removal Efficiency (%)
pH	7.52	6.56	12.77
Turbidity (NTU)	5.2	3.12	40.00
TSS (mg/L)	68	16	76.47
Nitrate (mg/L)	3.5	2.2	37.14
Nitrite (mg/L)	0.041	0.032	21.95
Phosphate (mg/L)	1.23	1.39	-
DO (mg/L)	6.71	5.6	16.54
BOD (mg/L)	59	15	74.58
COD (mg/L)	105.8	34.5	67.39
TC (MPN/100 ml)	900	350	61.11
FC (MPN/100 ml)	500	140	72.00
TKN	16.3	3.6	77.91

7.4 Tabulated Results Week-4

Sampling Date → 22/05/2024 Flow rate→ 6 lit/day Condition→With Plant

Table :8.Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	**Raw Water**	**Final Output**	**Removal Efficiency** (%)
pH	7.32	6.67	8.88
Turbidity (NTU)	6.31	3.23	48.81
TSS (mg/L)	86	24	72.09
Nitrate (mg/L)	3.3	2.6	21.21
Nitrite (mg/L)	0.023	0.021	8.70
Phosphate (mg/L)	1.13	0.01	99.12
DO (mg/L)	6.85	5.54	19.12
BOD (mg/L)	110.4	23	79.17
COD (mg/L)	231.84	40.3	82.62
TC (MPN/100 ml)	290	140	51.72
FC (MPN/100 ml)	170	90	47.06
TKN	22.8	5.7	75.00

7.5 Tabulated Results Week-5

Sampling date → 01/06/2024 Flow rate→ 6 lit/day Condition →With Plant

Table :9. Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	**Raw Water**	**Final Output**	**Removal Efficiency** (%)
pH	7.27	6.51	10.45
Turbidity (NTU)	6.644	3.03	54.39
TSS (mg/L)	84	28	66.67
Nitrate (mg/L)	5.2	4.3	17.31
Nitrite (mg/L)	0.102	0.09	11.76
Phosphate (mg/L)	1.25	0.41	67.20
DO (mg/L)	6.04	5.521	8.59
BOD (mg/L)	87	21.8	74.94
COD (mg/L)	191.4	37.96	80.17
TC (MPN/100 ml)	240	180	25.00
FC (MPN/100 ml)	140	70	50.00
TKN	23.2	4.4	81.03

7.6 Tabulated Results Week-6

Sampling date→ 11/06/2024 Flow rate → 6 lit/day Condition-With Plant

Table :10.Concentration of Physico-chemical & biological parameters and % removal in CW

Parameters	Raw Water	Final Output	Removal Efficiency (%)
pH	7.35	6.68	9.12
Turbidity (NTU)	6.926	2.95	57.41
TSS (mg/L)	72	26	63.89
Nitrate (mg/L)	2.7	2.4	11.11
Nitrite (mg/L)	0.098	0.091	7.14
Phosphate (mg/L)	2.59	4.23	-
DO (mg/L)	5.79	5.46	5.70
BOD (mg/L)	70	29	58.57
COD (mg/L)	161	43.6	72.92
TC (MPN/100 ml)	170	80	52.94
FC (MPN/100 ml)	80	40	50.00
TKN	21.5	4.3	80.00

7.7 GRAPHICAL REPRESENTATION-

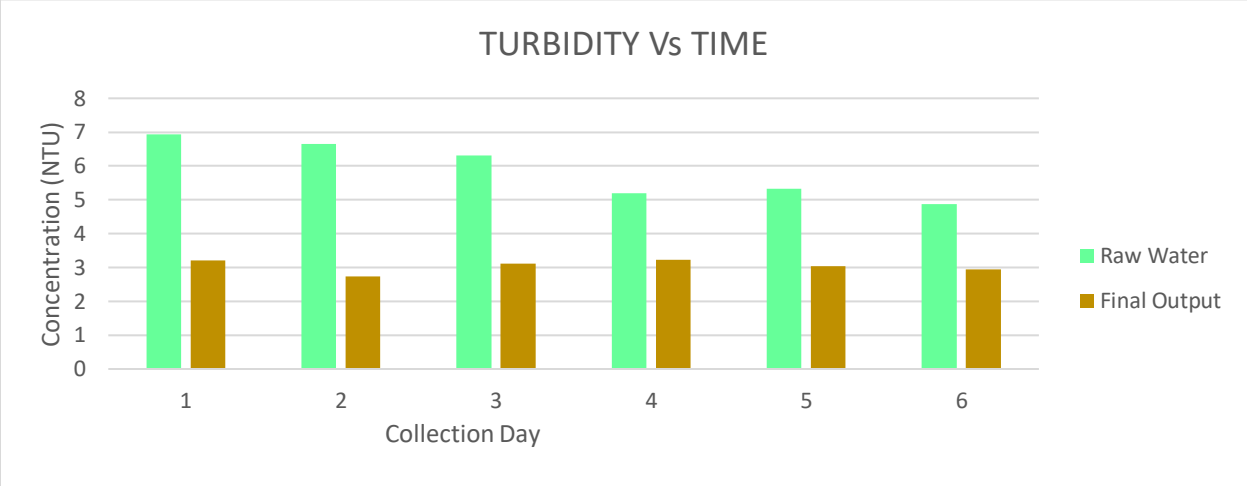


Fig.7.1. Extent of Turbidity removal in CW

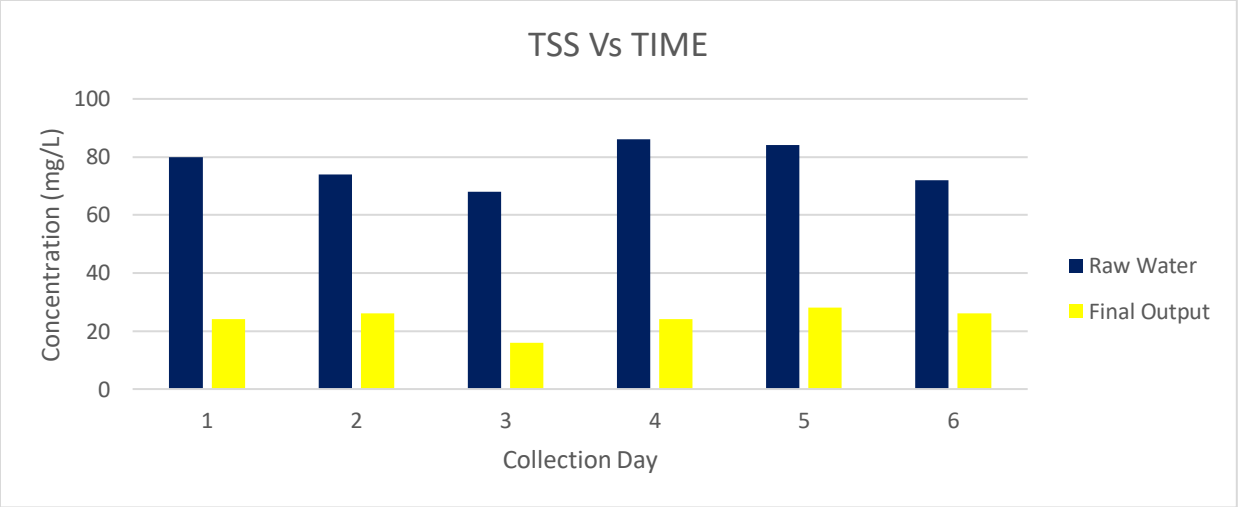


Fig.7.2.Extent of TSS removal in CW

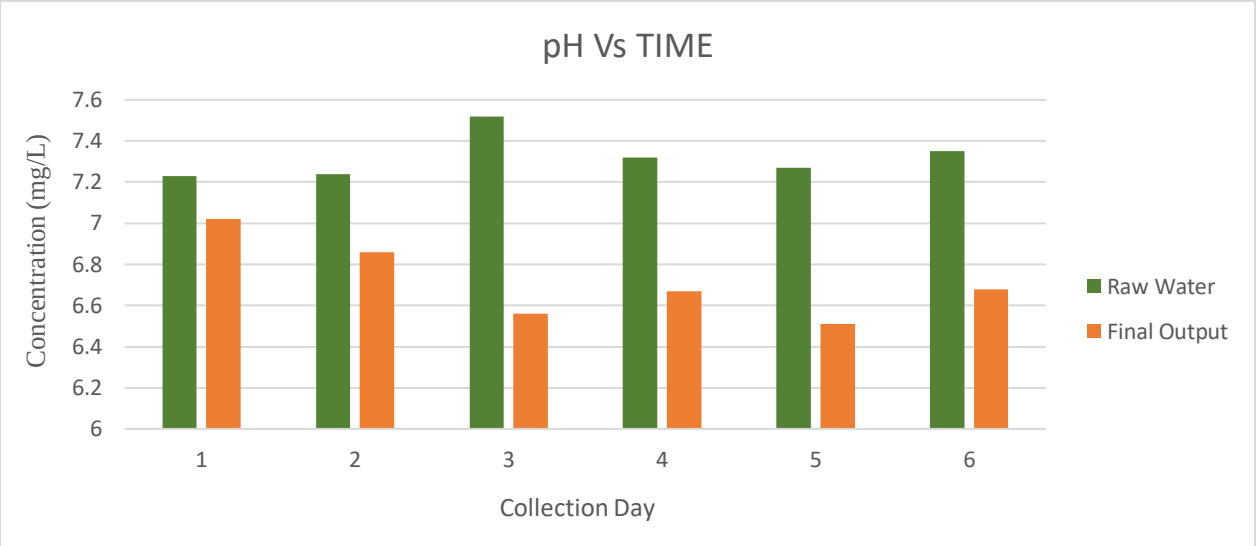


Fig.7.3.Extent of pH removal in CW

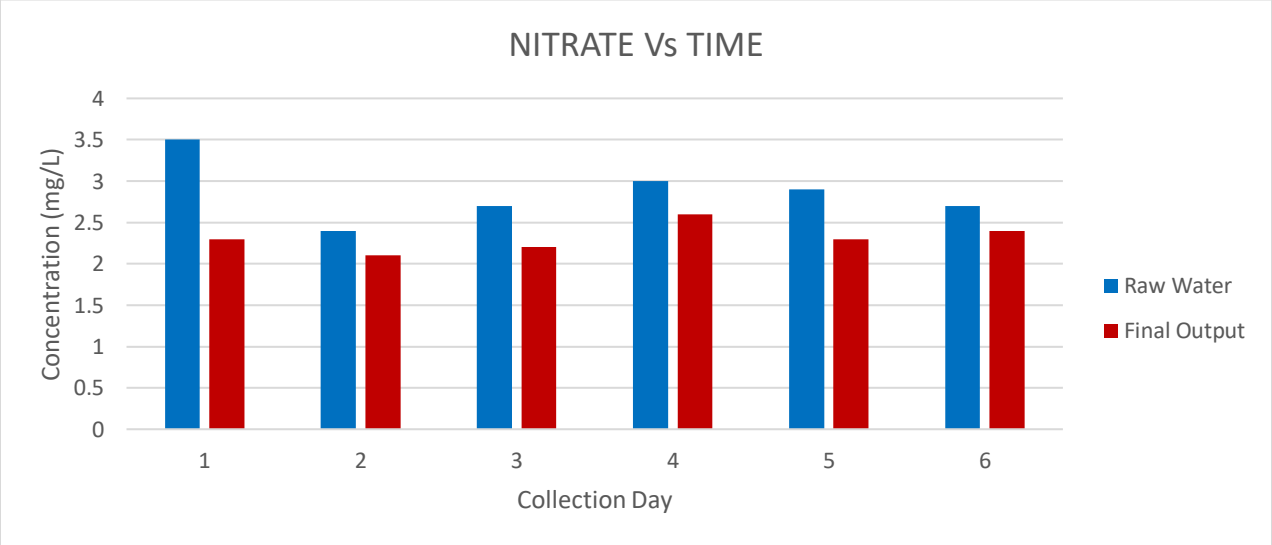


Fig.7.4. Extent of Nitrate removal in CW

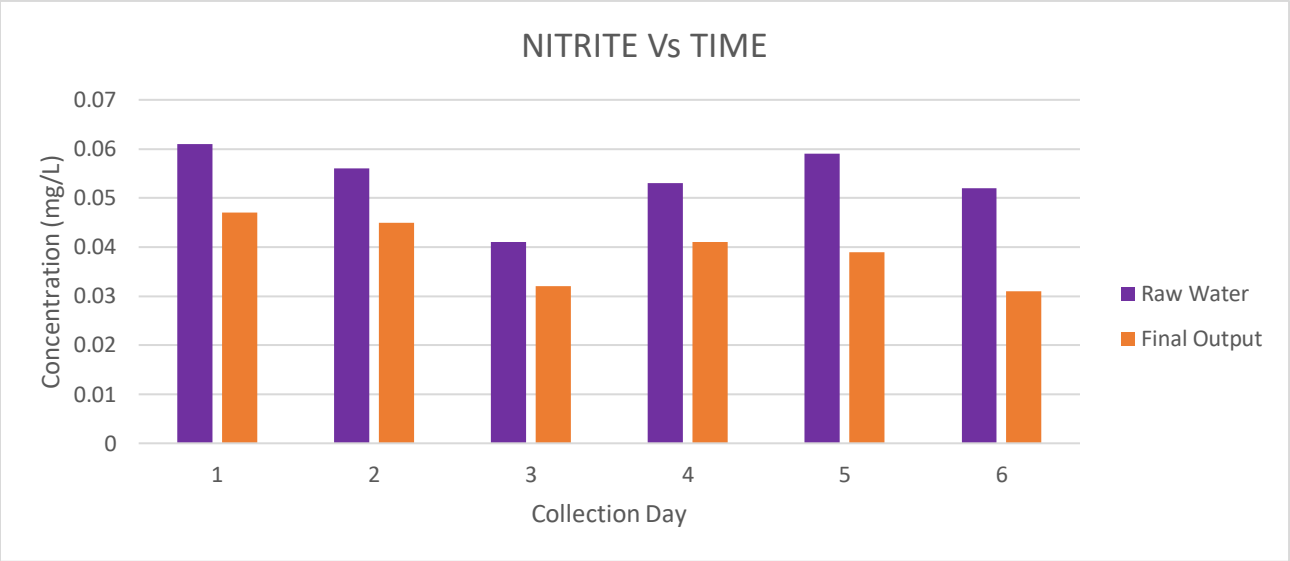


Fig.7.5. Extent of Nitrite removal in CW

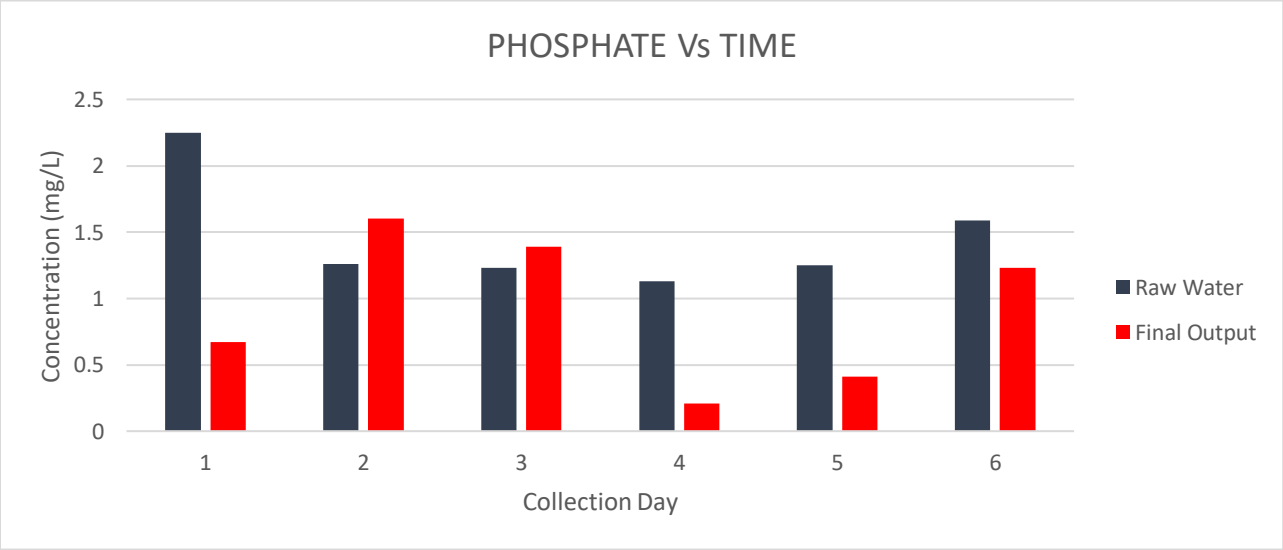


Fig.7.6. Extent of Phosphate removal in CW

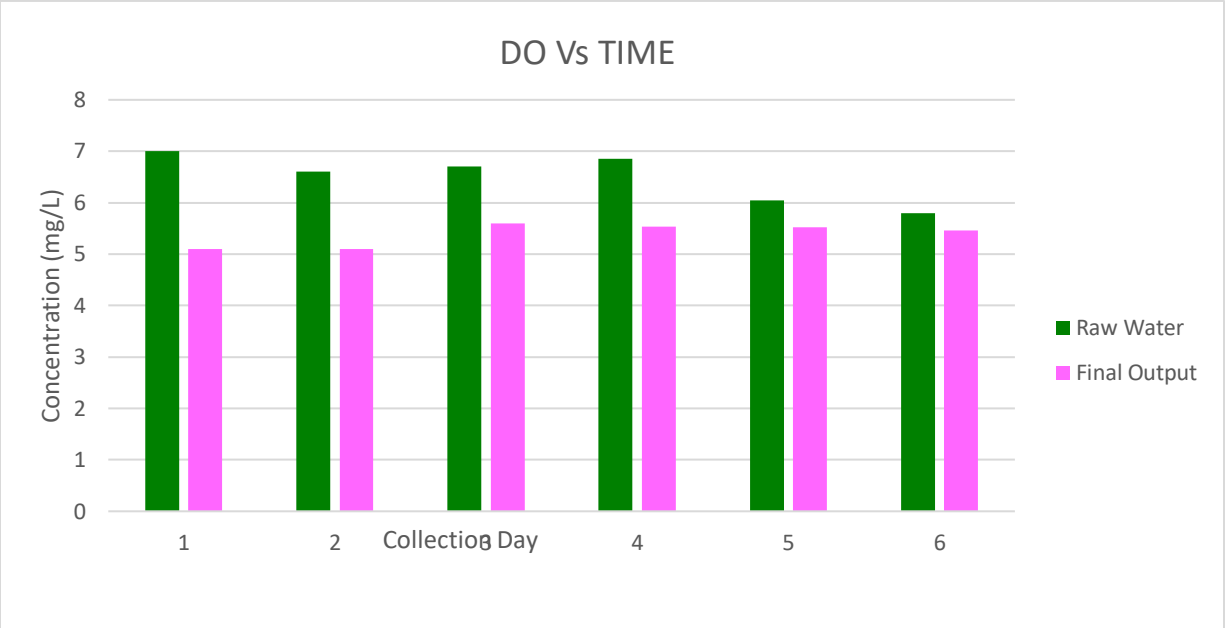


Fig.7.7. Extent of DO removal in CW

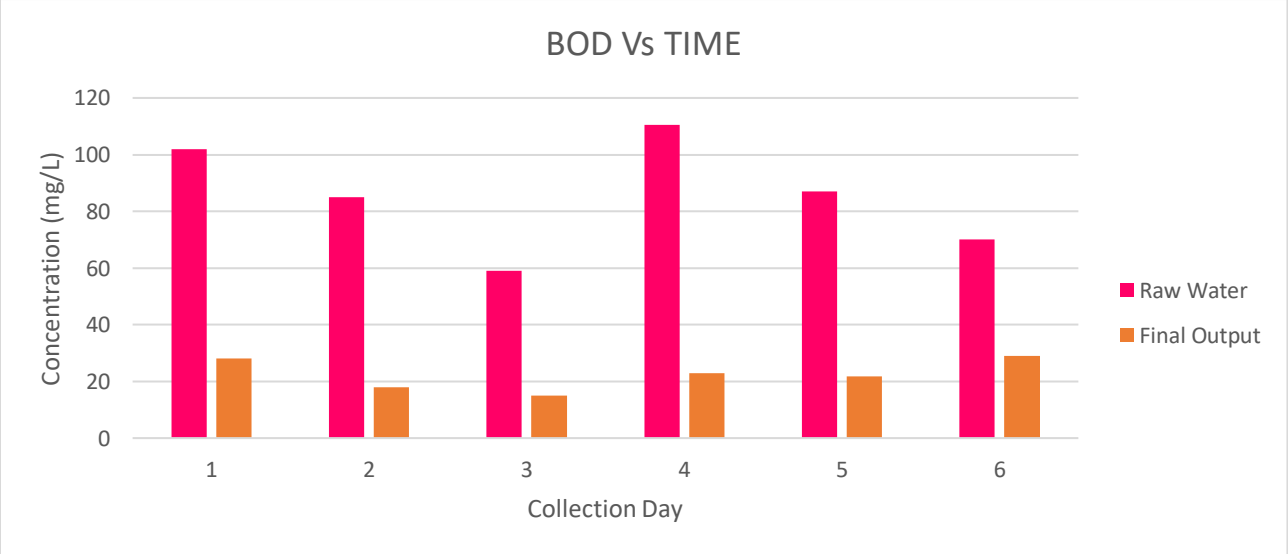


Fig.7.8. Extent of BOD removal in CW

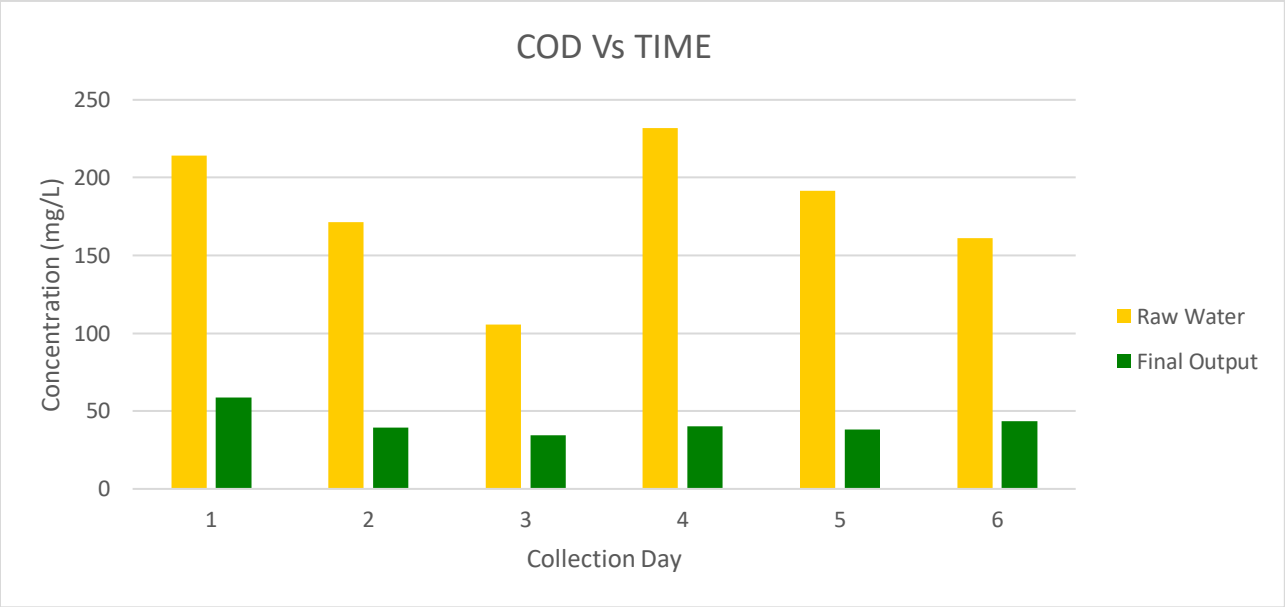


Fig.7.9. Extent of COD removal in CW

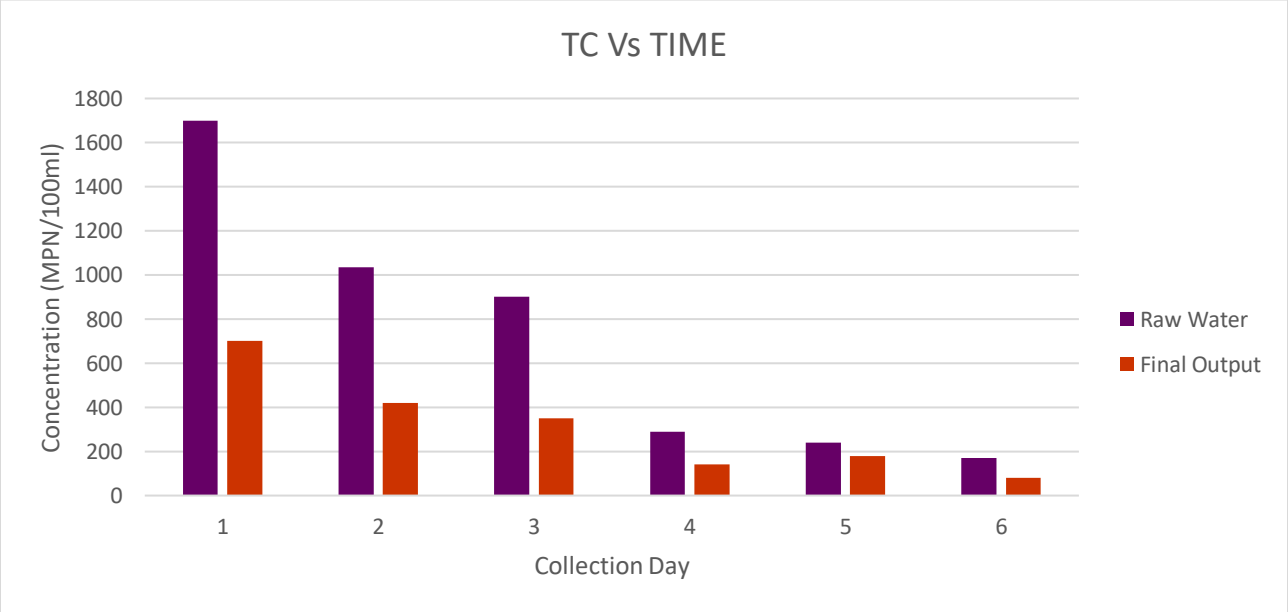


Fig.7.10. Extent of TC removal in CW

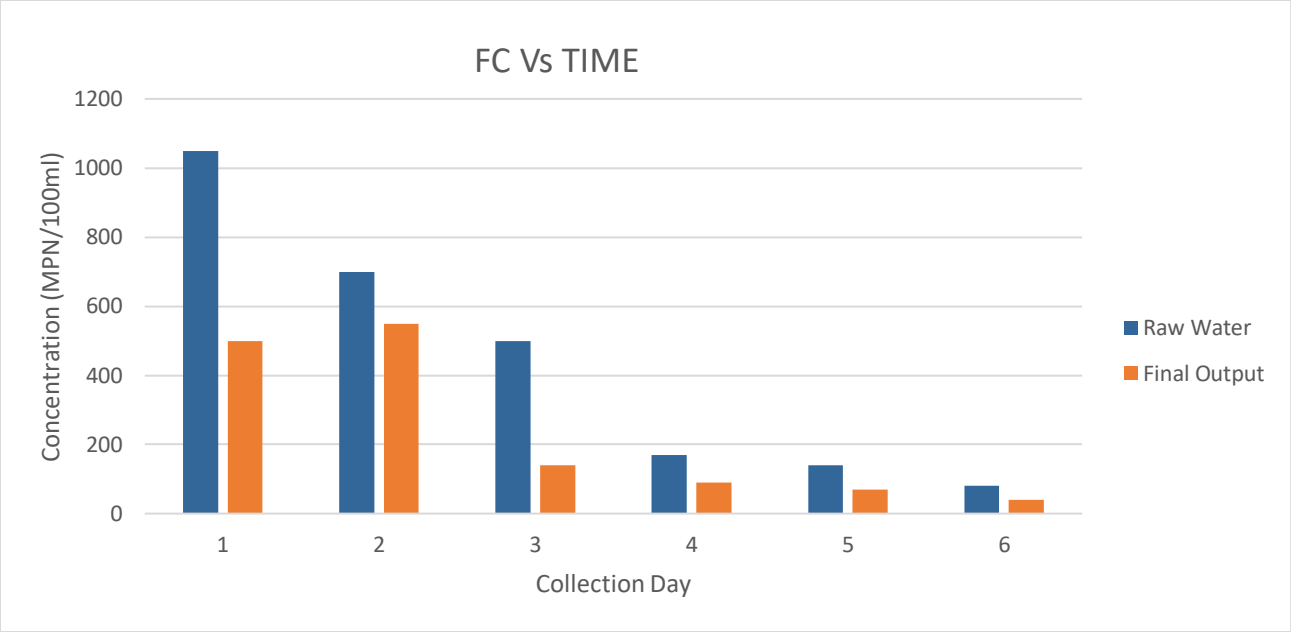


Fig.7.11. Extent of FC removal in CW

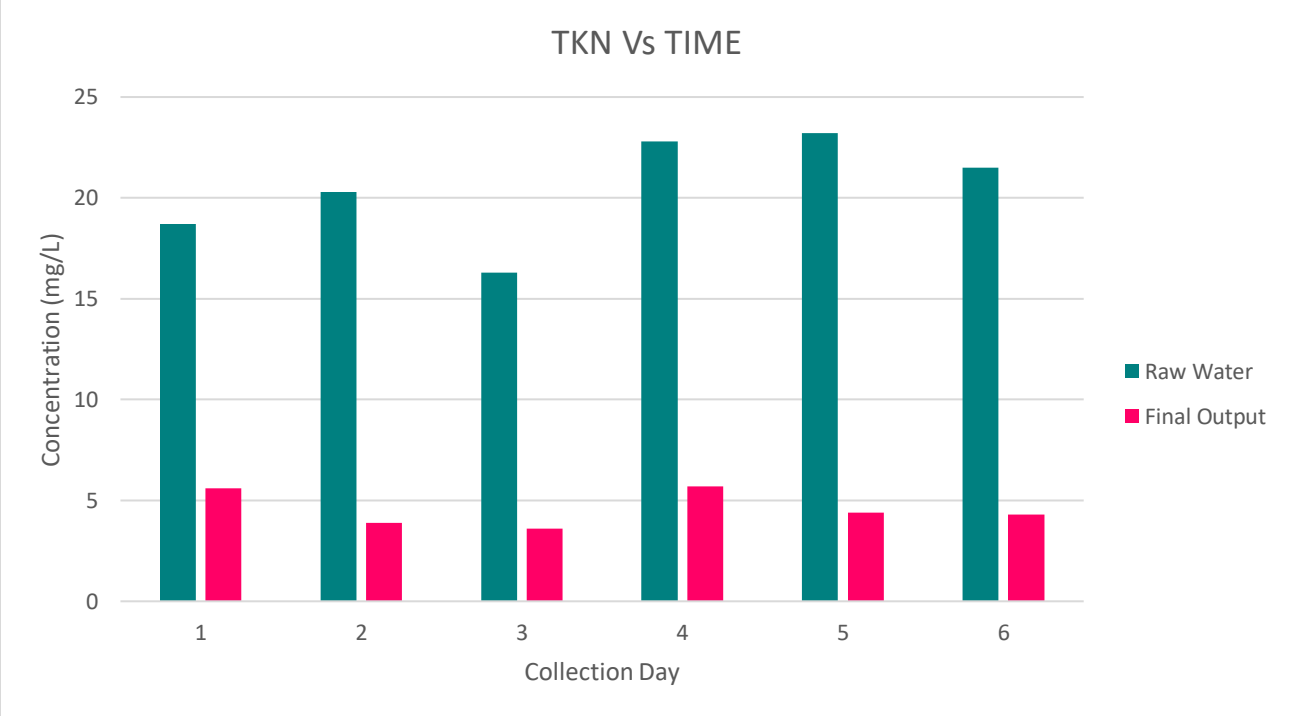


Fig.7.12.Extent of TKN removal in CW

7.8 Growth Rate of plant

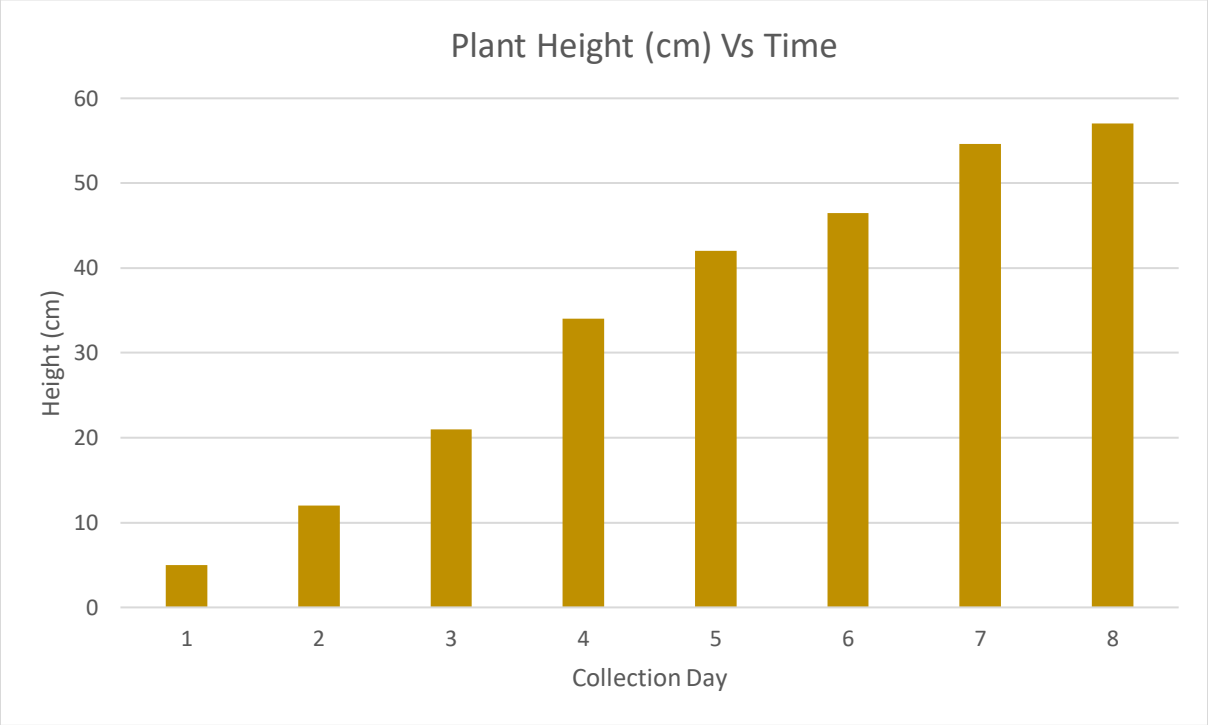


Fig.7.13. Growth rate of plant

7.9 Discussion

The results from the bench-scale model of the horizontal subsurface constructed wetland, utilizing ***Canna indica,*** demonstrate significant effectiveness in treating wastewater. The removal efficiencies observed for various parameters indicate that this system is capable of addressing multiple aspects of water pollution.

- Turbidity (57.41%) and Total Suspended Solids (76.47%): The substantial reduction in turbidity and TSS suggests that the horizontal subsurface constructed wetland is effective in removing particulate matter. The gravel or soil medium, along with the plant roots, plays a crucial role in trapping suspended particles and clarifying the water.

- Nitrate (65.71%) and Nitrite (22.95%): The removal of nitrate is notably high, reflecting the wetland's capacity for nitrification and denitrification processes facilitated by the microbial communities in the substrate and the plant roots. However, the lower removal efficiency for nitrite may indicate incomplete nitrite oxidation or possible nitrite accumulation, which could be addressed through system optimization.
- Phosphate (99.1%): The exceptional reduction in phosphate levels demonstrates the system's strong ability to remove phosphorus. This high efficiency is likely due to the adsorption of phosphates onto the substrate and uptake by the plant roots. Effective phosphorus removal is crucial for preventing eutrophication in receiving water bodies.
- Total Kjeldahl Nitrogen (81.03%): The high removal rate of TKN reflects effective nitrogen removal, achieved through the combined processes of microbial degradation and plant uptake. This result is consistent with the high nitrate removal, indicating robust nitrogen cycling within the system.
- Dissolved Oxygen (27.14%): The increase in DO suggests improved oxygenation of the water as it flows through the wetland, likely due to aeration provided by plant root systems and microbial activity. Enhanced DO levels are beneficial for maintaining aerobic conditions that support effective biological treatment processes.
- Biochemical Oxygen Demand (79.12%) and Chemical Oxygen Demand (82.62%): The significant reductions in BOD and COD highlight the wetland's efficiency in degrading organic matter. This is attributed to the combined action of microbial communities and plant uptake, which reduce the organic load in the wastewater.
- Total Coliform (61.11%) and Fecal Coliform (72%): The reduction in coliform bacteria indicates the wetland's potential for improving microbiological water quality. However, while these reductions are substantial, the system may not achieve complete disinfection, suggesting the need for additional treatment steps or post-treatment disinfection in applications requiring higher microbiological standards.

Overall, the performance of the horizontal subsurface constructed wetland model with Canna indica demonstrates its potential as an effective and sustainable wastewater treatment solution. The results indicate that the system can achieve substantial improvements in water quality by addressing key pollutants. Future research should

focus on optimizing design parameters, exploring the long-term performance, and assessing the economic feasibility of scaling up these systems for broader applications. Additionally, the evaluation of other plant species and the integration of complementary treatment methods could further enhance the efficiency and applicability of constructed wetlands.

CHAPTER 8

8 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

The bench-scale constructed wetland model, utilizing a rectangular glass tank with dimensions of 30 cm × 18 cm × 18 cm and planted with ***Canna indica***, demonstrated promising results in the treatment of wastewater collected from Jadavpur University. The experiment, which varied flow rates and retention times, provided valuable insights into the efficiency of the constructed wetland in removing various contaminants. The treatment process achieved notable reductions across multiple water quality parameters:

Turbidity (NTU)- 57.41%, Total Suspended Solids (TSS, mg/L)- 76.47%, Nitrate (mg/L)- 65.71%, Nitrite (mg/L)- 22.95%, Phosphate (mg/L)- 99.1%, Total Kjeldahl Nitrogen (TKN, mg/L)- 81.03%, Dissolved Oxygen (DO, mg/L)- 27.14%, Biochemical Oxygen Demand (BOD, mg/L)- 79.12%, Chemical Oxygen Demand (COD, mg/L)- 82.62%, Total Coliform (MPN/100 ml)- 61.11%, Fecal Coliform (MPN/100 ml)- 72%. These results underscore the effectiveness of the constructed wetland in improving wastewater quality by substantially reducing turbidity, suspended solids, nitrogenous compounds, phosphates, and organic contaminants. The high removal efficiencies achieved in parameters such as phosphate and COD suggest that *Canna indica* is an effective plant species for enhancing the performance of constructed wetlands. This bench-scale model provides a strong foundation for scaling up and further research, emphasizing the potential of constructed wetlands as a sustainable and efficient technology for wastewater treatment. Future studies should focus on optimizing operational parameters, exploring different plant species, and evaluating long-term performance to maximize the benefits of this natural treatment technology.

8.2 Limitations of the Present Study

Despite the promising results from the bench-scale model of the horizontal subsurface constructed wetland using *Canna indica*, several limitations must be acknowledged:

- Scale and Generalizability: The experiment was conducted on a small bench-scale model, which may not fully represent the behavior and performance of a full-scale constructed wetland system. Scaling up to larger systems may present challenges such as differing hydraulic and biological dynamics, which could affect overall efficiency.
- Retention Time Variability: The removal efficiencies observed are influenced by specific retention times in the bench-scale model. Variability in retention time can impact performance, and optimal retention times for different pollutants may not be fully captured in a small-scale setup.
- Substrate and Plant Limitations: The experiment used a fixed substrate and a single plant species (Canna indica). The effectiveness of other substrates and plant species, as well as their interactions, might differ. The performance of the system could vary with different combinations of plants and substrates.
- Influent Quality Variability: The wastewater collected from Jadavpur University campus may not represent the full spectrum of wastewater qualities encountered in other settings. Variability in influent composition can affect treatment performance and the generalizability of the results.
- Microbial Dynamics: The microbial communities responsible for the treatment processes in the constructed wetland may behave differently at a larger scale or with different operational conditions. The bench-scale model may not fully capture the complexities of microbial interactions and their impact on treatment efficiency.
- Operational Factors: Factors such as flow rate adjustments, maintenance, and the presence of operational anomalies were not fully addressed in the study. Real-world systems may face challenges related to operational management, which can influence treatment performance.

- Long-term Performance: The bench-scale study provides insights into short-term performance but does not account for long-term operational issues such as substrate clogging, plant health, or system stability over extended periods.
- Disinfection Efficiency: While reductions in total and fecal coliforms were significant, the constructed wetland may not achieve complete disinfection, which could be a limitation for applications requiring stringent microbiological standards.

Addressing these limitations in future studies through scaled-up trials, diverse influent characteristics, varied plant species, and long-term evaluations will be crucial for fully understanding and optimizing the performance of constructed wetlands for wastewater treatment.

8.3 Future Directions

The future direction of constructed wetlands for wastewater treatment is likely to involve several key trends and developments:

i. Technological Innovation: Advances in materials science, engineering, and biotechnology are expected to lead to the development of new and improved design techniques, materials, and treatment processes for constructed wetlands. This includes the use of innovative substrates, plant species selection, and bioaugmentation techniques to enhance treatment efficiency, resilience, and scalability.

ii. Integration with Green Infrastructure: Constructed wetlands are increasingly being recognized as valuable components of green infrastructure systems that provide multiple benefits beyond wastewater treatment, such as flood control, habitat restoration, and urban greening. Future developments may focus on integrating constructed wetlands with other green infrastructure elements, such as rain gardens, bioswales, and permeable pavement, to create multifunctional and resilient urban landscapes.

iii. Smart Monitoring and Management: The adoption of sensor technologies, remote monitoring systems, and data analytics tools is expected to enable more efficient and proactive management of constructed wetland systems. Real-time monitoring of water quality, hydraulic conditions, and vegetation health can help optimize performance, detect issues early, and inform adaptive management strategies for improved treatment outcomes.

iv. Climate Resilience: Climate change impacts such as increased rainfall variability, droughts, and rising temperatures are expected to influence the design and management of constructed wetlands. Future developments may focus on enhancing the resilience of wetland systems to climate-related stresses through measures such as adaptive management practices, vegetation selection for drought tolerance, and engineered features for flood control.

v. Resource Recovery: There is growing interest in exploring the potential for resource recovery from wastewater within constructed wetland systems. Future developments may include the integration of technologies for nutrient recovery, energy generation, and water reuse into wetland design and operation, thereby enhancing sustainability and circularity of the treatment process.

vi. Community Engagement and Education: Increasing emphasis on community engagement, public participation, and environmental education is expected to play a significant role in the future development and acceptance of constructed wetlands for wastewater treatment. Outreach efforts may focus on raising awareness about the benefits of wetland-based treatment, promoting citizen science initiatives, and fostering partnerships with local communities and stakeholders.

vii. Policy Support and Regulation: Policy frameworks and regulatory standards governing wastewater treatment are likely to evolve to promote the adoption of sustainable and nature-based solutions such as constructed wetlands. Future developments may include incentives for green infrastructure investment, integration of ecosystem services valuation into decision-making processes, and updated guidelines for wetland design, operation, and monitoring.

Overall, the future of constructed wetlands for wastewater treatment is characterized by a shift towards more innovative, integrated, and resilient approaches that leverage the natural treatment capacity of wetland ecosystems to address emerging challenges and promote sustainable water management practices. Continued research, collaboration, and knowledge-sharing will be essential to realize the full potential of constructed wetlands as cost-effective, environmentally friendly, and socially beneficial solutions for wastewater treatment in the years to come (Chowdhury et al. 2021).

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APPENDIX-A: LIST OF FIGURES

Figure No.	Contents	Page No.
2.1	Flow Diagram Of Sewage Treatment Process at AMU Plant	26
2.2	Flow Diagram Of Sewage Treatment Process at KALYANI Plant	27
2.3	Flow Diagram Of Sewage Treatment Process at IGNTU Plant	27
3.1	Flow diagram for a typical large scale Treatment Plant	28
3.2	Trickling Filter	33
3.3	Facultative Pond	35
3.4	Oxidation Pond	36
3.5	Constructed Wetland	37
4.1	Classification of Constructed Wetlands	38
4.2	Free Surface Flow Constructed Wetland	39
4.3	Horizontal and Vertical Subsurface Flow	41
4.4	Contaminant Removal Mechanism in Constructed Wetland	49
5.1	Map of Study Area	53
5.2	Flow Diagram of Treatment Process	54
5.3	Model of Horizontal Constructed Wetland	55
7.1	Extent of TURBIDITY removal in CW	90
7.2	Extent of TSS removal in CW	90
7.3	Extent of PH removal in CW	91
7.4	Extent of NITRATE removal in CW	91
7.5	Extent of NITRITE removal in CW	92
7.6	Extent of PHOSPHATE removal in CW	92
7.7	Extent of DO removal in CW	93
7.8	Extent of BOD removal in CW	93
7.9	Extent of COD removal in CW	94
7.10	Extent of TC removal in CW	94
7.11	Extent of FC removal in CW	95
7.12	Extent of TKN removal in CW	95
7.13	Growth Rate of Plant	96

APPENDIX-B:LIST OF TABLES

Table No.	Contents	Page no.
1	Status of Municipal Wastewater Generation and Treatment Capacity of Metropolitan Cities in India: (as per CPCB).	3
2	Status of Municipal Wastewater Generation and Treatment Capacity of Class-I Cities in India: (as per CPCB).	6
3	Status of Municipal Wastewater Generation and Treatment Capacity of Class-II Cities in India: (as per CPCB)	7
4	Future Scenario of sewage Generation in India.	9
5	Limit of Total Kjeldahl Nitrogen (TKN)	76
6	Concentration of Physico-chemical & biological parameters and % removal in CW	84
7	Concentration of Physico-chemical & biological parameters and % removal in CW	85
8	Concentration of Physico-chemical & biological parameters and % removal in CW	86
9	Concentration of Physico-chemical & biological parameters and % removal in CW	87
10	Concentration of Physico-chemical & biological parameters and % removal in CW	88
11	Concentration of Physico-chemical & biological parameters and % removal in CW	89

APPENDIX-C: LIST OF ABBREVIATIONS

Sl. No.	Abbreviation	Full Form
1	STP	Sewage Treatment Plant
2	WSP	Waste Stabilization Pond
3	AP	Anaerobic Pond
4	FP	Facultative Pond
5	MP	Maturation Pond
6	MLD	Millions Of Litres Per Day
7	CPCB	Central Pollution Control Board
8	ASP	Activated Sludge Process
9	TF	Trickling Filter
10	AL	Aerated Lagoon
11	OP	Oxidation Pond
12	PHED	Public Health Engineering Department
13	AT	Aeration Tank
14	CW	Constructed Wetland
15	SRT	Solid Retention Time
16	HRT	Hydraulic Retention Time
17	MLSS	Mixed Liquor Suspended Solids
18	MLVSS	Mixed Liquor Volatile Suspended Solids
19	TDS	Total Dissolved Solids
20	TSS	Total Suspended Solids
21	DO	Dissolved Oxygen
22	RBC	Rotating Biological Contractors
23	BOD	Biochemical Oxygen Demand
24	COD	Chemical Oxygen Demand
25	TC	Total Coliform
26	FC	Fecal Coliform
27	WHO	World Health Organizations
28	CPHEEO	Central Public Health And Environmental Engineering Organization
29	PST	Primary Sedimentation Tank
30	SST	Secondary Sedimentation Tank