DESIGN AND EVALUATION OF CONSTRUCTED WETLAND SYSTEM FOR DOMESTIC WASTEWATER TREATMENT

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

By

Jaspreet Singh

Registration Number: 41800306

Supervised By

Dr. Janaki Ballav Swain (22747)

Civil Engineering (Assistant Professor)

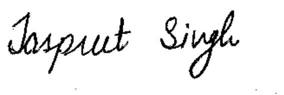
Lovely Professional University

LOVELY PROFESSIONAL UNIVERSITY, PUNJAB

2023

CANDIDATE’S DECLARATION

I, hereby declared that the presented work in the thesis entitled **Design and evaluation of constructed wetland system for domestic wastewater treatment**” in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision **Dr. Janaki Ballav Swain** working as **Assistant Professor**, in the School of **Civil Engineering** of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



(Signature of Scholar)

Name of the scholar: Jaspreet Singh

Registration No.: 41800306

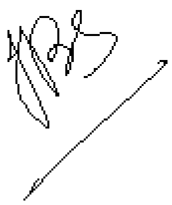
Department/school: Civil Engineering

Lovely Professional University,

Punjab, India

CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled **"Design and evaluation of constructed wetland system for domestic wastewater treatment" s**ubmitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the School of Civil Engineering, is a research work carried out by **Jaspreet Singh, 41800306**, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



(Signature of Supervisor)

Name of supervisor: Dr. Janaki Ballav Swain

Designation: Assistant Professor

Department/school: Civil Engineering

University: Lovely Professional University

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At the very onset, I surrender myself before the Almighty Lord for blessing me with the best of what I could have had. Be it this thesis, the personal associated with it or the outcome of this research pursuit, all of it is HIS GRACE, MERCY and BLESSINGS. He has made this possible, and I thank to Almighty Lord with all humility and surrender.

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This thesis is dedicated to my loving and caring son, ***Dakshpreet Singh***.

(Jaspreet Singh)

Abstract

Due to fast population increase, water demand is also rising, leading to excessive demand. Untreated sewage water contaminates groundwater, causing many diseases that affect human health and surroundings. Pollution is caused by industrial activity, mining, oil extraction in the sea, traffic, pesticides used in farming, thermal power plant waste, poor drainage, and gut waste through the anus. Physical, chemical, and biological techniques are utilized to naturally filter wastewater. Wastewater passes through sediments, sand beds, root zones, plant roots, and biomass zones, activating degradation and disposal. This allows oxidation and aerobic breakdown. Organic and inorganic materials, nutrients, pathogens, and total solids must be removed from residential wastewater. Constructed Wetlands enhances organic-rich water quality and can be used in emergency situations viz. flooding, severe rain, and recreation. Constructed wetlands could be a stand-alone waste water solution. In the present study, the properties of domestic raw water sample collected from conventional wastewater treatment unit and constructed wetlands were investigated. These samples were taken from Sewage treatment plant town "Bambianwali, Jalandhar. The present research was carried out on waste water samples collected both before and after the onset of the monsoon to deal with organic and inorganic materials, nutrients, pathogens and total solids. Sewage treatment effectiveness was evaluated using various parameters including pH, temperature, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). To deal with the removal of pathogens and solid waste, Constructed Wetlands (CW) approach was used which is a combination of Biochemical and Geochemical processes. The advantage of the CW over the conventional sewage treatment was its effectiveness even at the cold temperature as it depends on biologically active system i.e., microbial and plantation. The domestic waste water variables were further investigated for CW samples taken from Neela Hauz Lake, South Delhi. The sample variables from constructed wetland and conventional wastewater treatment unit were compared and after complete investigation it was found that both methods present the almost similar average efficiency in case of all variables under study, but the cost analysis for CW was found to be 1.82 Rs/litre whereas for STP it was 10 Rs/litre approximately. Considering all the factors, the cost efficiency of CW, the ease of processing and its effectiveness even at the cold temperature makes the CW the better and efficient method for the wastewater treatment.

Key words: Sewage Treatment Plant, Constructed Wetland, pH, TSS, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Environment

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Dedicated to

Almighty God and my family members…

Chapter 1: Introduction

1.1 General

The water is the most essential thing for the sustenance of the life on the earth. With the continuous increase in population and equivalent urban development, the demand for fresh water is increasing. This increase in demand results in increased wastewater generation. With this increase in wastewater generation and negligence in its management is the cause of contamination of fresh water resources. Moreover, the growing population is contributing in increasing the environmental concerns particularly in India (Takpere 2015). In earlier days, the urban areas get affected due to dense population of the country, but now the effect of the pollution is visible on rural areas as well. Due to the fact that water is one of the most vital things on earth, it serves a wide variety of functions, including washing, bathing, drinking, and, most significantly, working in agriculture and manufacturing (Kaur and Kamboj 2019). Hence, should not be wasted and proper utilization need to be ensured.

Due to the growing population, people around the world are facing the problem of clean drinking water, and as a consequence, the fresh water requirement is also increasing day by day (Kumar et al. 2020). The domestic or grey water is the wastewater which does not contains fecal contamination but generated in the household. Domestic or grey water generated from households and commercial sites is dumped directly into these streams which lead in contamination of fresh water. In order to save the water, sewage treatment plants (STP) are being constructed by the Government in various parts of the country. The STP's is used to process of removing the solids particles and other contaminants present in the wastewater primarily for domestic waste (Bhatia et al. 2017). The process includes physical, chemical and biological treatment to deal with unwanted objects from the sewage and make them safe for reuse (Khan et al. 2017) . The waste extracted after processing the sewage is usually in semi-solid state which is known as "sludge". The sludge further can be used for agriculture use and can be disposed as well. The process of physical, chemical and biological treatment helps to clean the sewage which protects the public health and contributes in sustainable environment. The public health is one of the major concern as it is estimated that 1.8 million peoples are died till date due to the water borne diseases (Asiwal et al. 2016). The hazardous sewage not only affects the water but also on air, soil and agriculture. The systematic disposal of sludge should be indispensable for sustainable environment (Aghalari et al. 2020). The effective wastewater treatment plays important role in saving the water and discourage unnecessary water usage. Therefore, it's necessary to process the wastewater with proper treatment system before the water publicly utilized for irrigation/agriculture purpose.

The discharge of wastewater is common practice in many developing countries i.e., India which leads to pollute ground water as well as underground water. Since, there is not much treatment plants are installed in the country; there is considerable difference in the generation of wastewater and processing of wastewater. In nation, the domestic waste water generally consists of waste from institutes, residential buildings and commercial places. In general, the domestic wastewater composed of polluted water, total solids (TS) etc. (Gautam et al. 2013). The total solids largely consist of organic matters which are sticks, vegetables, human waste, papers, etc. In the STP, dealing with these organic matters can be done by an anaerobic procedure. The existing technology of processing the wastewater i.e., STP's are reduce the waste manure and contributes to make our natural water streams like river, canal, ponds etc. clean (Salvi 2021).

There is a major issue of "Water scarcity" specially in village/remote areas of developing nations (Deshmukh 2017). Recently, awareness about wastage of water and concerns about water conservation has been increased and peoples are accepting the truth. In today's time, implementation of effective water system in villages also become very important to save the environment. As per estimation, 80 percent of the waste which is generated by India and China is used for irrigation propose (Deshmukh 2017). Hence, the village life also gets affected as most of the irrigation is done in rural areas. STPs can be helpful for processing wastewater in rural areas due to the high concentrations of organic materials, pathogens, nutrients, and hazardous substances and pesticides found in the waste produced there (Maawali et al. 2020). The primary treatment which consists of Fine and coarse screens, sedimentation tank, grit chamber, etc. can reduce the biochemical oxygen demand (BOD) up to 20 to 30 percent and Total suspended solids (TSS) up to 50 to 60 percentile (G and VM 2019). The efficiency of STP can be reached up to 85 to 90 percentile (Dixit et al. 2020). Due to the high efficiency, the proper management and treatment of wastewater becomes essential for better health and sustainable environment (Gupta et al. 2018).

The conventional method of treating wastewater consists of sedimentation tank where the flow of water is very less so that the particles can settle down at the bottom. Due to having less flow in water, the chances of algae growth are very high which may again make the water unsustainable. By viewing such reason, the usage of wetland systems appears more effective as compare to traditional wetland systems. Study suggests that there are main four reason for biological process in aquatic environment are availability on nutrients, temperature, intensity of light and notably water bodies (Zalewski 2003).

1.2 Sewage Treatment Plant (STP)

Sewage Treatment Plants (STP) is used for processing of wastewater which is highly expensive in a densely populated area. The consequent nationwide resonance of the need for low-cost and high-efficiency municipal wastewater treatment was no small thing. There is a strong need of new technology like Constructed Wetland (CW) which can reduce the treatment expenditure of wastewater (Wu et al. 2014; Vymazal 2010). The rapid increase in population makes the places denser and add extra pressure on Environment (Kumar and Dutta 2019). India's population is rising, thus the country must find ways to reduce, reuse, and recycle water to meet its future freshwater needs. The application of treated water can be proved beneficial for agricultural irrigation. CW is more cost-effective and less harmful to the environment than conventional STP since it requires almost no mechanical equipment.

Natural way of treating the wastewater is used to take benefits of purifying the water through physical, chemical and biological processes (Liu et al. 2016). The wastewater goes through network of sediments, sand beds, root zone, plant roots, biomass zones which activates the diverse degradation and removal process. This process also enables the oxidation and aerobic degradation. The primary goal of residential wastewater processing is to remove or treat organic and inorganic materials, nutrients, pathogens, and total solids (Liu et al. 2016).

Removal of pathogens and solid waste become possible as CW is a passive treatment method which is a combination of Biochemical and Geochemical processes (Li et al. 2014; Sandoval et al. 2019). The CW has the ability to perform its functioning even in the cold temperature as it depends on biologically active system i.e., microbial and plantation (Rousseau et al. 2004). A complex process is involved to purify domestic waste as the physical, chemical and biological processes influence each other, and in addition, these processes are happening simultaneously, which makes it difficult to understand (Ilyas and Masih 2017). The use of CW is inexpensive as it does not require mechanical equipment and robust chemical solutions for processing wastewater (Haberl et al. 2003). Moreover, there is a major issue of water environment including poor quality and shortage of water (Vymazal 2010). CW has the ability of ground water recharge; it can play a vital role towards sustainable development.

1.3 Constructed Wetland

CW is environment-friendly and offers an affordable way of treating the wastewater. Though CW has many benefits, it does have certain drawbacks, such as a higher land need compared to traditional STP. As a result, it can serve as a practical natural facility in cities when land is not too expensive. Moreover, in hilly areas, it will become difficult to find out suitable location for CWs. CW can be built with more precision and allow to conduct more experimentation with suitable composition of plantation and soil layers (Saeed and Sun 2012). This natural process involving vegetation, soil interaction and microbial to helps in treating wastewater (Solano et al. 2004). The CW (CWs) is not carrying high construction or maintained cost as compared to sewage treatment plants (STP) (Rozema et al. 2016).

The domestic sewage can be evaluated through the constructed wetland. Moreover, study shows that there are many countries which have started operation of constructed wetland as a prime on-situ treatment of domestic wastewater (Rizzo et al. 2020). Without proper treatment, wastewater from homes can contaminate aquifers and lead to an increase in the spread of illness. Contaminated water not only affects the humans but also to plants, aquatic life and animals as well. The major reason behind pollution is industrial activities, mining works, leakage during extraction of oil in sea, transportation activities, pesticides used during farming, waste from thermal power plants, improper drainage and waste matter discharged from the intestines through the anus. The major diseases due to contaminated water are Typhoid fever, Polio, cholera, Hepatitis A, Diarrhea, etc.

The constructed wetland can be utilized to process the domestic waste, industrial waste and moreover the storm water as well. The wetlands are usually submerged with water throughout the year or depending upon weather of the area. Sometimes it becomes dry as well due to the evaporation of water during high temperature as well as due to seepage through surface. Monsoon is generally considered as best source of such wetlands.

The constructed wetlands are considered as cheap in comparison to traditional waste water treatment plant due to having less construction cost (Ilyas and Masih 2017; Dordio and Carvalho 2013). The requirement of the area for construction of wetland is also very less. Moreover, since it does not require any machinery hence its maintained cost is negligible. The construction of such wetland is very simple and does not have any complicated design due to which high skilled labour or other special construction material is also not required. Countries like India where the population is very dense, the wetland systems can process the agricultural waste, industrial waste, storm water and more importantly domestic waste.

Despite these benefits, there are also some drawbacks to consider. In comparison to traditional treatment plants, the created wetland has a longer retention duration (Piñeyro et al. 2019). These wetlands required land hence the construction of such wetland shall become costly if the land is expensive. Moreover, it will be less effective where the water availability is less or area/land usually remains. The climate plays an important role in such construction. Once the constructed wetlands are constructed then their working is less expensive and easy to maintain (Solano et al. 2004; Gautam et al. 2013).

It is common practice in conventional waste water treatment plants to employ chlorine for disinfection, which poses health risks to both humans and aquatic life (Langergraber 2008). All work in man-made wetland environments is completed without the use of any synthetic chemicals. Due to the world's ever-increasing population, there is a constant and growing demand for water. Research from the World Water Assessment Programme indicates that forty percent of the global population would have water scarcity issues by the year 2030 (Almuktar et al. 2018).

1.4 Advantages of using constructed wetlands

The use of the constructed wetlands has the following advantages:

1. **Financial aspect:** Constructed wetlands are more cost-effective than conventional waste water treatment plants, and the materials required in their creation are free or low-cost.
2. **Operation and Maintenance:** As there is no large machinery or equipment used, the running and upkeep expenses are minimal.
3. **Environmental gain**: While traditional wastewater treatment plants utilize chemicals like chlorine to disinfect wastewater, a built wetland can do the same job without the use of harmful substances or fossil fuels.
4. **Efficiency**: The wastewater which is treated in constructed wetland able to match the standards and can be used for agriculture purpose.
5. **Designing aspect**: Constructed wetlands, in contrast to conventional waste water treatment plants, have straightforward designs and necessitate just a little amount of professional labour for their building.

1.5 Hypothesis of the study

The Constructed Wetlands can be utilized as a natural way of improvement in water quality specially the water which contains organic particles. The same CW's can play an important role during the emergency conditions such as flooding, heavy rainfall and for recreational uses as well. Another important factor regarding constructed wetland is since the water is available on the surface on earth naturally, it will help to recharge the ground level or it helps in maintaining the water table. The water which is processed through the CW's can be utilized for irrigation, fisheries, construction usage and for domestic use as well. The CW's also supports the carbon cycle and helps in supplying the nutrients and other useful material to the water living bodies. It has been found that these CW's are also act as a habitat to migratory birds which shift their places with respect to the various seasons. All of the above-mentioned points make the construction of wetlands very important for environment aspect.

From the foregoing discussions it was felt that the constructed wetlands are having edge as compared to the conventional wastewater treatment plants. Since there is an urgent need to cope with the shortage of water, the wastewater should be properly treated with low cost for which this research is undertaken. Further, there is need of time to study the wider range of wastewater and pollutant types. Constructed wetlands could be suitable solution to make it sustainable waste water solution as a stand-alone treatment.

1.6 Research Objectives

Considering this knowledge gap and drawing from a review of the relevant literature, researcher proposes the following. These were the goals that the research set out to accomplish:

i. To investigate the properties of domestic raw water sample from conventional wastewater treatment unit.
ii. To study the completely treated wastewater discharged variables of conventional sewage treatment unit.
iii. To analyze the domestic waste water variables after the operation of constructed wetland.
iv. To collate the sample variables from constructed wetland and conventional wastewater treatment unit.

1.7 Outlines of the thesis

Chapter-1: Introduction- It describes about the sewage treatment plant and constructed wetlands need of these plants, hypothesis and objectives the work etc.

Chapter-2: Review of literature- This section includes in-depth review of literature for the overall work.

Chapter-3: Materials and Methodology- The chapter details about materials used for the study and how experimental work has been done.

Chapter-4: Results and discussion- Experimental investigation is carried out and data is collected from each experiment, graphical and tabular representation is done for better understanding.

Chapter-5: Summary and Conclusion- Overall summary of the thesis is detailed in this section.

Chapter 2: Review of Literature

2.1 Overview

Treatment of wastewater to be adopted should be eco- friendly where should not require special equipment and electricity. There are various systems employed for the treatment which constitutes an interface between terrestrial system and the aquifer systems Today the wastewater requires high level of treatment so as to get rid of the contaminants to be safe for further use There are many other wastewater treatment techniques, including filters and chemical treatments, activated sludge and oxidation ponds but the setup is expensive and is difficult to operate. There are several emerging technologies for wastewater treatment like constructed wetlands, microbial fuel cells, electro-coagulation; phyco remediation etc. out of these, constructed wetland is the technique which does not require any special equipment and electricity. These are eco-friendly and are economically sustainable and efficient wetlands which are acknowledged as effective wastewater treatment method and it could be used to treat different wastes generating from sewage, paper mill industry, pulp, glass, petrochemical, grey water, effluent from dairy, brewery and many more industries. It had multiple advantages like raising the importance of wastewater, habitat enrichment, use in various fields etc. Economically they are cheap as easy to operate, they require less labour, cheaper instrument requirements. Plants are used in the wetlands which are selected according to the prevailing environmental conditions and availability. Table 2.1 shows a brief literature review of this study.

Table 2.1: Brief literature review on STP and constructed wetlands used

Author	**Title of the manuscript**	**Study Area**	**Climate**	**Materials/Methodology**	**Outcomes**
(Haberl et al. 2003)	Constructed Wetlands for the Treatment of Organic Pollutants			Study has been made of surface flow and subsurface flow, further sub-surface flow divided into two parts i.e., vertical and horizontal flow.	Study suggests need to put light of black box "Constructed Wetland" so that the efficiency can be improved.
(Solano et al. 2004)	Constructed wetland as a Sustainable solution for Wastewater Treatment in Small villages	Spain	Humid and rainy season	Study on removal of BOD, COD, TSS, TC and TF from municipal waste water	High levels of BOD, COD and TSS removal for all treatments were obtained, lowest hydraulic application i.e., 75 mm day_1 performed better.
(Ren et al. 2007)	Optimization of Four Kinds of Constructed Wetlands Substrate Combination Treating Domestic Sewage	Hubei, China	Humid	Study on four different type of Constructed wetland substrate i.e., hollow brick crumbs, fly ash, coal cinder and activated carbon pallets.	Study found that combination of fly ash and coal cinder gives best results in absorbing COD, hollow brick crumbs give the best result in removing the TP whereas activated carbon pallets found not suitable.
Ashutosh et al. 2011)	Constructed wetlands: an approach for wastewater treatment	India.	Humid	Study mechanism of removal of contaminants from wastewater	Study found microorganisms are capable of removing toxic organic compounds by aerobic or anaerobic degradation processes.

(Dordio and Carvalho 2013)	Constructed wetlands with light expanded clay aggregates for agricultural wastewater treatment	Évora, Portugal	Humid	Study using light expanded clay aggregate as surface bed and planted with Phragmites australis was investigated	Study shows that the light weight clay aggregates make structure lighter but less effective.
(Mustafa 2013)	Constructed Wetland for Wastewater Treatment and Reuse: A Case Study of Developing Country	Pakistan	Mild temperature	Study has made on removal of BOD, COD, TSS, NH4-N, TC, FC for the pre-treated domestic waste water. Study has been made for 8 months on energy consumption	Study suggested that pre-treatment offer better results. Moreover, the treated water can be utilized for irrigation use, study also indicates that there is very less use of electricity.
(Morato et al. 2014)	Key design factors affecting microbial community composition and pathogenic organism removal in horizontal subsurface flow constructed wetlands	Spain	Cold	The role of key design factors which could affect microbial removal and wetland performance, such as granular media, water depth and season effect was evaluated in a pilot system consisting of 8 parallel HSSF constructed wetlands treating urban wastewater	Constructed wetlands constitute an interesting option for wastewater reuse since high concentrations of contaminants and pathogenic microorganisms can be removed with these natural treatment systems.
(Arivoli et al. 2015)	Application of vertical flow constructed wetland in treatment of heavy metals from pulp and paper industry wastewater	Tamil Nadu, India	Humid	Four pilot scales VFCW were used. Ratio of irrigation was varied. Polythene sheets were used.	Results show the removal of iron, copper, manganese, zinc, nickel and cadmium to 74, 80, 60, 70, 71 and 70 percent respectively.

(Çakir et al. 2015)	A study on the effects of different hydraulic loading rates (HLR) on pollutant removal efficiency of subsurface horizontal-flow constructed wetlands used for treatment of domestic wastewaters	Edirne	Rainy and warm season	Effect of hydraulic loading level on removal efficiency	Hydraulic loading needs to be monitored for efficiency
(Lu et al. 2015)	Study on method of domestic Wastewater treatment through netype multi-layer artificial wetland	China	Humid	Study on new type multiple layers with plant density, Water temperature and influent contamination	Plant density with higher temperature helps in making the operations more effective.
(Merino-Solís et al. 2015)	The Effect of the Hydraulic Retention Time on the Performance of an Ecological Wastewater Treatment System: An Anaerobic Filter with a Constructed Wetland	Chapala, Jalisco, Mexico		Study accesses the treatment using up flow anaerobic filters with horizontal surface flow.	Up flow anaerobic filters can remove organic waste and Horizontal subsurface constructed wetland can remove nitrogen content from waste water with 3 days detention period.
(Wu et al. 2015)	A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation	China	Humid	Use of sustainable design for wetland construction	Water depth, loading road etc. needs to be monitored for efficiency

(ElZein et al. 2016)	Constructed wetland as a Sustainable Water Treatment Method in communities	Egypt	Warm to hot weather	Theoretical studies about the usage of wastewater, its treatment method and CW's, research also use analytical approach by citing real time examples and its benefits.	Researcher found that due to low cost, CW's are economical. Moreover, eco-friendly as well which will socially benefit, CW's able to save more expenditure till its life span.
(Tao et al. 2017)	Designing constructed wetlands for reclamation of pre-treated wastewater and storm water			Study on designing of constructed wetland for waste water reclamation, contaminants loading charts as a design tool.	Challenging to consistently meet microbiological guidelines for high-quality reuses.
(Wang et al. 2017)	Constructed wetlands for wastewater treatment in cold climate — A review		Cold season	Study has been done on free water surface, sub surface flow and hybrid wetland systems on cold places	Better performance of Constructed wetlands found during summers, in cold weather there is less effect of BOD5, COD and TSS.
(de Matos et al. 2018)	Clogging in horizontal subsurface flow constructed wetland: influence factors, research methods and remediation techniques			Effect of clogging in surface bed of construction wetland with special attention towards genesis is studied	Clogging in surface bed of constructed wetland is important parameter to make the structure sustainable
(Ramachandra et al. 2018)	Optimization treatment of Domestic Wastewater through Constructed Wetlands	Bangalore, India	Humid	Study deals with possibility of bioremediation to process the domestic waste water to make it usable and deals with water shortage.	Results shows that CW's helps to remove the nutrients from wastewater and make it portable.

(Sgroi et al. 2018)	Removal of organic carbon, nitrogen, emerging contaminants and fluorescing organic matter in different constructed wetland configurations	Italy	Humid	The elimination of organic carbon, nitrogen, five emerging organic contaminants (EOCs) and fluorescence signature was evaluated in two treatment lines comprising different constructed wetland (CW) configurations	The highest removal of BOD5 (81%), COD (67%), TOC (72%) and fluorescing organic matter were observed in the UVF wetland
(Yadav et al. 2018)	Development of the "French system" vertical flow constructed wetland to treat raw domestic wastewater in India	Goa, India	Tropical	Two different plant species (Typha angustata and Canna indica) were considered for their nutrient removal efficiency and biochemical methane potential (BMP) efficiency in two stage vertical CWs.	The current footprint that is required for VFCW, it will be an attractive option for rural areas as it required less maintenance and energy to operate.
(Kamal et al. 2019)	Treatment of Sewage Water Through Constructed Wetland by Typha Latifolia	India	Humid	Investigation on Typha latifolia had planted in domestic waste for duration of 30 days with retention period of 7 days	Typha latifolia efficiency increases with time duration to purify the waste water, plant proved to be effective.
(Kumar and Dutta 2019)	Constructed wetland microcosms as sustainable technology for domestic wastewater treatment: an overview	India	Humid	Study effect on pH, DO and Temperature on hydraulic loading rate, hydraulic retention time, diversity of macrophytes and supporting media.	Carbon, HLR, HRT, pollutant loads are depending on temperature and important to study for efficiency
(Mao and Huang 2019)	Research on performance improvement of			Discussion on CW's i.e., landscape, irregular design, clogging, limited life span	Study concludes that since CW's are environment friendly, it makes the land green due to

	constructed wetland wastewater treatment system			and processing performance, particle size, plant type and water inflow	which the regional value of land increases, CW's act as an environmental education
(Mao and Huang 2019)	Optimizations on Supply and Distribution of Dissolved Oxygen in Constructed Wetlands: A Review	China		Optimizations on Supply and Distribution of Dissolved Oxygen in Constructed Wetlands	Based on oxygen supply characteristics, the current review illustrated the deficiencies of insufficient oxygen supply and unreasonable DO distribution in traditional CWs for WW treatment.
(Park et al. 2019)	Floating treatment wetlands supplemented with aeration and biofilm attachment surfaces for efficient domestic wastewater treatment	New Zealand		Study on post treatment using floating treatment wetland with aerated bio-firm	Study suggests that floating treatment wetland with aerated bio-firm can be utilized
(Shingare et al. 2019)	Constructed wetland for wastewater reuse: Role and efficiency in removing enteric pathogens	Maharashtra, India	Rainy and hot season	Enumerates the use of constructed wetland in removal of pathogens present in waste water.	The method of constructed wetland found effective on removing pathogens.
(Thalla et al. 2019)	Performance evaluation of horizontal and vertical flow constructed wetlands as tertiary treatment option for secondary effluents	Karnataka, India	Warm to hot weather, rainy season	Comparison between horizontal subsurface flow and vertical flow in post-treating the effluent in secondary biological treatment system	Vertical flow found better than horizontal subsurface flow

(Vidya Vijay et al. 2019)	Domestic wastewater treatment performance using constructed wetland	Tamil nadu, India	Warm and Humid	Study on CW's vegetation, soil and associated microbial assemblages	CW's vegetation, soil type and microbial assemblages are important parameters for efficient treatment operation
(Vidya Vijay et al. 2019)	Sustainability of constructed wetlands using biochar as effective absorbent for treating wastewaters	India	Humid	Study shows coconut shells used as biochar, combination of CW's and biochar taken to improve the efficiency.	Combination of CW's with biochar (coconut) reduces the pH, turbidity and other physico - chemical parameter
(Bakhshoodeh et al. 2020)	Constructed wetlands for landfill leachate treatment: A review	Perth, Australia	Humid	Comprehensive review on practices, application and research of constructed wetland leachate	The BOD5, COD, TP, Ammonia, LKN, TN and TSS for horizontal/vertical/hybrid, free water surface were found effective solution in constructed wetland
(Haydar et al. 2020)	Performance evaluation of hybrid constructed wetlands for the treatment of municipal wastewater in developing countries	Lahore, Pakistan	Humid	Study aimed to evaluate the innovative maneuver of constructed wetland, vertical and horizontal flow with plant species, continues and batch operations are monitored	After 4 days detention period, BOD, COD and TSS are satisfied as per standards with continues operation
(Khalifa et al. 2020)	Effect of media variation on the removal efficiency of pollutants from domestic wastewater in constructed wetland systems	Mansoura, Egypt	Warm to hot weather	Effect on replacement of aggregates with low-cost waste material in CW.	Low-cost material found effective in operation and reduce cost of structure

(Li et al. 2020)	Nitrogen and phosphorus removal performance and bacterial communities in a multi-stage surface flow constructed wetland treating rural domestic sewage	Hunan, China	Rainy, warm and humid season	Study on multi-stage surface flow constructed wetland using plant and sediments	Study suggests that the multiple-stage flow is sustainable technology
(Pinney et al. 2020)	Transformations in dissolved organic carbon through constructed wetlands	USA	Cold	Study on plant based constructed wetland, organic carbon was analysed varying different HRT	Wetlands with short HRTs would reduce the amount of DOC leached from plant material.
(Wang et al. 2020)	Comprehensive evaluation of substrate materials for contaminants removal in constructed wetlands	China	Warm season	Study has been made on all substrate material i.e., natural, artificial and agricultural/industrial material	Study suggests that natural material along with agricultural/industrial material is more effective as the cost of natural material
(Zhao et al. 2020)	Constructed Wetlands for Water Treatment: New Developments	China	Warm season	Study effect of organic amendments with hydraulic flow on selenium removal	Effect of organic amendments with hydraulic flow is important parameter to study on selenium removal
(Jan Vymazal et al. 2021)	Recent research challenges in constructed wetlands for wastewater treatment: A review	China	Warm season	Study the effect of vegetation and microbiology of wetlands	Study suggests microbiology play a crucial role during wastewater treatment in CW

Based on the literature review, it has been observed the through needs to be done on the comparison between STP and CW. The efficiency during the variable discharge in CW need to studied further since it may affect the effectiveness of the system.

2.2 Research Gap

From the literature review it has been observed that there is huge requirement to find out sustainable method to purify the waste water as current method i.e., conventional treatment method is costly and have high maintenance cost. Moreover, due to usage of chlorine/alum, side effects are also visible. In such conditions when the population and water requirement is increasing day by day, constructed wetland show positive sign in processing the waste water. Presently, there is no specific code for designing of constructed wetland, so the work on the constructed wetland is still going on and few studies have reported specially with processing of domestic waste water. Most of the studies are focusing the BOD, COD and TSS present in waste water but other parameters are required to be studied as well which will help to make the operation of wastewater sustainable and eco-friendly. These constructed wetlands are not so famous due to lasting effects on wetlands like discharge of industrial waste which gets mixed with wetlands, stream channelization, urban runoff, dam construction, etc. due to which these wetlands are not so famous.

Chapter 3: Study Area and Methodology

3.1 General

It is recognized that there are serious water pollution problems in Punjab, Delhi and other parts of India, mainly due to untreated wastewater. Rivers i.e., the Satluj, Beas, Ganga, etc., that flow through heavily inhabited areas, are contaminated. 80 percent of wastewater in India is not treated and flows directly into the country's rivers, polluting the main sources of drinking water. Indian cities together produce about 40 billion liters of wastewater per day, and only 20 percent is processed through treatment plants (phys.org, 2013). Therefore, the treatment and reuse of wastewater is an urgent in growing country. Treatment of water becomes more and more important in country like India due to massive increase of population.

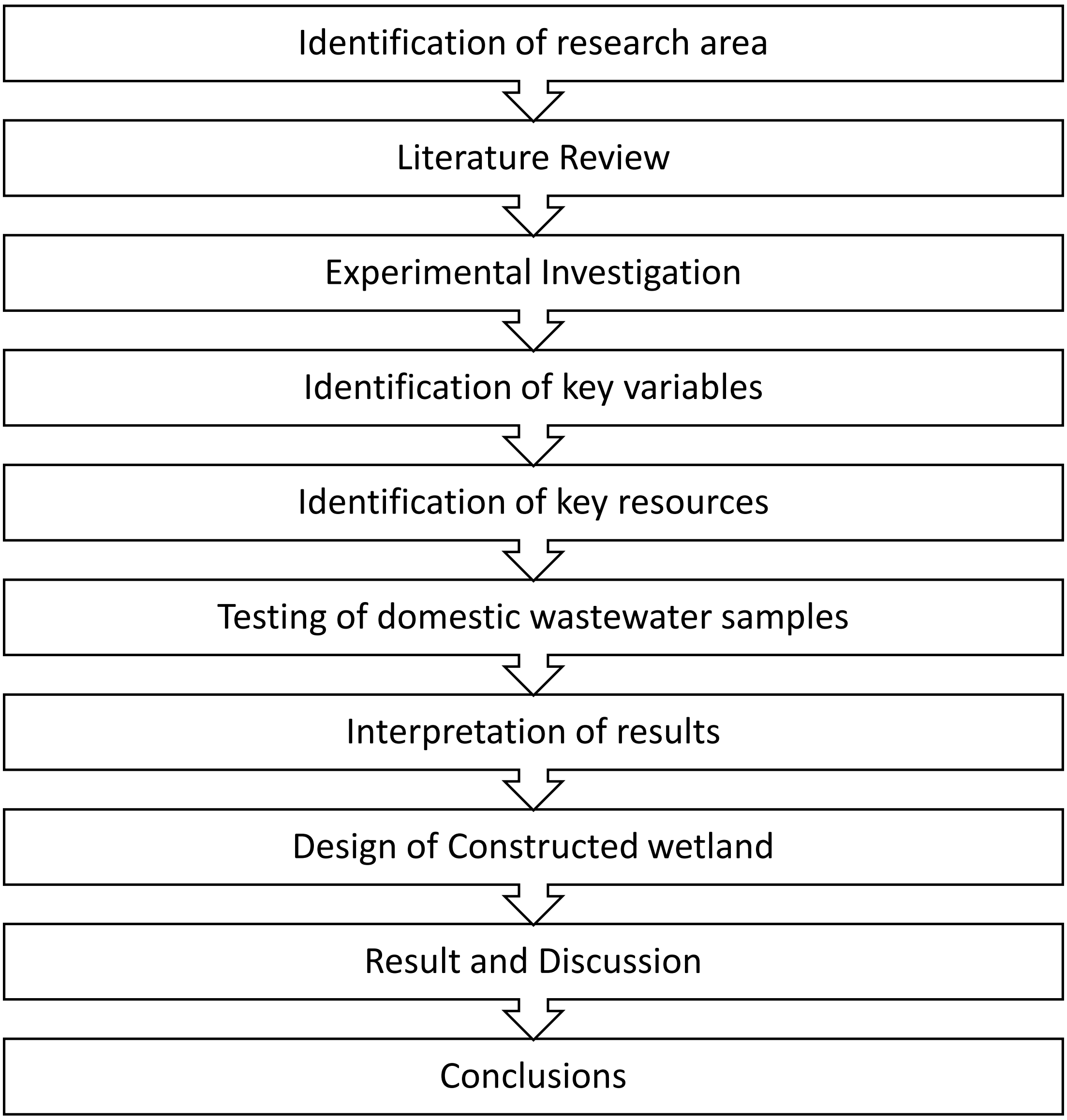

Figure 3.1: Flow chart of methodology

3.2 Study Area

The samples of household domestic wastewater are collected from the Sewage treatment plant in the town of Bambianwali, Jalandhar, which is run by the Government of Punjab and has a capacity of 10 MLD. The area is located 16 kilometers away from Phagwara and 14 kilometers away from Jalandhar. The "Bambianwali" sewage treatment plant mostly received the water which is belongs to domestic area. Surrounding land belongs to agriculture hence there is not much industry in said area. The testing has been done in Government approved lab near treatment and fulfills the norms (permissible limits) of Central Pollution Control Board (CPCB).

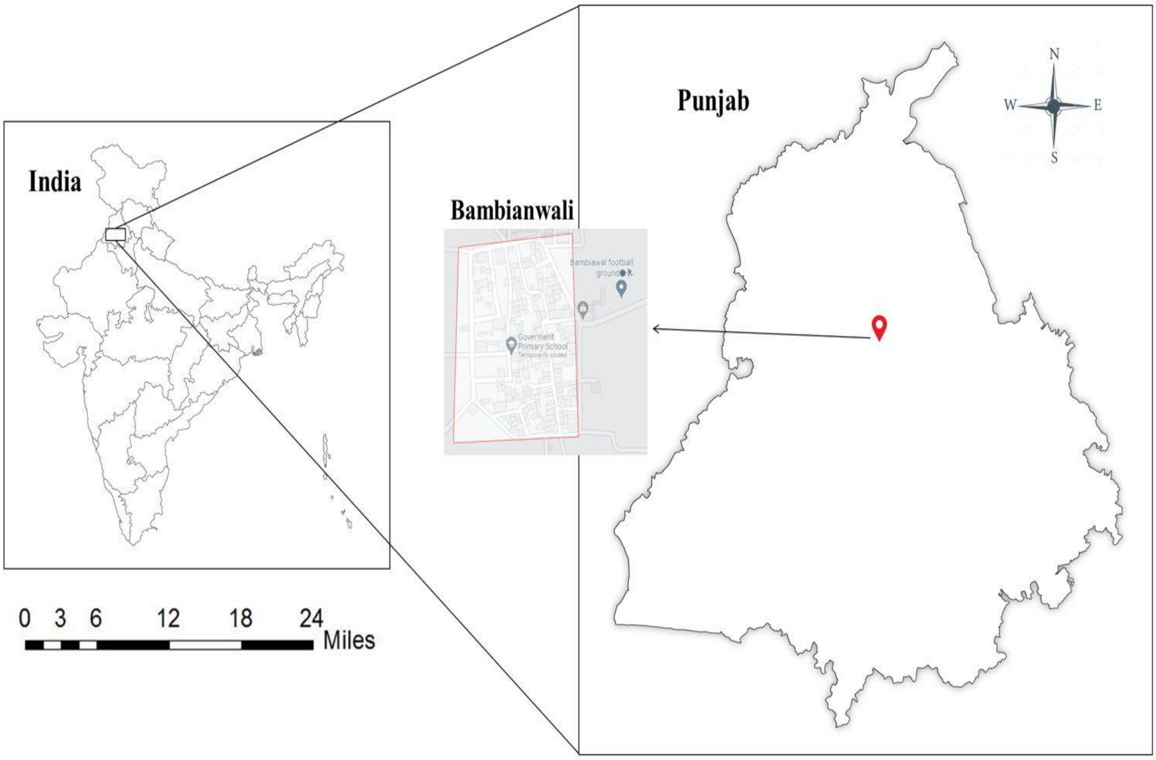

Figure 3.2: Location of Bambianwali sewage treatment plant

The "Bambianwali" Sewage Treatment Plant consist of the following steps of treatment. Initially the wastewater collected in "Inlet Chamber" so that flocculation in flow can be managed. Further, the screens are provided in order to remove floating matters and coarse particles. Then the wastewater goes through the mechanical chamber followed by "SBR basins" which is a type of activated sludge process. MEP/Blower room is utilized for processing the wastewater. The wastewater further goes into the chlorine contact tank for disinfection after which it goes through the process of tonner shed and sludge sump/sludge pump house.

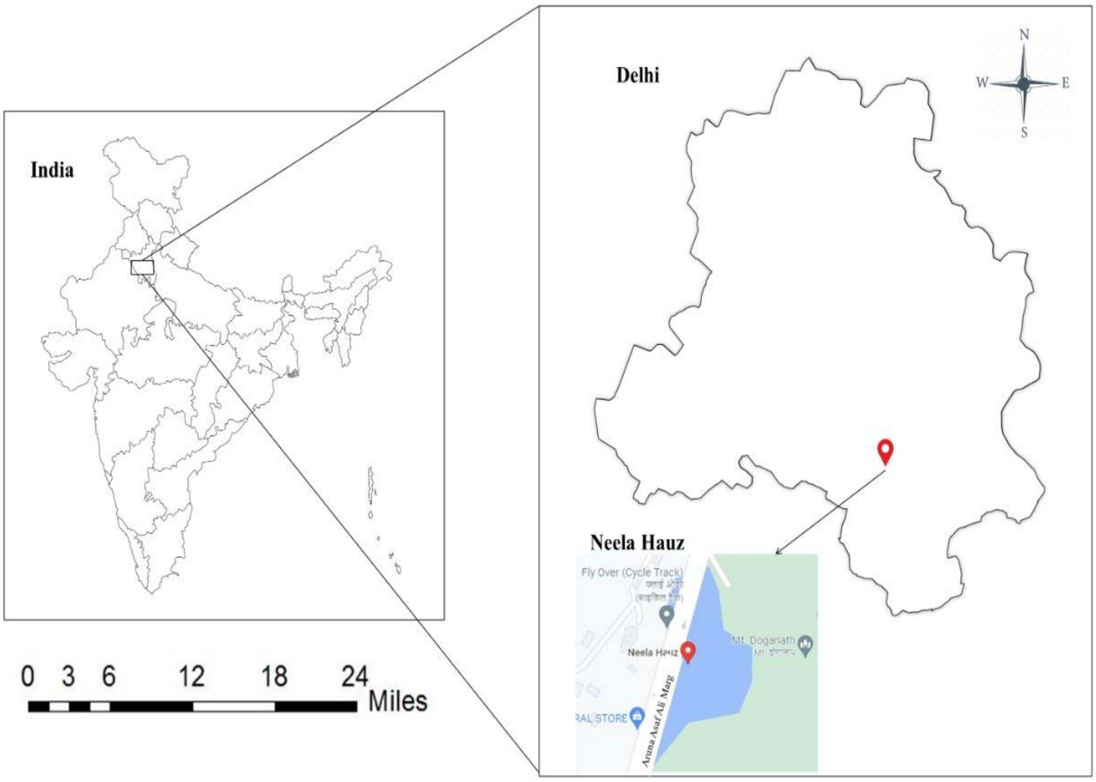

Figure 3.3: Location of Neela Hauz lake

The testing samples for CW were taken from its outlet, which is located near Neela Hauz lake, South Delhi, and receives the wastewater (untreated) from Kishan Garh and Vasant Kunj, Delhi. The collected samples were then subjected to requisite testing. Thereafter, the water is further disposed into Yamuna river. The testing has been conducted in a locally available laboratory (fulfilling the norms of Central Pollution Control Board, CPCB).

3.3 Data collection

During the study total 1944 samples are collected in which nine different parameters i.e., pH, TSS, Temp, COD, BOD, TKN, N, P, SO_4 are taken and analyzed. In order to understand the variation in the wastewater flow, samples are taken for total 27 days which also helps to get the more accuracy. The wastewater samples are collected in BOD bottle using "Composite sampling method".

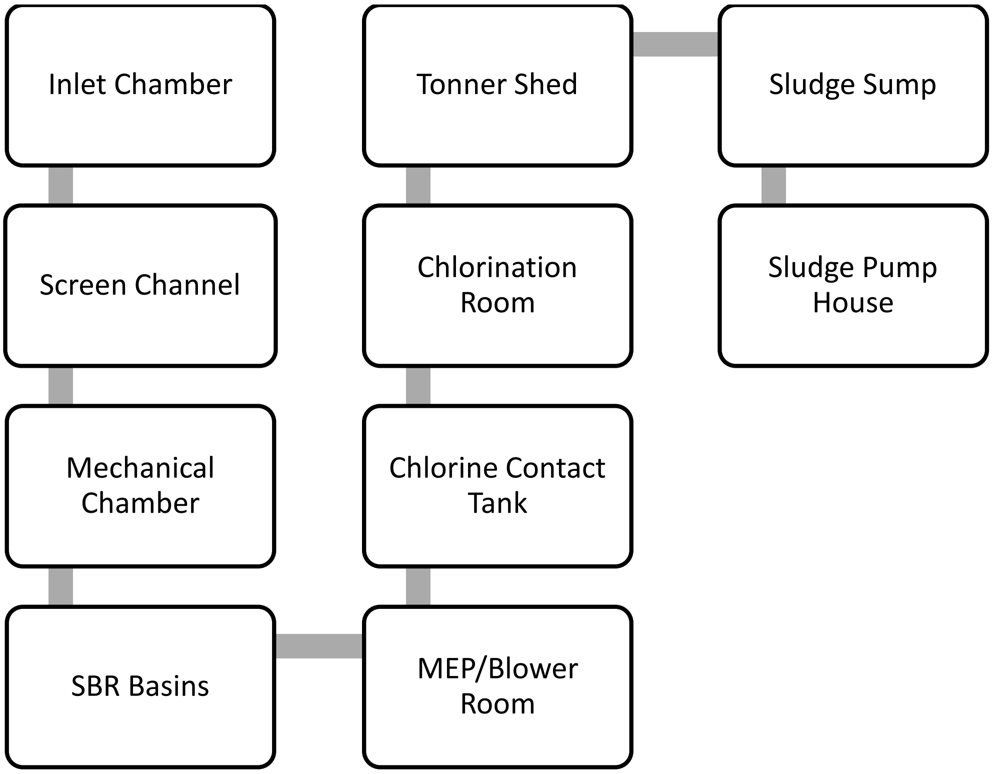

Figure 3.4. Flow chart of process of sewage treatment plant

3.4 Domestic Wastewater Analysis

During the testing in the lab, samples were taken throughout the month for better accuracy. The various parameters like pH, Temperature, BOD, COD and TSS were taken under consideration which helps to examine the effectives of sewage treatment plant.

pH indicates the free hydrogen ions present in the wastewater. The addition of acidic/basic chemicals are important steps of sewage treatment plant since it separates the dissolved waste from the raw water. These dissolved solids keep moving inside the wastewater due to which settlement of the contaminates are very less. The contaminants can be settle down by increase the pH value due to which positive changed ions of metal makes bond with negatively hydroxide ions. In results of positive and negative charged ions, it erects heavy and unfathomable metal ions which could settle down easily in the wastewater. During the experimentation, Labline pH meter (Model: HI96107) has been utilized.

Presence of **TSS** in higher amount creates the critical environment for the aquatic life. The presence of TSS blocks the sun light to enter into the waterbody due to which it lowers the potential of algae to process the food as well as oxygen. The TSS content has been found by using IS 3025 (Part 15 & 17) – 2003 in which glass fiber filter contain

Pore Size 1.5 µm, Diameter 47 mm has been used. Prior to the weight of the filter paper, the filter paper has been dried in over at 105°C**.**

COD content indicates the organic content presence in the wastewater. The higher value of COD indicates higher content of the organics waste. The domestic waste largely consists of the organic wastes. While calculating the COD content, 2.5 Ml of sample, 1.5 ML of Potassium dichromate and 3.5 ml sulfate-sulfuric acid has been used. The closed reflux method in which Hach DRB 200 has been used for the determination of COD content in the wastewater.

BOD is basically bio-chemical oxygen demand. The organic matter should be decomposed for the treatment of the wastewater under the aerobic conditions. The aerobic condition i.e., presence of oxygen content in the wastewater can be calculated by biochemical oxygen demand. The BOD test samples has been put under 5 days' incubation period at the temperature of 20°C. BOD digital incubator (Model: BOD171) has been used for BOD testing.

TKN content is found to know the Ammonia and Nitrogen content in the wastewater. The access amount of the ammonia can lead to eutrophication i.e.; increase plant growth eventually kills fishes. The TKN has been found using Hach TNT 880.

Domestic wastewater has higher amount of sludge which is the source of **nitrogen**. Higher amount of nitrogen not only leads to algae in the wastewater but also has ill effects on human health. Nitrate-nitrogen (NO3-N), Nitrite-nitrogen (NO2-N) and Ammonia-nitrogen (NH3-N) can be found in the wastewater by Nitrogen content. The N, P and SO_4 content has been found using ultraviolet (UV) spectrophotometry method.

3.5 Design of Preliminary/Primary treatment of Constructed Wetland

Prior to the design of constructed wetland, it's an important to step to remove the particle which are settleable, Hence Preliminary/Primary treatment is must. During the process of preliminary treatment, the floating or coarse particles are removed by using the screens. If these particles able to enter into constructed wetland, there may be clogging in the constructed wetland. After the wastewater goes through the screen i.e., preliminary process, next step is to deal with suspended solids in Primary treatment process in which septic tank has been provided. During the step of septic tank, the suspended solids settle down in the tank due to gravitational force. The preliminary and primary treatment process of constructed wetland are design as per constructed wetland manual by United Nations Human settlements Programme.

Figure 3.5. 10 MLD Sewage treatment plant, a) STP capacity, b) Automatic screens, c) Fine screens, d) Processed wastewater chamber, e) Aeration chamber, f) Lab set-up, g) STP lab, h) Testing equipment's

Chapter 4: Results and Discussion

4.1 Introduction

The characteristics of wastewater were analyzed for both STP as well as CW plant in this study. Initial and final characteristics of wastewater were investigated in the laboratory. The parameters were pH, temperature, COD, BOD, TSS, TKN, N, P, SO_4 etc. were measured according to APHA standards for obtaining the efficiency of the STP and CW plants respectively. Varying discharge was also analyzed during pre-monsoon and post-monsoon session for both plants. All experiments were carried out according to APHA. Sample collection was done properly and each experiment was done thrice for accuracy. The characteristics of wastewater were analyzed daily for each session and mean value was calculated from it.

4.2 STP results

Table 4.1 represents the Pre-monsoon testing results in which the effectiveness of the traditional sewage treatment plant shows the promising results.

Table 4.1: Pre-monsoon testing results of traditional Sewage treatment Plant

Parameter	Mean		Median		Standard Deviation		Permissible limits as per CPCB	Standard/ Specification/ Method followed
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment		
pH	7.1	7.1	7.1	7.1	0.1	0	6.5-9.0	IS 3025 (Part 11)
Temp. C	23.2	23.29	23.1	23.2	0.9	1	<30	-
TSS (mg/l)	309.1	16.4	310	16	2.9	1.5	20	IS 3025 (Part 17)
COD (mg/l)	313.8	39.81	314	40	3.1	2.3	50	IS 3025 (Part 58)
BOD (mg/l)	111.4	7.2	112	7	2.9	1.4	10	IS 3025 (Part 44)
TKN (mg/l)	33.21	6	33.1	6.1	1.1	0.3	<10	IS 3025 (Part 34)
N (mg/l)	27.91	4.9	27.9	4.8	0.6	0.2	<10	APHA 4500 B
P (mg/l)	4.51	1.71	4.5	1.7	0.3	0.2	2	IS 3025 (Part 31)
SO_4 (mg/l)	46.9	26.9	47	27	3.4	1.8	150	IS 3025 (Part 24)

The TSS content has been found on very higher side as 309.1 mg/l during the inlet and 16.4 mg/l at the outlet of the STP. The effectiveness of treatment is also noted in COD content where the mean value found out to be 313.8 mg/l and 39.81 mg/l at inlet and outlet respectively.

The BOD content in the wastewater found 111.4 mg/l which effect the aquatic life but STP system found effective on removing the BOD content from the wastewater as the BOD content comes down to 7.2 mg/l which is under the limit of CPCB and good to be disposed into natural water channels. As per IS 3025 part 34, the TKN content should not be more than 10 mg/l and the STP able to deliver desirable results as the TKN content decrease from 33.21 mg/l to 6 mg/l. In order to control the growth of aquatic plants and algae, it is important to find out nitrogen content is wastewater. The testing results show the nitrogen content decrease from 27.91 mg/l to 4.9 mg/l which is good to be disposed-off. The similar kind of results are found in phosphorus content where the testing results shows the value of P declined from 4.51 mg/l to 1.71 mg/l hence it will not support the growth of the algae and macrophytes which may reduce the water quality. The higher content of sulfate may lead to bitter taste or it may also damage plumbing system hence it is important to know the content of sulfate. Before wastewater entire into the STP, the testing value found out to be 46.9 mg/l which is not to high but the STP system shows the effectiveness and brought the value down to 26.9 mg/l.

Table 4.2 represents the post-monsoon results where the average temperature of the wastewater is found lower than the Pre-monsoon results but since the wastewater is in flowing condition, there is not much bigger impact on the system efficiency of STP. The TSS and COD found under the desirable limits prescribed by the CPCB. The BOD content is found 5 percent as compared to the pre-monsoon data. Despite of low temperature as compared to the pre-monsoon data, there is not much effect of the parameters like TNK, N, P and SO_4 as all the testing results at outlet of STP found under the limits.

Table 4.3 represents the Pre-monsoon results with variables where no impact has been found on pH since the standard deviation valve comes out to be zero. But since the flow is uneven, small variation has been found out in TSS at inlet value as the testing samples shows standard deviation value as 4.3. Similar kind of results noted down in case of COD and BOD as well where the testing samples results comes out to be 4.2 and 3.6 respectively.

Table 4.2: Post-monsoon testing results of traditional Sewage treatment Plant

Parameter	Mean		Median		Standard Deviation		Permissible limits as per CPCB	Standard/ Specification/ Method followed
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment		
pH	7.1	7.1	7.1	7.1	0.1	0.1	6.5-9.0	IS 3025 (Part 11)
Temp. C	21	21.4	21	21.3	0.5	0.9	<30	-
TSS (mg/l)	307.4	16.5	308	16	5.5	1.6	20	IS 3025 (Part 17)
COD (mg/l)	309.9	39.9	311	39	6.9	2.2	50	IS 3025 (Part 58)
BOD (mg/l)	111.4	7.3	111	7	3.1	1.3	10	IS 3025 (Part 44)
TKN (mg/l)	34.1	6.1	34.1	6.2	0.7	0.3	<10	IS 3025 (Part 34)
N (mg/l)	28.31	5	28.4	4.9	0.4	0.3	<10	APHA 4500 B
P (mg/l)	4.5	1.7	4.5	1.7	0.3	0.2	2	IS 3025 (Part 31)
SO_4 (mg/l)	47.1	25.7	48	26	3.2	1.2	150	IS 3025 (Part 24)

Since the wastewater received from the domestic area, the TKN content found out as 33.8 which has to be processed. At the outlet of STP, value of both TNK and N found out as 6.2 mg/l hence the treated water can be disposed-off into Satluj river as its done earlier. Eutrophication in wastewater can reduce the water quality further hence it is important to know the content of P in wastewater which comes out to be 4.9 mg/l before wastewater enters into treatment plant and 1.7 mg/l at the outlet of the STP.

Table 4.3: Pre-monsoon testing results (variable) of traditional Sewage treatment Plant

Parameter	Mean		Median		Standard Deviation		Permissible limits as per CPCB	Standard/ Specification/ Method followed
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment		
pH	7.1	7.1	7.1	7.1	0.0	0.0	6.5-9.0	IS 3025 (Part 11)

Temp. C	23.6	24.6	24.1	24.7	0.9	0.5	<30	-
TSS (mg/l)	310.2	16.0	311.0	16.0	4.3	1.3	20	IS 3025 (Part 17)
COD (mg/l)	310.1	40.3	311.0	40.0	4.2	2.0	50	IS 3025 (Part 58)
BOD (mg/l)	113.1	7.5	112.0	8.0	3.6	1.0	10	IS 3025 (Part 44)
TKN (mg/l)	33.8	6.2	33.8	6.2	0.4	0.3	< 10	IS 3025 (Part 34)
N (mg/l)	27.9	6.2	27.8	6.3	0.3	0.4	< 10	APHA 4500 B
P (mg/l)	4.9	1.7	4.9	1.6	0.2	0.1	2	IS 3025 (Part 31)
SO_4 (mg/l)	47.0	35.3	48.0	36.0	2.9	2.2	150	IS 3025 (Part 24)

Table 4.4 shows the testing results of Post-monsoon with variable and similar to pre-monsoon, there is not much impact due to the variable. The major reason behind the same is that the STP is also consist of collection chamber where the entire wastewater can be collected at same place hence the variation in the flow does not have much impact of the efficiency of the system. Since the collection chamber is under the ground only hence it increases the cost of pumping the water.

Table 4.4: Post-monsoon testing results (variable) of traditional Sewage treatment Plant

Parameter	**Mean**		**Median**		**Standard Deviation**		**Permissible limits as per CPCB**	**Standard/ Specification/ Method followed**
	Before Treatment	**After Treatment**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**		
pH	7.1	7.1	7.2	7.1	0.1	0.0	6.5-9.0	IS 3025 (Part 11)
Temp. C	22.0	22.3	22.0	22.3	1.0	1.4	<30	-
TSS (mg/l)	312.0	16.3	311.0	17.0	5.8	1.1	20	IS 3025 (Part 17)
COD (mg/l)	313.4	40.4	312.0	40.0	4.8	2.0	50	IS 3025 (Part 58)
BOD (mg/l)	112.4	7.8	112.0	8.0	2.1	1.2	10	IS 3025 (Part 44)
TKN (mg/l)	33.7	6.0	33.8	5.9	0.3	0.2	<10	IS 3025 (Part 34)
N (mg/l)	26.8	5.0	27.6	4.9	4.7	0.2	<10	APHA 4500 B

P (mg/l)	4.9	1.8	4.9	1.8	0.2	0.2	2	IS 3025 (Part 31)
SO_4 (mg/l)	47.1	27.1	48.0	27.0	2.9	2.1	150	IS 3025 (Part 24)

At the inlet of STP, the TSS content in wastewater found out to be 312 mg/l but after the process in STP, it come down to 16.3 mg/l which is under the limit. The similar kind of system efficiency has been noted in case of BOD and COD where the samples results shows the value of 7.8 mg/l and 40.4 mg/l respectively at the outlet. Although, the SO_4 content in wastewater at inlet found already under the limit but still the content further decrease to 27.1 mg/l hence waster can be disposed-off.

Figure 4.1: pH value of traditional Sewage treatment Plant

Figure 4.1 represents the relationship of before and after treatment of pH value in wastewater. The results primarily suggest the similar effectiveness of the STP system irrespective of the temperature. There is not much difference has been found in pH due to change in the temperature. The average PH value found to be 7.1 during pre-monsoon and post monsoon season. When it comes to consider the variable discharge, still there is not much effect of the efficiency due to presence of wastewater collection chamber in the STP. During the variables discharge the standard deviation value of pH found out as 0. The overall results of pH testing samples shows the reliability of the system and found water save to dispose into natural water flow.

Figure 4.2 summarized the TSS results of STP wastewater samples along with variables used in Pre and Post monsoon season. During the pre-monsoon session, there is not variation in the TSS content since there is uniform flow of wastewater and particles gets settle down with respect to time. The similar kind of results shows in Post-Monsoon season as well where the 16.5 mg/l at the outlet. On the other side, there is lot of variation has been found during the variable since there is lot of fluucation in the flow of wastewater and heavier particles started floating rather than settling down. The traditional STP consist of sedimentation tank where particles get settle down due to their own weight. Due to the presence of sedimentation tank, the TSS value comes down 16.4 mg/l. Due to the irregular supply of wastewater, the effect has been found out on post monsoon results as well where the efficiency further decrease to 16.3 mg/l but still under the permissible limit and is safe for disposal into the water streams. The standard deviation value in case of Post-Monsoon session seems on the higher side as 5.5 hence heavy variation in the sediment have been noted down.

In order to deal with non-uniform flow, the STP consist of wastewater collection chamber but since the collection chambers are underground structures hence it required pump to take the wastewater into desired level. Moreover, since the suspended solids cannot be allowed to settle in the collection chamber, continues pumping system is required which increase the running as well as maintenance cost of the STP. The same collection creates foul smell as well near the STP.

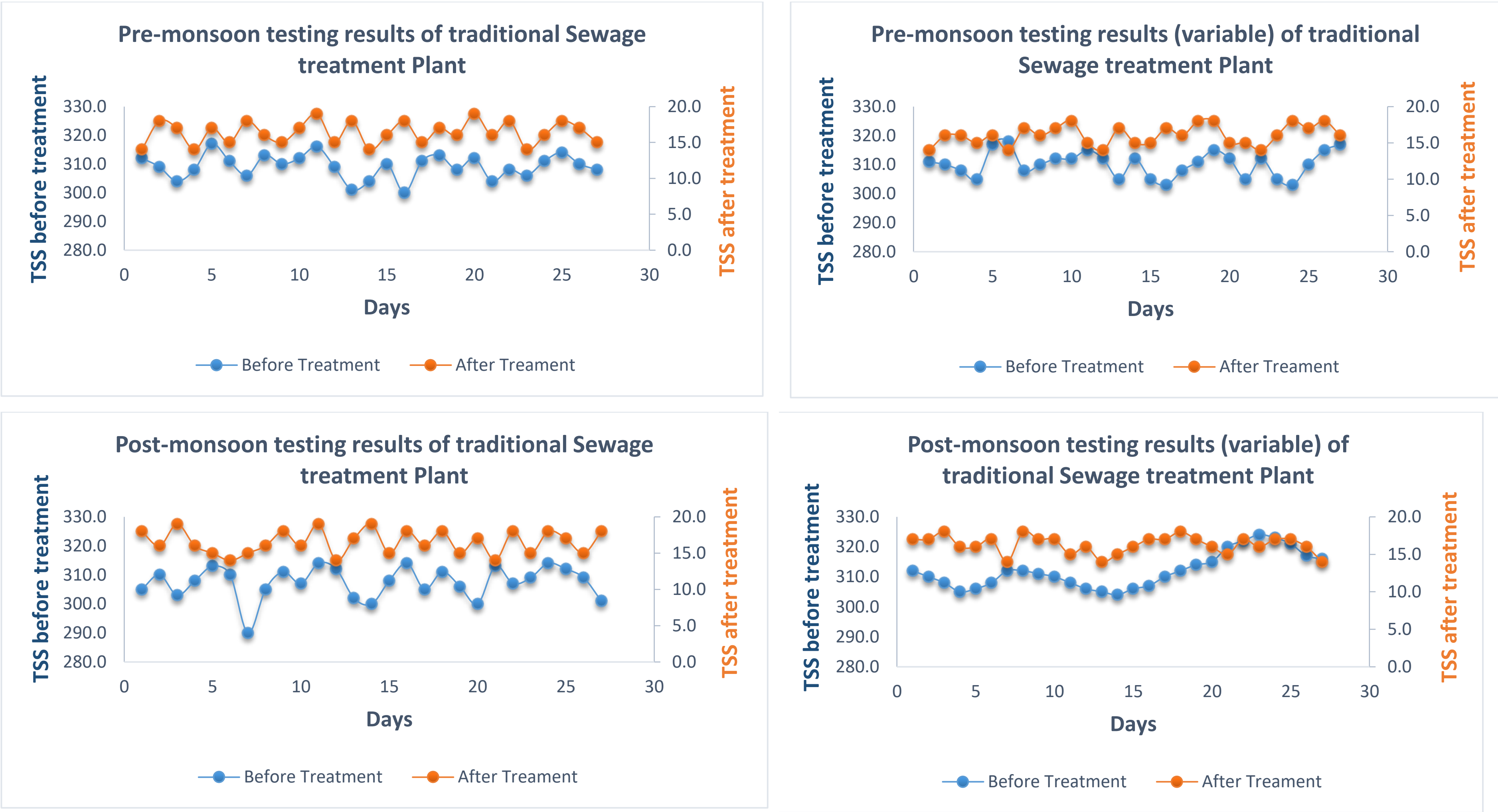

Figure 4.2: Total Suspended Solids test results of traditional Sewage treatment Plant

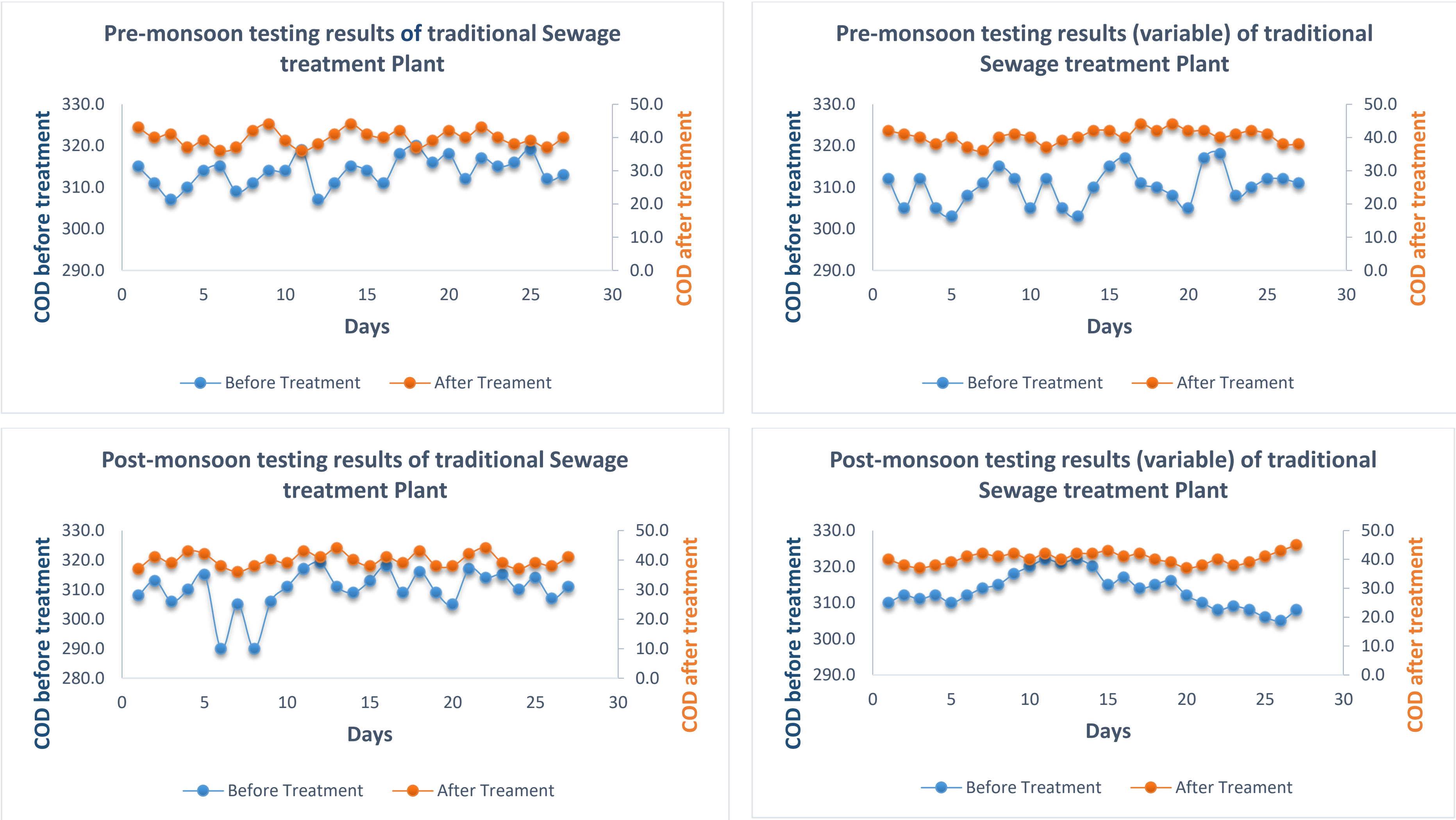

Figure 4.3: COD test results of traditional Sewage treatment Plant

Figure 4.3 summarize the effectiveness of STP in case of COD. The mean value of COD at inlet of STP found to be 309.9 mg/l and 39.9 mg/l at the outlet which is under the permissible limit of 50 mg/l. This indicates the amount of oxygen consumed by organic matters. The similar kind of results is observed during the testing of variable in Pre-monsoon and Post-monsoon. The mean value of COD during variable flow found out to be 310.1 mg/l at the inlet and 40.3 mg/l at the outlet of STP. The efficiency of the system does not get affected due to change in the temperature hence this makes the STP to use in during the high or low temperature as well. The domestic wastewater consists of aerobic and anaerobic. The pH value found out to be 7.1 at both placed i.e., inlet and outlet.

Figure 4.4 shows the different results of BOD testing samples. The average value of the inlet tests was 111.4 mg/l, indicating a high organic load in the influent that needs to be treated before being discharged into the water body. After the process in STP, the value at the outlet found out to be 7.2 mg/l which is under the prescribed limit. Small variation also been observed during the pre-monsoon results where the standard deviation value comes out to be 3.1 prior to treatment and 2.3 after the treatment. The variation of the results found out to be decreased after the process in STP which indicates the effectiveness of the system. This variation in the samples further increases in case variable sewage flow since the discharge keep on increasing as well as decreasing due to the water demand. The standard deviation values go up at 3.6 as compared to the value of 2.9 when there was constant flow of the wastewater. But here also due to the effectiveness of STP system the value further goes down to 1.0 which is highly impressive. While comparing to the post-monsoon results, it has been identified that there is not much impact of the variation in the results due to the change in the temperature. The temperature of the wastewater samples found out to be 112.4 mg/l at the inlet and 7.8 mg/l at the outlet. In this particular case, the minimum values found out to be 105 mg/l and maximum value found as 115 mg/l. When it comes on Post-monsoon results using variable, again the variation is observed but after the entire process in STP, the values of BOD found out to be 7.8 mg/l which is under the permissible limit of 10 mg/l.

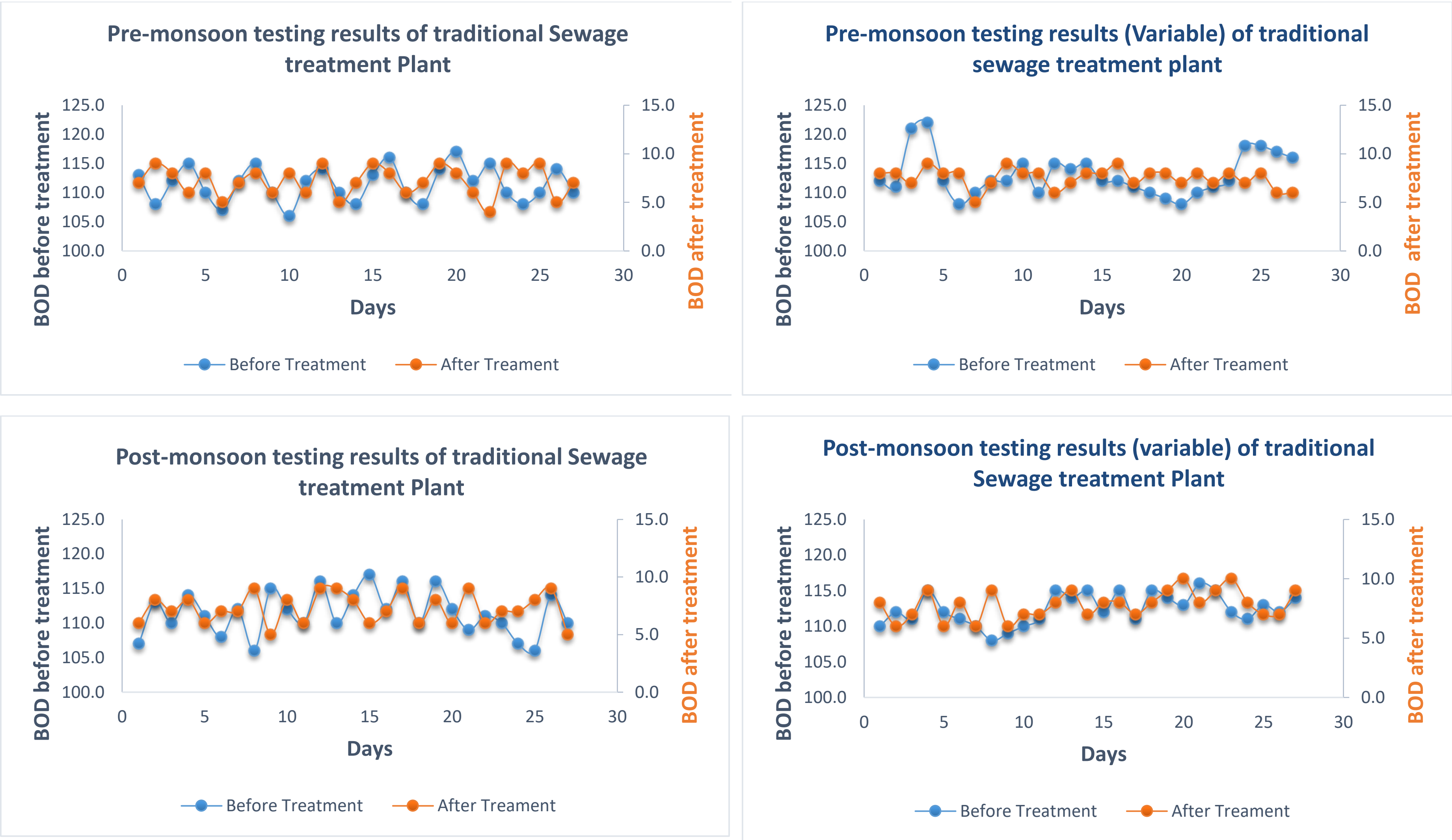

Figure 4.4: BOD test results of traditional Sewage treatment Plant

Figure 4.5 summarized the testing results of TKN after the processing through STP. The testing has been done as per IS code: 3025 (part 34). The initial indicates the higher content of TKN as 33.21 mg/l at the inlet which is quite high and leads to algae in water body. After the process through STP, the values found under desirable limit of 6 mg/l. Since the wastewater belongs to domestic area, there is not much variation in the said value. The content of TKN found increased during the post monsoon season due to the lower temperature. However, there is not much impact on the variation of the wastewater since the STP consists of collection chamber where the effect of higher/lower discharge minimized. On the other hand, when it comes to TKN using variable, the mean value comes out to be 33.8 mg/l which is again on the higher side at the temperature of 23.6 degree Celsius. At the outlet, the mean value of TKN found 6.2 mg/l at the temperature of 24.6 degree Celsius. The temperature of the wastewater increase by 1 degree Celsius due to the process in STP.

Figure 4.6 Shown the testing result of Nitrogen content presence in wastewater. The Pre-Monsoon results shows higher content of N presence in sewage as the mean value comes out to be 27.91 mg/l which should not be more than 10 as per APHA 4500 B standards. The process of STP found effective in removing the N content as the testing result at outlet found as 4.9 mg/l which is highly impressive and ready to be disposed into any natural water channel. The similar fort of result found in case of Post Monsoon results where the temperature dropdown to 21.4 ℃ as compared to 23.29 ℃found during Pre-Monsoon results. When it comes to variable wastewater discharge, N content found 27.9 mg/l in case of inlet during pre-monsoon and 26.8 mg/l during post-monsoon which is further reduced after the STP process to 6.2 mg/l and 5.0 mg/l respectively.

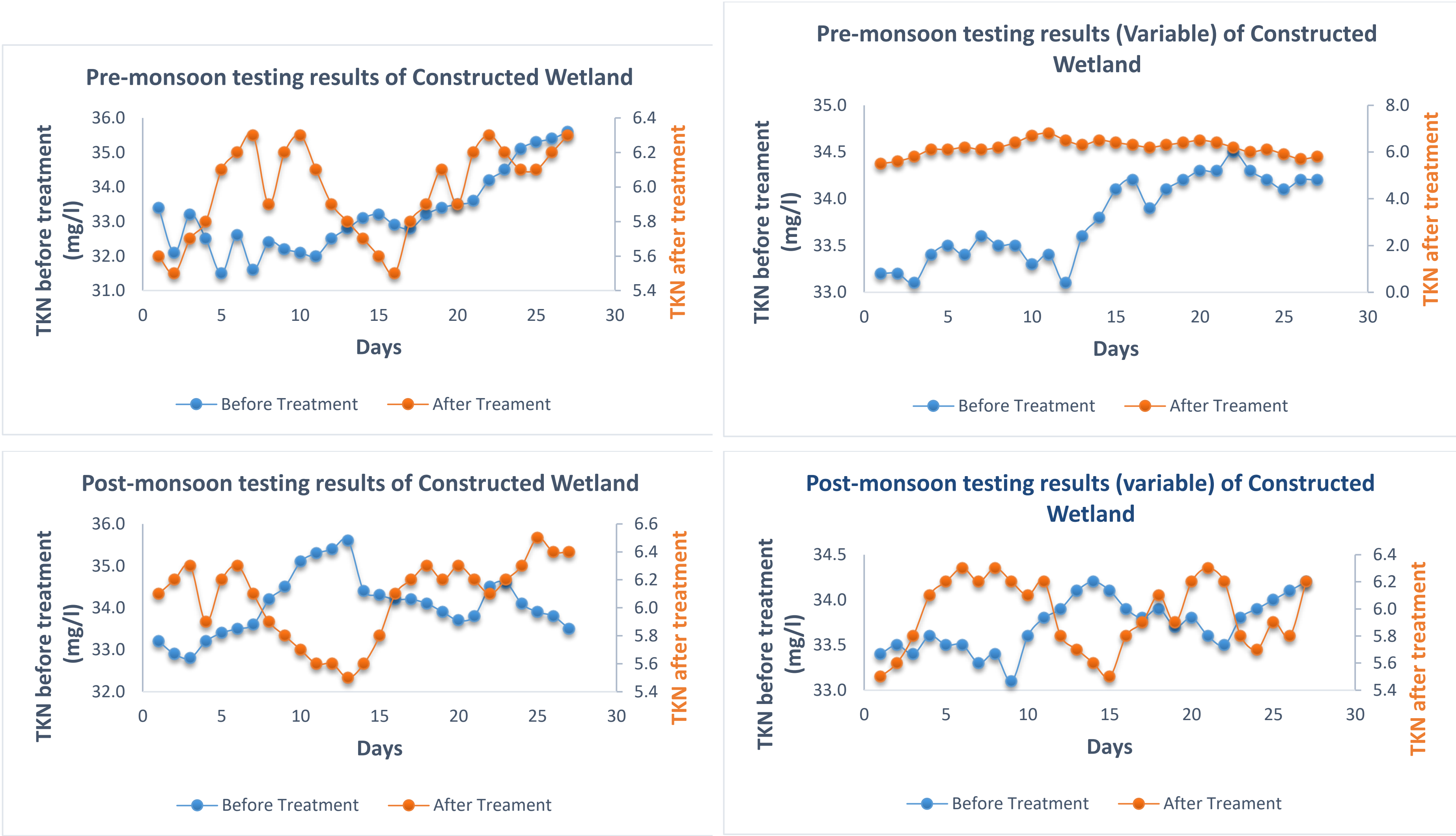

Figure 4.5: TKN test results of traditional Sewage treatment Plant

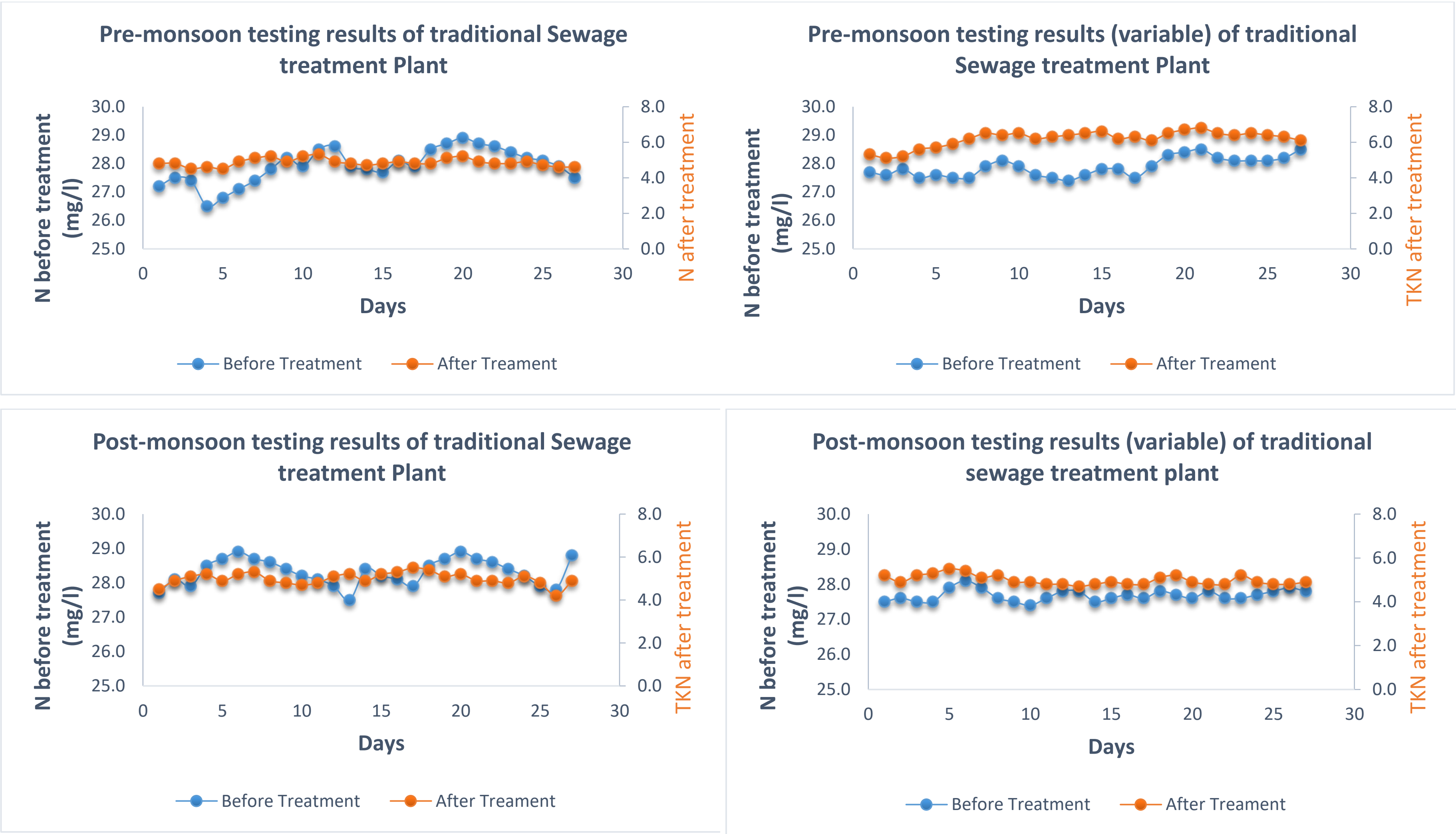

Figure 4.6: Nitrogen test results of traditional Sewage treatment Plant

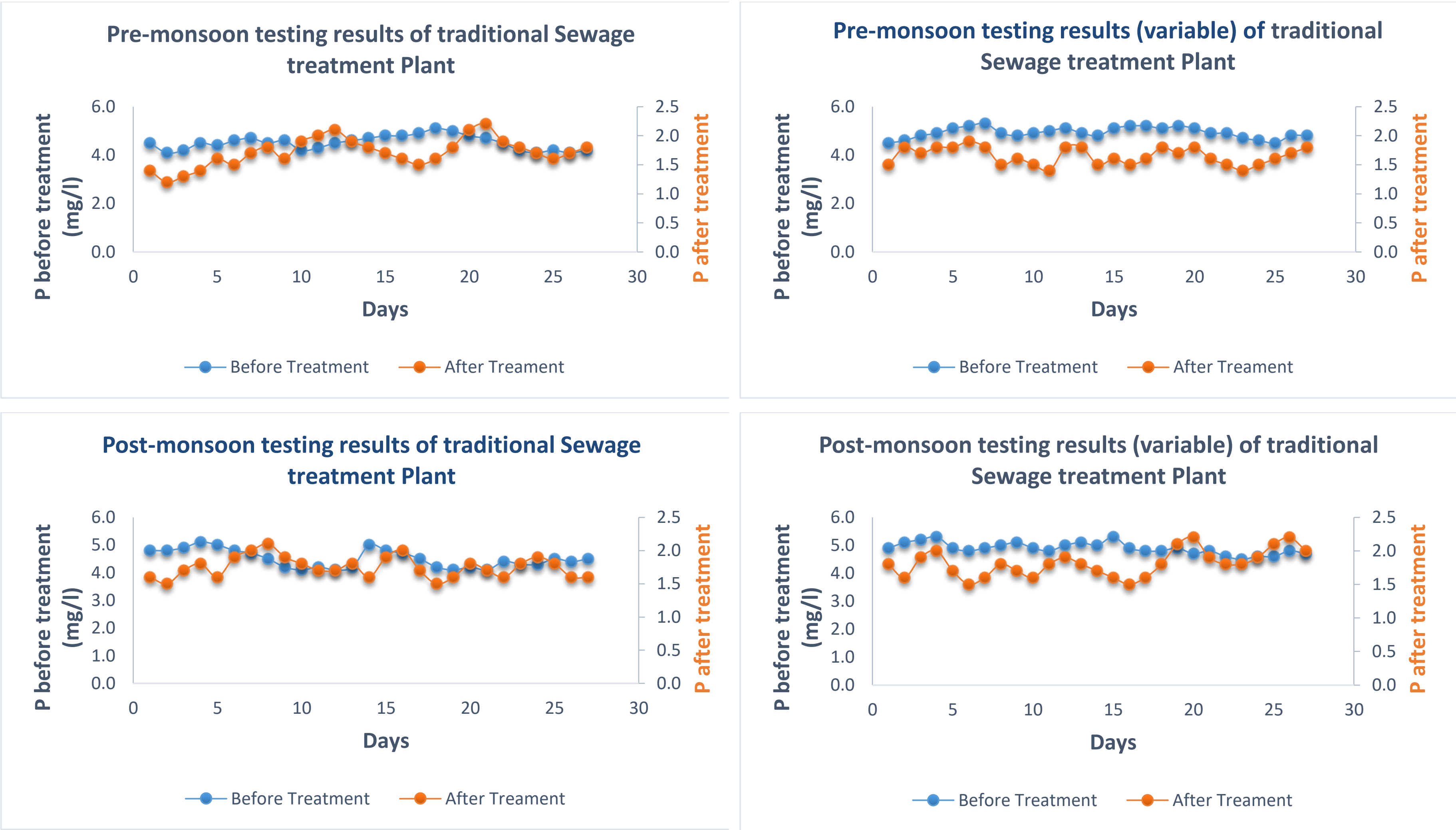

Figure 4.7: Phosphorus test results of traditional Sewage treatment Plant

Figure 4.7 summarized the testing results of phosphorus content presence in the domestic sewage. Since the source of phosphorus is human excreta, various detergents used for washing cloth, etc. hence the content of the P has been found at the inlet as 4.51 mg/l which is higher as compared to the prescribed value. After the process in STP, the P content decreased to 1.71 mg/l due to the various process involved in STP such as Screening, Sedimentation tank, Filters, etc. Post-monsoon results shown similar results as 4.5 mg/l and 1.7 mg/l at inlet and outlet respectively. The efficiency of removal of P does not get effected even after the change is the temperature as well as during the variable discharge as well. Even standard deviation results shown the continuity in the process and negligible variation of P content as the value at inlet found as 0.2 and 0.1 at outlet. This shows the higher effectiveness of the STP system.

Figure 4.8 indicate the results of sulfates content presence in the wastewater. Since the sulfates are natural occurring anion in surface and subsurface water hence the presence of the same is obvious hence if the wastewater directly disposed into the natural water body then SO4 content shall goes into the higher level and will give bitter taste. Hence the removal of SO_4 is again an important parameter. The testing is done by following IS code 3025 (Part 24). The pre-monsoon results indicate 46.9 mg/l presence of sulfates at inlet of STP and 26.9 mg/l at the outlet. Although, the system is not that much effective but the same is under the permissible limit which can be further disposed into water body. In case of Post-monsoon season, the Content of sulfate found out to be 47.1 mg/l at the inlet and 25.7 mg/l at the outlet hence results seems slight better as compared to Pre-monsoon results. In case of variable discharges, the efficiency decreases to 35.3 mg/l from 47 mg/l at the temperature of 24.6 degree Celsius and 23.6 degree Celsius respectively.

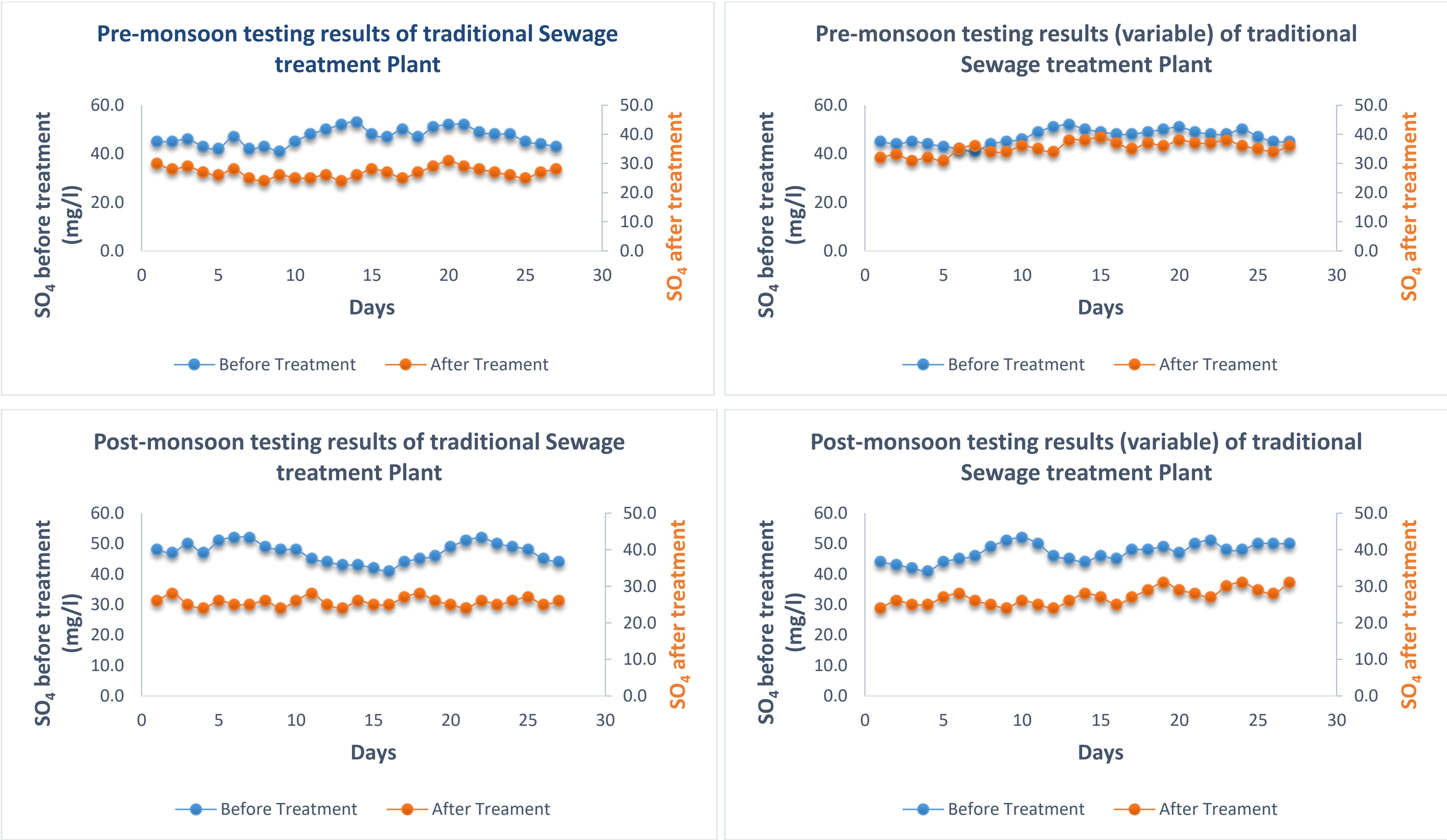

Figure 4.8: Sulphate test results of traditional Sewage treatment Plant

4.3 Testing results of Constructed Wetland

Table 4.5 summarized the testing results of constructed wetland during the Pre-monsoon season. In the initial testing results, the characters of the influents used in this study are shown in table 1. All the tests were repeated thrice to arrive at the best values. The mean value at the inlet of CW is found to be 7.72 whereas after treatment, the pH valve goes down to 6.91 and hence, found effective in treating the wastewater. Throughout testing, the temperature was also monitored which has been observed as 26.15 ℃ at inlet and 26.52 ℃ at outlet, 4 hence it represents that temperature has negligible significance. Since the sewage comes through the run-off, the amount of total suspended solids (TSS) is found on higher side as 346 mg/l. As the wastewater goes through the dense layer of plantation and fine layer of base and sub-base course, the value of TSS comes down to 18.07 mg/l at the outlet.

Table 4.5: Pre-monsoon testing results of Constructed Wetland

Parameter	**Mean**		**Median**		**Standard Deviation**		**Permissible limits as per CPCB**	**Standard/ Specification/ Method followed**
	Before Treatment	**After Treatment**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**		
pH	7.72	6.91	7.8	6.9	0.15	0.15	6.5-9.0	IS 3025 (Part 11)
Temp. C	26.15	26.52	26.2	26.5	0.18	0.17	< 30	-
TSS (mg/l)	346	18.07	346	18	2.6	1.21	20	IS 3025 (Part 17)
COD (mg/l)	37.4	8.67	37	8	1.62	1.78	50	IS 3025 (Part 58)
BOD (mg/l)	44.07	9.67	44	10	1.98	0.94	10	IS 3025 (Part 44)
TKN (mg/l)	35.05	9.44	35.2	9.4	0.38	0.21	< 10	IS 3025 (Part 34)
N (mg/l)	30.44	8.65	30.4	8.6	0.21	0.13	< 10	APHA 4500 B
P (mg/l)	7.49	2.56	7.5	2.6	0.14	0.16	2	IS 3025 (Part 31)
SO_4 (mg/l)	64.44	61.33	65	61	1.55	1.31	150	IS 3025 (Part 24)

Table 4.6 represents the Pre-monsoon testing results with variables of CW along with permissible limits. The results found slight decrease in pH content as the value found at inlet is 7.89 and after the treatment 6.89 at the outlet. There is not much variation in the results as standard deviation values shows the value of 0.12 which represents small variation. The TSS content found very high at the inlet which is 342.82 mg/l at the inlet. This presence of high content of TSS is found due to the variable discharge of wastewater. But after the process in CW, the values fall down to 20.63 mg/l with is acceptable. The testing of COD content has been done following IS 3025 (part 17) and found under the acceptable limit of COD of 50 mg/l but the same could be processed before disposing into water channel.

Table 4.6: Pre-monsoon testing results (variable) of constructed wetland

Parameter	**Mean**		**Median**		**Standard Deviation**		**Permissible limits as per CPCB**	**Standard/ Specification/ Method followed**
	Before Treatment	**After Treatment**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**		
pH	7.89	6.89	7.9	6.9	0.09	0.12	6.5-9.0	IS 3025 (Part 11)
Temp. C	26.37	26.61	26.4	26.6	0.12	0.12	< 30	-
TSS (mg/l)	342.82	20.63	343	21	0.98	1.66	20	IS 3025 (Part 17)
COD (mg/l)	37.49	8.33	38	8	1.07	1.25	50	IS 3025 (Part 58)
BOD (mg/l)	44.74	9.3	45	9	1.2	1.12	10	IS 3025 (Part 44)
TKN (mg/l)	34.13	9.51	34.2	9.6	0.15	0.23	< 10	IS 3025 (Part 34)
N (mg/l)	31.33	9.56	31.4	9.5	0.15	0.11	< 10	APHA 4500 B
P (mg/l)	7.65	1.93	7.6	2	0.09	0.12	2	IS 3025 (Part 31)
SO_4 (mg/l)	64.85	61.52	65	62	1.46	1.26	150	IS 3025 (Part 24)

Table 4.7 summarized the testing results of Post-monsoon season parameters. The average temperature during the post-monsoon season found 24.3 degree Celsius. During the Post-monsoon season, the similar kind of results are observed as found during the pre-monsoon which reflects the almost negligible effect of temperature on pH, TSS and other parameters. In case of pH content, there is declined in the value found from 7.82 to 6.73

which is acceptable as per standards of CPCB. The TSS content found 336.2 mg/l at the inlet and 18.59 at the outlet. P content has been found on the higher side even after the process in CW as the content at the outlet found 2.1 mg/l which is 0.1 higher as compared to the permissible limit set by CPCB.

Table 4.7: Post-monsoon testing results of Constructed wetland

Parameter	**Mean**		**Median**		**Standard Deviation**		**Permissible limits as per CPCB**	**Standard/ Specification/ Method followed**
	Before Treatment	**After Treatment**	**Before Treatment**	**After Treatment**	**Before Treatment**	**After Treatment**		
pH	7.82	6.73	7.8	6.7	0.13	0.11	6.5-9.0	IS 3025 (Part 11)
Temp. C	24.34	24.23	24.3	24.2	0.13	0.09	< 30	-
TSS (mg/l)	336.2	18.59	337	18	2.42	1.16	20	IS 3025 (Part 17)
COD (mg/l)	35.96	7.33	36	7	1.14	1.63	50	IS 3025 (Part 58)
BOD (mg/l)	42.5	8.63	42	9	1.46	0.48	10	IS 3025 (Part 44)
TKN (mg/l)	33.89	9.63	33.9	9.8	0.21	0.43	< 10	IS 3025 (Part 34)
N (mg/l)	30.68	9.4	30.7	9.5	0.14	0.28	< 10	APHA 4500 B
P (mg/l)	7.62	2.1	7.6	2.1	0.1	0.08	2	IS 3025 (Part 31)
SO_4 (mg/l)	62.96	62.78	63	63	1.32	3.1	150	IS 3025 (Part 24)

Table 4.8 summarized the post-monsoon results along with variable discharge after the treatment through CW. The results indicate the system in effectiveness of the CW in all the parameters. The BOD content in wastewater falls from 41.09 mg/l to 9.41 mg/l which is highly impressive. The system works in effective way even after the variation in the discharge and at the lower temperature as compared to the pre- monsoon season. But in case of SO4, the results seem surprising as the content of SO4 increased to 64.7 mg/l from 61.52 mg/l. The same is happening due to the presence of small boulders and pebbles. However, SO4 value found still under the permissible limit set of CPCB hence safe to be disposed into the water body.

Table 4.8: Post-monsoon testing results (variable) of Constructed Wetland

Parameter	Mean		Median		Standard Deviation		Permissible limits as per CPCB	Standard/ Specification/ Method followed
	Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment		
pH	7.87	6.87	7.84	6.9	0.08	0.1	6.5-9.0	IS 3025 (Part 11)
Temp. C	24.27	24.22	24.2	24.2	0.16	0.15	< 30	-
TSS (mg/l)	336.74	20.78	337	21	1.07	1.55	20	IS 3025 (Part 17)
COD (mg/l)	35.7	7.33	335	7	1.27	2.45	50	IS 3025 (Part 58)
BOD (mg/l)	41.09	9.41	141	9	0.97	1.13	10	IS 3025 (Part 44)
TKN (mg/l)	33.73	9.56	33.7	9.6	0.1	0.45	< 10	IS 3025 (Part 34)
N (mg/l)	30.61	9.26	30.7	9.2	0.17	0.31	< 10	APHA 4500 B
P (mg/l)	7.64	1.98	7.6	2	0.06	0.1	2	IS 3025 (Part 31)
SO_4 (mg/l)	61.52	64.7	61	65	1.6	1.33	150	IS 3025 (Part 24)

Figure 4.9 shows the testing results of pH parameter for various seasons. It is important to find out the pH as the high amount of freely moving hydrogen lends to make sewage more acidic and if the number of free hydrogen is less than hydrogen ions it becomes basic. pH has the ability to effect the sewage chemically hence presence of hydrogen ion become essential to monitor. Figure 4.9 represents the testing result of pH where the median value comes out to be 7.8 at the inlet chamber and 6.9 at the outlet chamber. The decline of 0.9 pH represents the effectiveness of processes involved in CW. The standard deviation value has been observed as 0.15 during, before and after treatment of wastewater. During the stretch of testing samples, the process shows the reliability in the process since the results are found consistent and reliable. Similar results are found in case of pre-monsoon with variables. The pH value falls from 7.89 to 6.89 which shows the effectiveness of the CW system.

During the Post-monsoon testing results the average temperature found 24.34 ℃ at the inlet and 24.23 ℃ at the out let. However, the change of temperature did not impact the system efficiency and pH found 7.82 at the inlet which is higher than desirable limit. But after the treatment at CW, the value came down to 6.73. In case of testing results of post-monsoon with variables, the efficiency decreased negligible from 7.87 to 6.87 which is slightly higher than the previous results. The overall results indicate the CW is able to deal with pH parameter in all types of weather conditions.

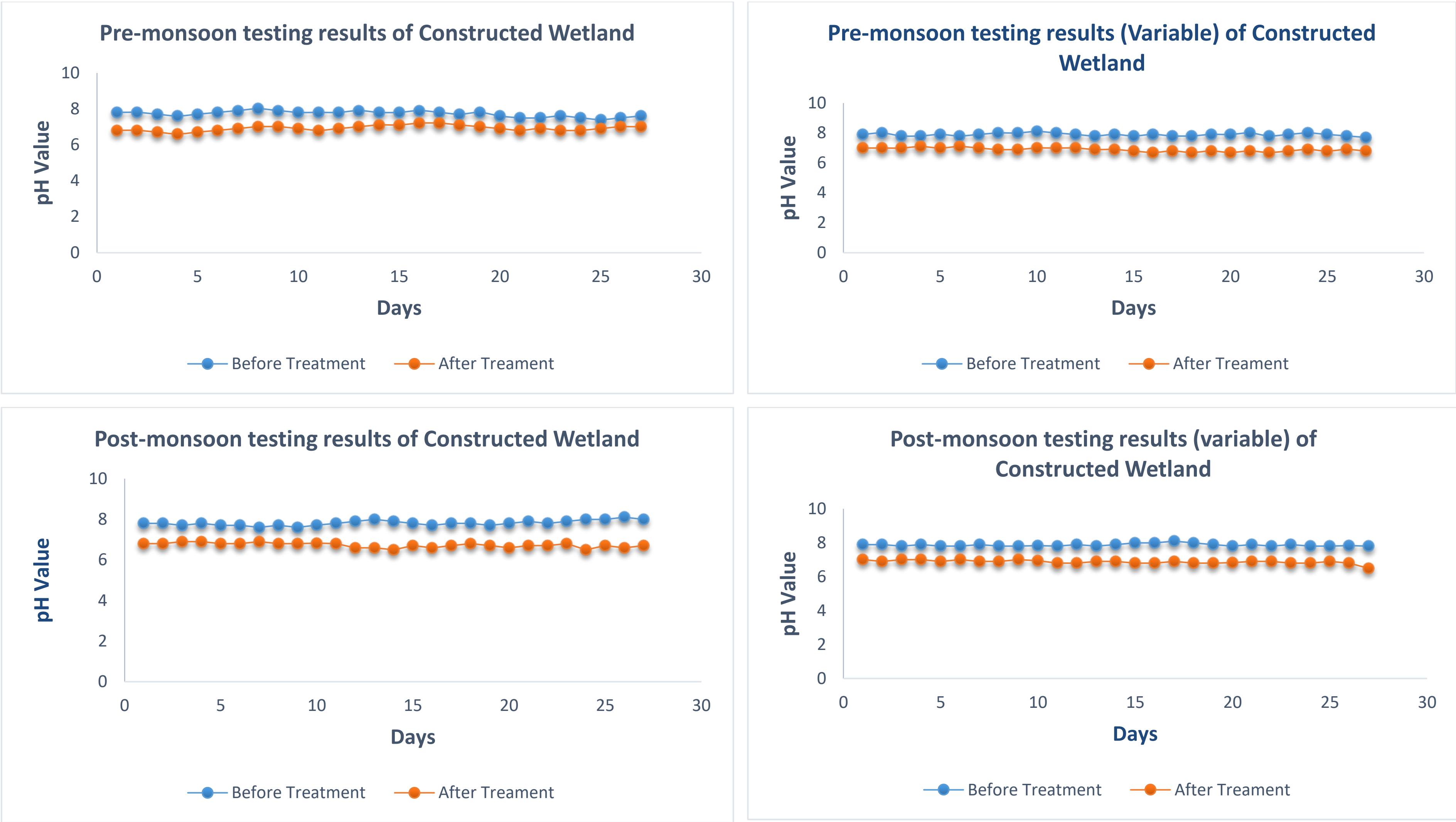

Figure 4.9: pH value of Constructed Wetland Samples

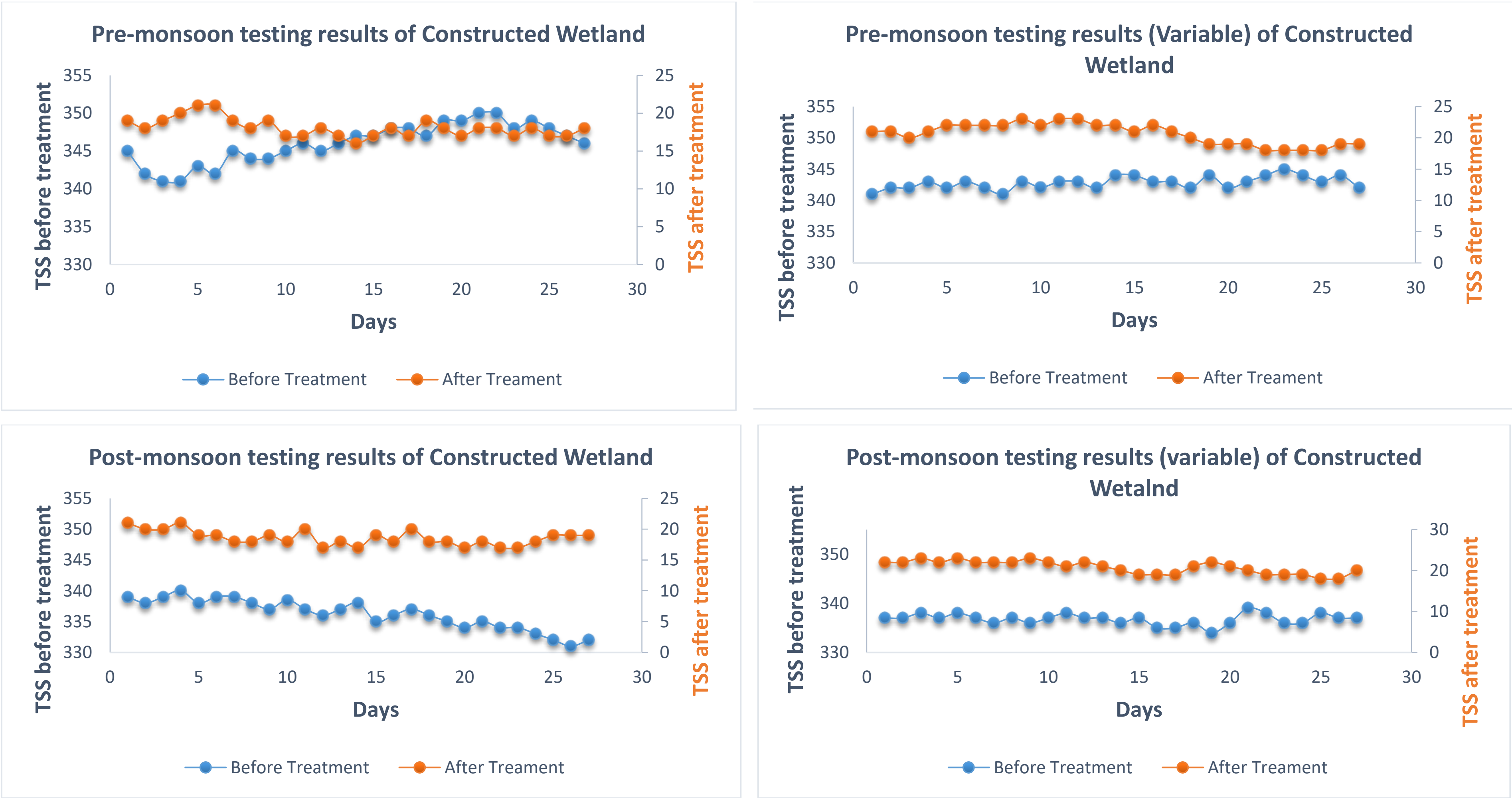

Figure 4.10: TSS value of Constructed Wetland Samples

The domestic wastewater generally consists of pathogens and heavy metals which contaminates the environment. Human activities increase the hazardous elements in wastewater such as bacteria, lead, mercury and pesticides which not only harm the environment but also contaminates the groundwater, hence it is important to find the presence of TSS in wastewater. Figure 4.10 represents the higher value of TSS 346 mg/l present in the wastewater at inlet of CW. Due to the process of sedimentation and filtration, the presence of TSS comes down to 18.07 mg/l which is acceptable as per permissible limit prescribed by CPCB. The gradual reduction in the content of suspended solids represents the promising process of purifying the wastewater. Since the amount of suspended solids comes under the permissible limit, the water can be discharged into natural stream such as rivers, canals, reservoirs, etc. The further wastewater can be used for irrigation, agriculture, and construction activities, etc. when it comes to variable flow in CW, as shown in figure 4.10, the treatment system does not get effected much due to change in temperature as well as with variable. The results seem quite promising and the processed water can be disposed into the water channels.

In the system of CW, the existence of organic matter substances allows higher concentration of chemical oxygen demand. The COD found to be effectively removed from the wastewater and noted as per permissible limit 50 mg/l as per CPCB. The experimental testing of 27 days' samples shows consistency in the removal of COD content after the retention time of 24 hrs. The efficiency of CW is found to be nearly 80 percent to process the wastewater. Figure 4.11 represents the samples testing results of COD which indicates the presence of dissolve oxygen present is wastewater. The COD value is identified since it gauges the short term effect on wastewater effluents. The COD content has been decreased to 8.67 mg/l from 37.4 mg/l which represents the effectiveness of CW. The standard deviation values at inlet lies at 1.78 which also reflects the flocculation in COD content due to human activities. The COD content in case of variable discharge found out 37.49 mg/l at the inlet and 8.33 mg/l at the outlet. However, in this case the standard deviation value found is 1.07 at inlet and 1.66 at the outlet. The higher variation in the standard deviation is due to the variable discharge. The COD removal capacity does not get effected due to the lower temperature as COD found at inlet during the post-monsoon season with average temperature of 24.34 degree Celsius is 35.96 mg/l and 7.33 at the outlet of the CW. As expected in case of post monsoon with variable testing samples results, the standard deviation value found 1.27 at the inlet and 2.45 at the outlet. The same is happen due to the variable discharge.

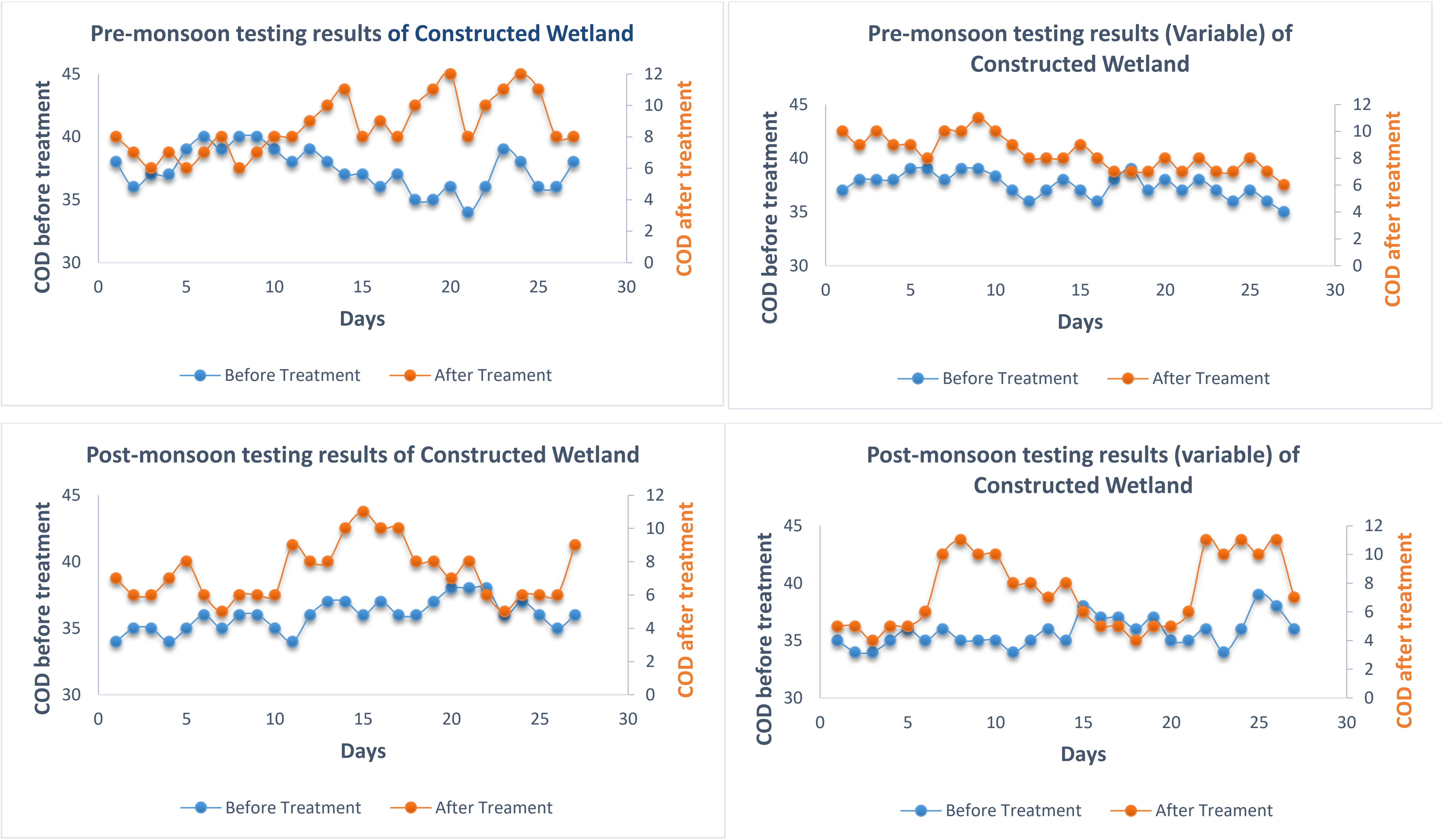

Figure 4.11: COD value of Constructed Wetland Samples

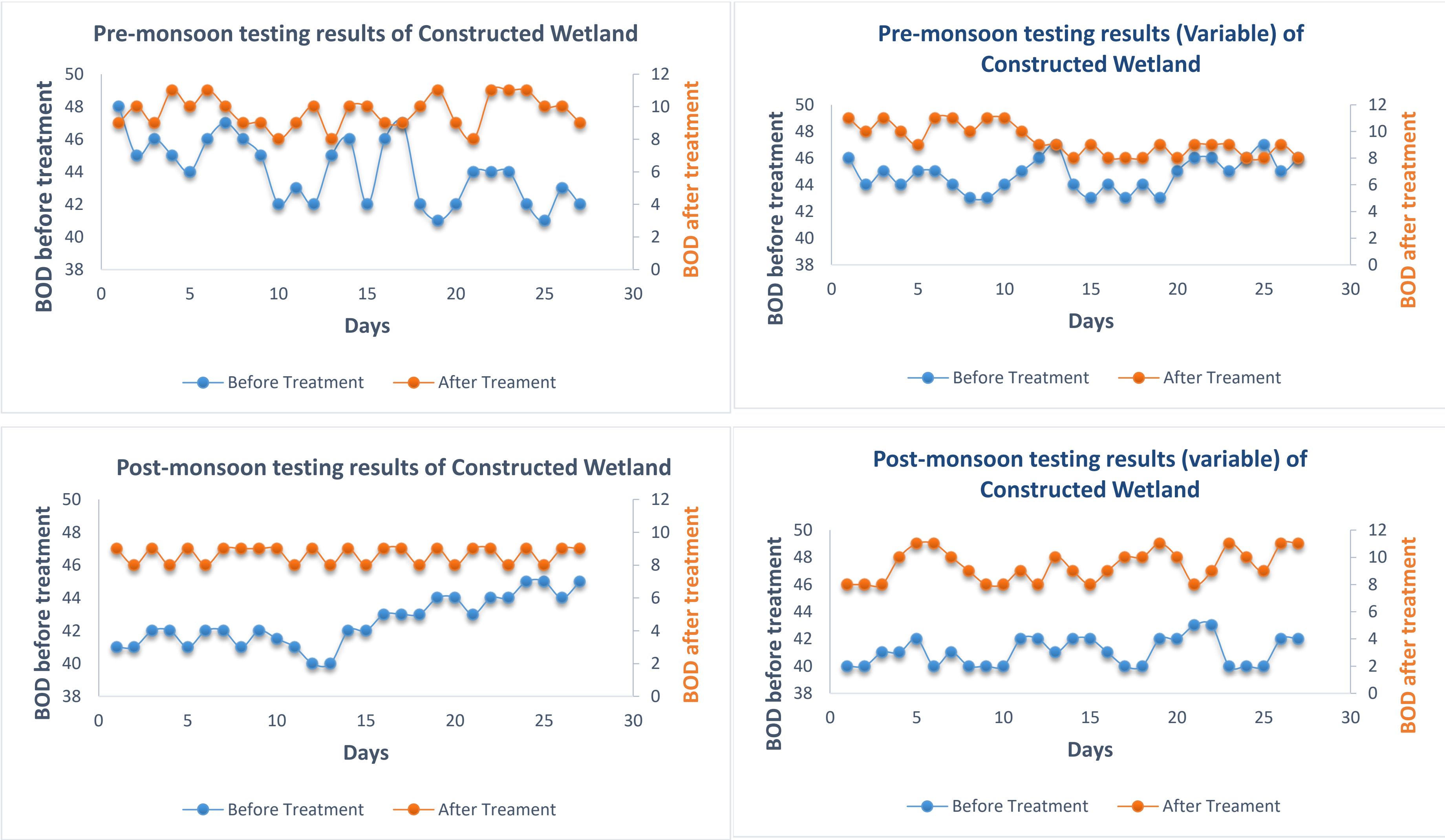

Figure 4.12: BOD value of Constructed Wetland Samples

Similar to COD, as shown in Figure 4.12, BOD also shows promising results as the outlet value reduce to 9.67 mg/l as compared to inlet value of 44.07 mg/l in CW. The removal of BOD in vegetated submerged wetland is happening due to the aerobic microbial degradation and sedimentation processes. The standard deviation values of BOD samples show the value as 0.94 which reflects the consistency in the process. Since the BOD is one of the important parameter as it assesses the effect of discharged waste water on aerobic biological organisms. When it comes to variable discharge, there is no effect of variable discharge since the BOD content found 44.74 mg/l at the inlet and 9.3 mg/l at the outlet. Similar to the COD, there is not much impact of change in temperature of BOD parameter. The average temperature found during the post-monsoon is 24.34 degree Celsius and BOD content found 42.5 mg/l at the inlet. After the process in CW, the temperature further reduces to 24.23 degree Celsius and BOD content is 8.63 which is acceptable. When it comes to variable discharge, the BOD content found 41.09 mg/l and 9.41 mg/l at inlet and outlet respectively.

TKN helps to find out the total concentration of organic nitrogen and ammonia. Since ammonia helps to provide nitrogen to plants, hence the growth of plants in CW can be monitored. High amount of total nitrogen leads to over plantation in CW and can clog the pores thereby significantly affecting the processing of the wastewater. As shown in the figure 14, the TKN value found to be 9.44 mg/l at outlet which is reduced from 35.05 mg/l at inlet. The high content of TKN not only effects the efficiency of CW but also increases the vegetation in case the water is disposed-off into natural water body like rivers, reservoirs, etc. When it comes to variable discharge, the TKN found higher 34.13 mg/l prior to the treatment and 9.51 mg/l after the treatment in the CW. In case of Post-monsoon results, the TKN content found to be 33.89 mg/l at the inlet which will increase plantation if it directly disposed into the water body. But after the process, the TKN falls to 9.63 mg/l which is acceptable. TKN in important factor not only in terms of disposal of wastewater into water body but also it will increase plantation in CW itself in case of higher TKN value which will further clog the CW process. The similar kind of results found in case of variable discharge as well where the TKN content falls from 9.56 mg/l to 33.73 mg/l which is suitable to dispose the water as per CPCB.

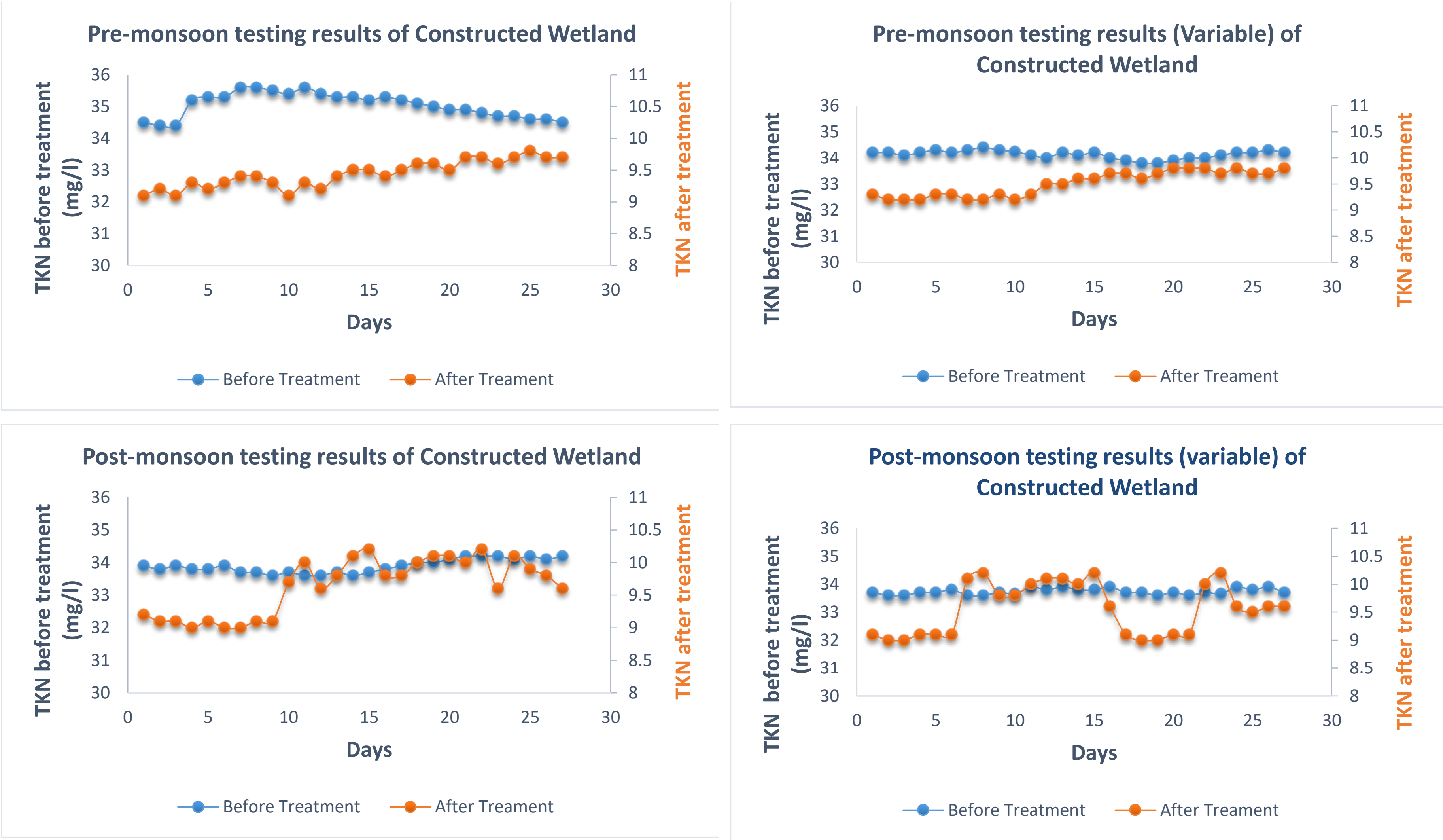

Figure 4.13: TKN value of Constructed Wetland Samples

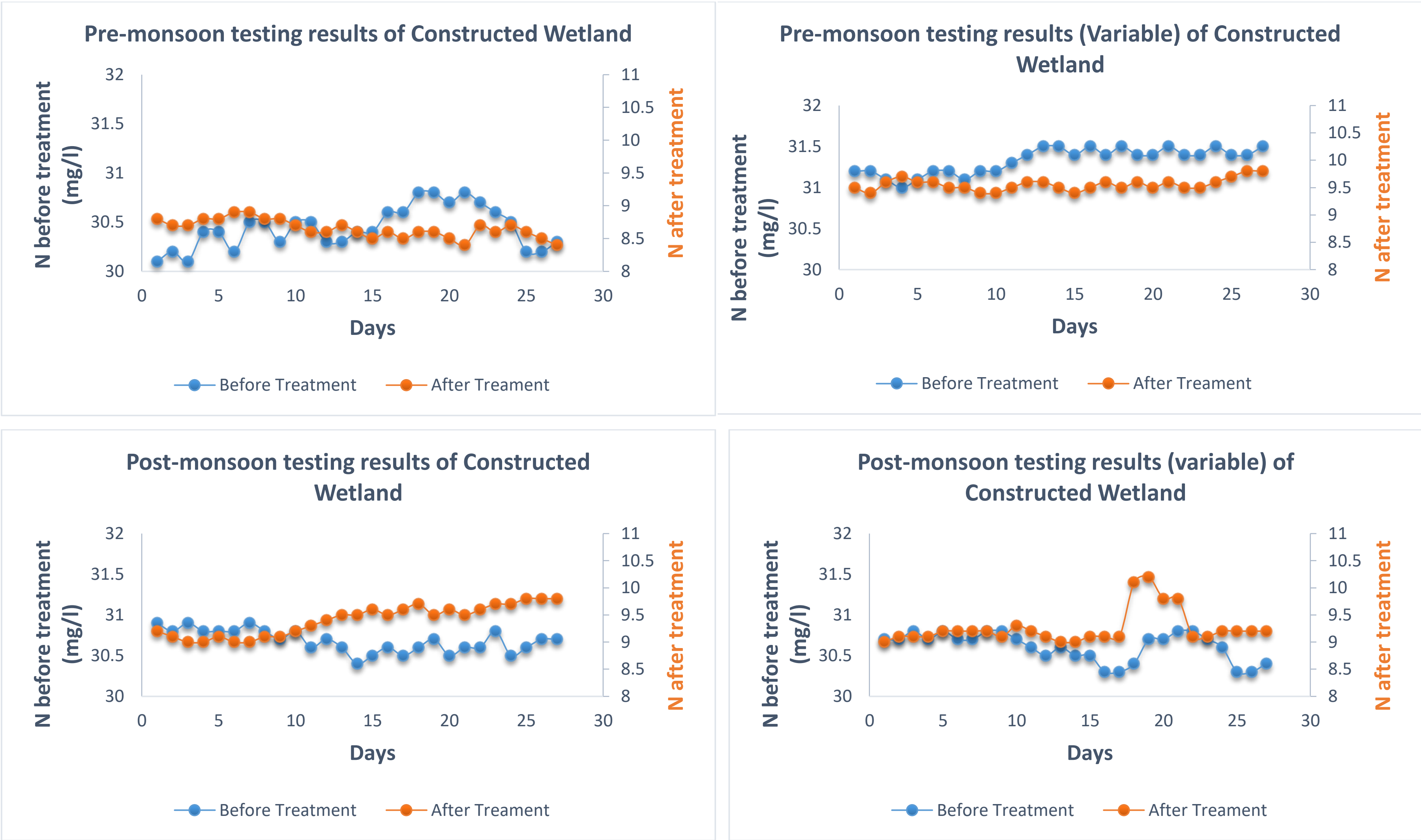

Figure 4.14: Nitrogen value of Constructed Wetland Samples

Figure 4:14 The domestic waste is generally consisting of human waste, food from kitchen, certain types of soaps and detergents which are the source of nitrogen in wastewater. The quantity of nitrogen also depends on population, higher the population, higher will be nitrogen content in waste water. The different plant species, differs with preferred form of nitrogen absorbed along with type of soil. The content of nitrogen during the pre-monsoon testing samples in CW is found to be 30.44 mg/l at the inlet and 8.65 mg/l at the outlet chamber. Moreover, since it is a natural process, the standard deviation value also shows the promising results as 0.21 and 0.13 at inlet and outlet, respectively. The effectiveness of CW comes out to be more than 80 percent. The pre-monsoon variables results show the higher content of N at the inlet as 31.33 mg/l and 9.56 mg/l at the outlet of CW. The higher variation found during the post-monsoon with variables discharge. The curves show certain increase in the content of N. The same is happening due to the change in the flow due to which participles which were settle down, they start floating ion wastewater. However, after the entire process in the CW, the average content of N found as 9.26 mg/l which is lesser than the CPCB permissible limit of 10 mg/l. The higher content of the N can also be due to the dead animals and their wastes which should be kept away from the CW for its efficient working.

Figure 4.15 represents the variation in phosphorous content in wastewater samples. Before treatment the pre-monsoon testing sample shows the mean value of 7.49 mg/l which is higher than prescribed limit of CPCB. After the treatment value goes down to 2.56 mg/l but does not able to satisfy the standards of wastewater disposal. As per standards the value should not be more than 2 mg/l hence it will lead to higher plant and animal growth. The main sources of phosphorous in wastewater in human excreta and some detergents. Hence it is important to control the amount of phosphorous. The pre-monsoon variable discharge shows the higher content of P 7.65 mg/l which is very harmful and cannot be directly disposed as it will contaminate the water. But after the process in the CW, the P content found under the permissible limit of 2 mg/l. In case of post monsoon results, the P content was 7.62 mg/l prior to the treatment and 2.1 after the treatment which is still 0.1 higher than permissible limit. The variable discharge shows the better results as value after the entire process as 1.98 mg/l which is acceptable.

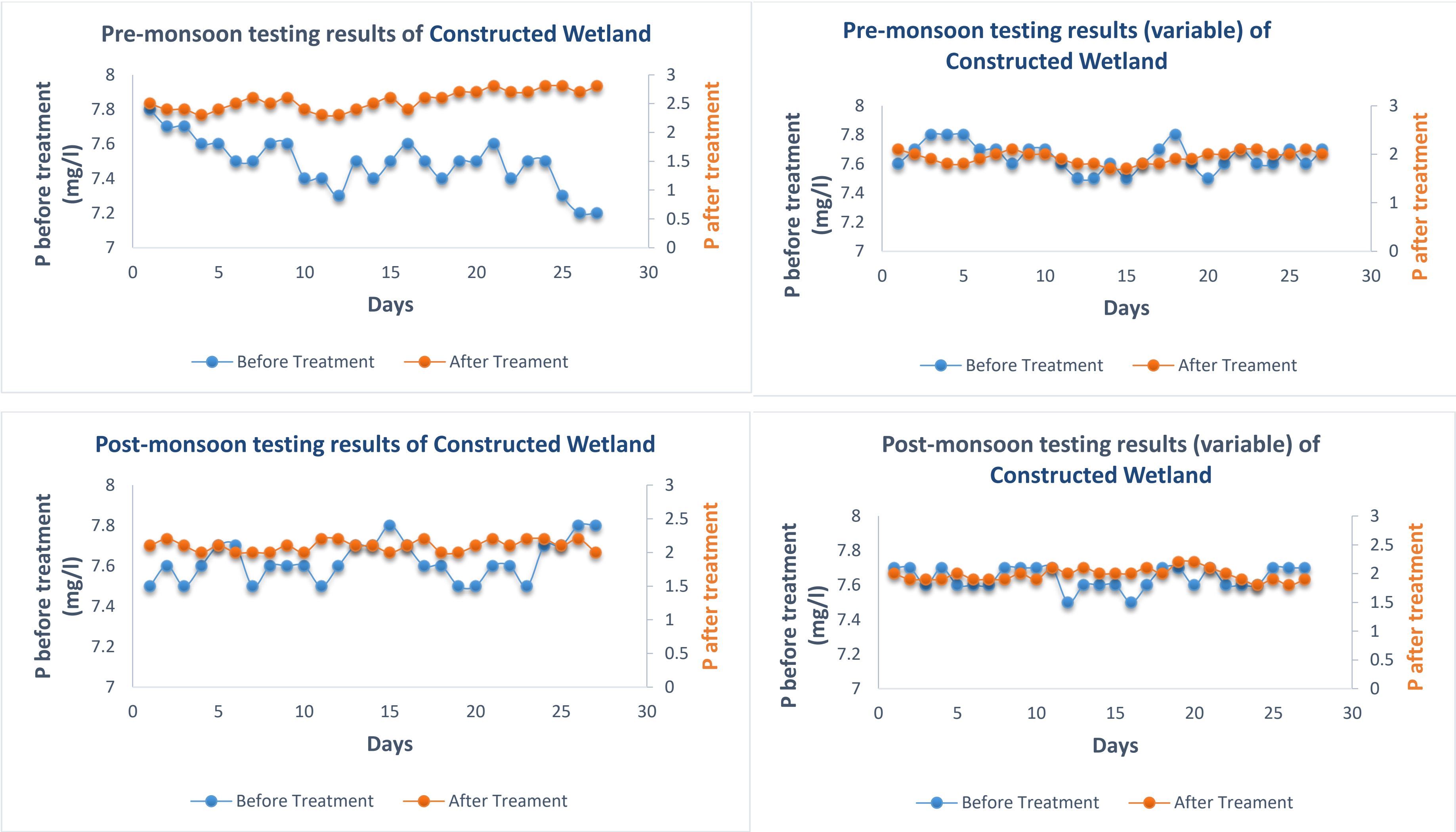

Figure 4.15: Phosphorus value of Constructed Wetland Samples

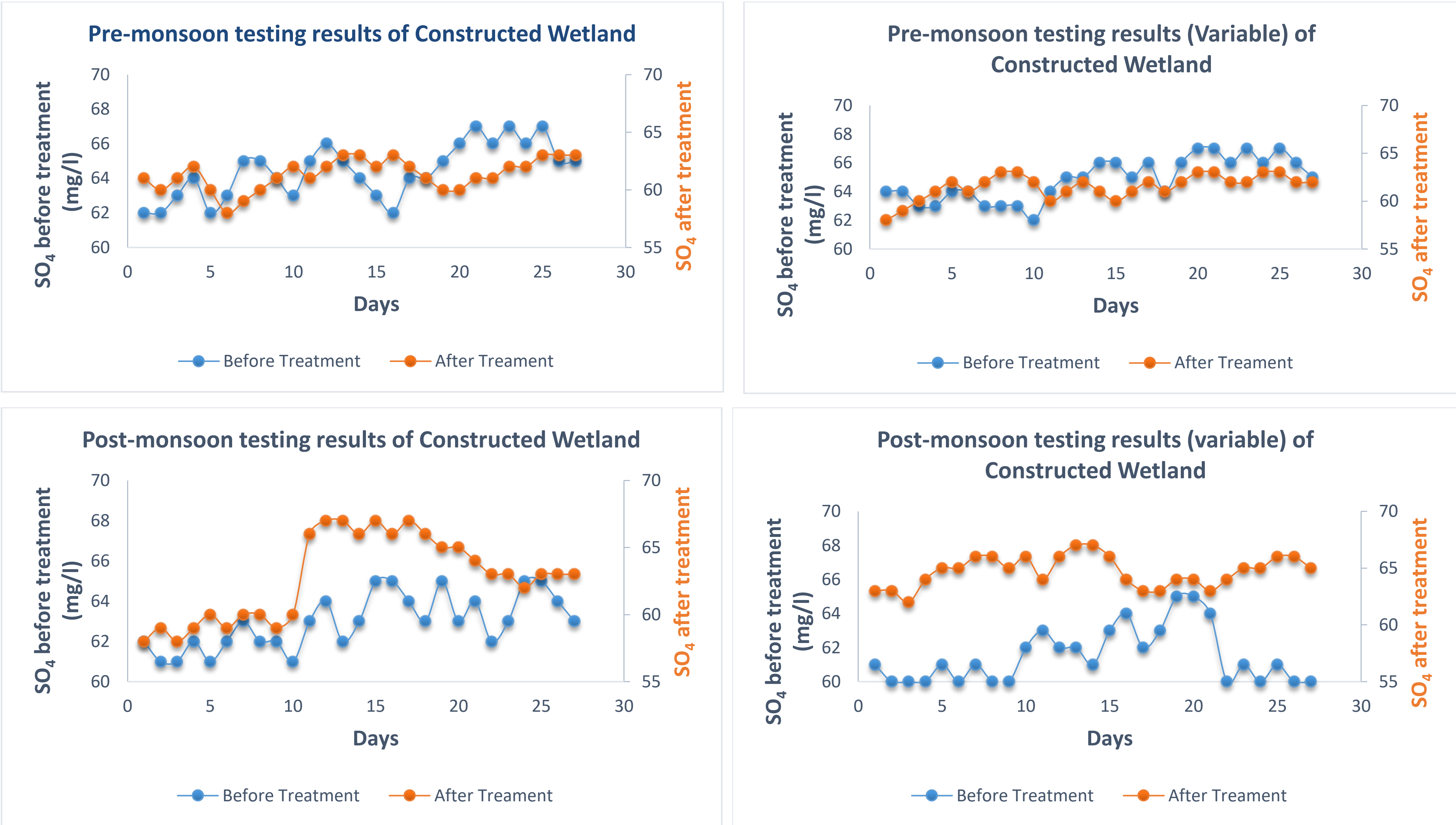

Figure 4.16: Sulphate value of Constructed Wetland Samples

The main source of sulfate in the wastewater is freshwater from ground water or surface water. Sulfate is not only present in domestic wastewater but also in freshwater as well. Since it is natural process and can affect the taste of the water in natural streams, it is important to check the amount of sulfate present in wastewater. The results show lot of flocculation's in the results of testing samples as the standard deviation is 1.55 and 1.31 at inlet and outlet, respectively. The mean value of sulfate test samples shows inlet value 64.44 mg/l and outlet value 61.33 mg/l which is acceptable.

4.4 Comparison between Traditional Sewage Treatment Plant and Constructed Wetland

Table 4.9 represents the average efficiency comparison of traditional STP and CW. The results indicate CW have better efficiency as compared to the STP in case of pre-monsoon TSS results as the efficiency of STP is 94.7 percentile whereas the CW efficiency is 94.8 percentile. When it comes to variable discharge of wastewater they efficiency dropdown from 94.8 percentile to 94 percentiles hence indicates the CW perform better in case of constant flow of wastewater. STP is able to deal with variable discharge due to presence of collection chamber where entire wastewater first gets collected and then further move for treatment by using pumping system.

On the other hand, greater efficiency difference observed in case of COD since the efficiency of STP is found 87.3 percentile whereas CW efficiency is found 76.7 percentile. When it comes to post-monsoon results, the efficiency of CW increase to 79.5 percentile due to which it fulfils the norms of CPCB. Similar kind of results are observed in BOD testing samples where STP efficiency is found as 93.5 percentile and CW efficiency is 78 percentiles only. However, again in case of post-monsoon results, the efficiency increased to 79.7 percentile. TKN results shows the efficiency of STP 73.1 percentile in case of pre-monsoon and 72.1 percentile in case of variable discharge hence it has been observed that CW is capable to handle variable discharge of wastewater as well. This parameter helps to save the cost of construction of wastewater collection chamber and pumping cost as well.

The N results indicates the STP have higher efficiency as compared to the CW treatment. The pre-monsoon results indicate the 82.6 percentile efficiency of STP whereas CW have 71.6 percentile efficiency. However, the lower efficiency still able to fulfil the norms of CPCB to dispose the wastewater into water channel. Interestingly, the variable flow wastewater decreases the efficiency of both the treatment systems. It has been also found that there is not much difference in treatment process due to the temperature difference as post monsoon results indicates the similar kind of results as shown during the pre-monsoon results.

Table 4.9: Average efficiency Comparison of Traditional Sewage Treatment Plant and Constructed Wetland

Parameters	Pre Monsoon		Pre Monsoon (Variable)		Post Monsoon		Post Monsoon (Variable)	
	Sewage Treatment Plant (STP)	**Constructed Wetland (CW)**	**Sewage Treatment Plant (STP)**	**Constructed Wetland (CW)**	**Sewage Treatment Plant (STP)**	**Constructed Wetland (CW)**	**Sewage Treatment Plant (STP)**	**Constructed Wetland (CW)**
Total Suspended Solids (TSS)	94.7	94.8	94.8	94	94.6	94.5	94.8	93.8
Chemical oxygen demand (COD)	87.3	76.7	87	77.8	87.1	79.6	87.1	79.5
Biochemical oxygen demand (BOD)	93.5	78	93.3	78.2	93.5	79.7	93.1	77.1
Total Kjeldahl Nitrogen (TKN)	82	73.1	81.7	72.1	82.2	71.6	82.3	71.7
Nitrogen (N)	82.6	71.6	77.8	69.5	82.4	69.3	82	69.7
Phosphorus (P)	62	65.9	66.5	74.7	60.9	72.5	62.8	74.1
Sulfates (SO_4)	42.4	40.8	24.6	5.1	45.3	0.3	42.4	0

The CW found more efficient as compared to the STP process in case of P since the average efficiency in case of CW found 65.9 percentile and STP average efficiency found 62 percentiles. The efficiency further increased in case of variable discharge in both the cases but still CW performed better here. The CW treatment system lagged in case of SO_4 where the efficiency of STP observed 42.4 percentile and CW found 40.8 percentile only due to which treated water seems difficult to disposed into water streams. The efficiency further decreased to 0.3 percentile in case of post monsoon results which are not acceptable. Hence, the CW system can be used where the SO_4 content is found lesser in domestic wastewater. The efficiency found decreased due to the presence of natural aggregates present in the CW system which helps to treat the wastewater.

4.5 Pre-Monsoon Testing results:

Table 4.10 summarized the average efficiency comparison of STP and CW during the Pre-monsoon where it has been observed that CW has higher efficiency as compared to the STP. In case of TSS, the CW treatment system shows efficiency of 94.8 percentile whereas the STP efficiency observed as 94.7 percentile. Hence in this case CW has been found more reliable results. When it comes to the COD parameter, STP have better performance since it has 10.33 percentile higher efficiency as compared to the CW. However, CW tests results comes under the permissible limits set by CPCB. Similarly, BOD efficiency shows the effectiveness of the treatment system. The STP found more than 15 percent efficient than CW.

Table 4.10: Average efficiency comparison of Pre-Monsoon test results

Parameter	**Sewage Treatment Plant (STP)**	**Constructed Wetland (CW)**
Total Suspended Solids (TSS)	94.7	94.8
Chemical oxygen demand (COD)	87.3	76.7
Biochemical oxygen demand (BOD)	93.5	78
Total Kjeldahl Nitrogen (TKN)	82	73.1
Nitrogen (N)	82.6	71.6
Phosphorus (P)	62	65.9
Sulfates (SO_4)	42.4	4.8

Figure 4.17 shows both STP as well as CW treatment system able to remove the TKN content from domestic wastewater and observed the efficiency of 82 percentiles and 73.1 percentile respectively. When it comes to N content, STP efficiency found 82.6 percentile and 71.6 percentile in case of CW. The CW found higher efficiency by 3.9 percentile as compared to STP in case of P. The same is feasible due to biological treatment in CW which is essential before the wastewater disposed into water channel. The bag consists of alum which is cheaply available in the market, can also be dipped in the wastewater to remove the P content from

the domestic wastewater. The STP shows much higher efficiency in case of SO_4 where testing results shows STP has 42.4 percent efficiency whereas CW has 4.8 percent efficiency only. Hence, CW could be used where the less amount of SO4 content found in domestic wastewater.

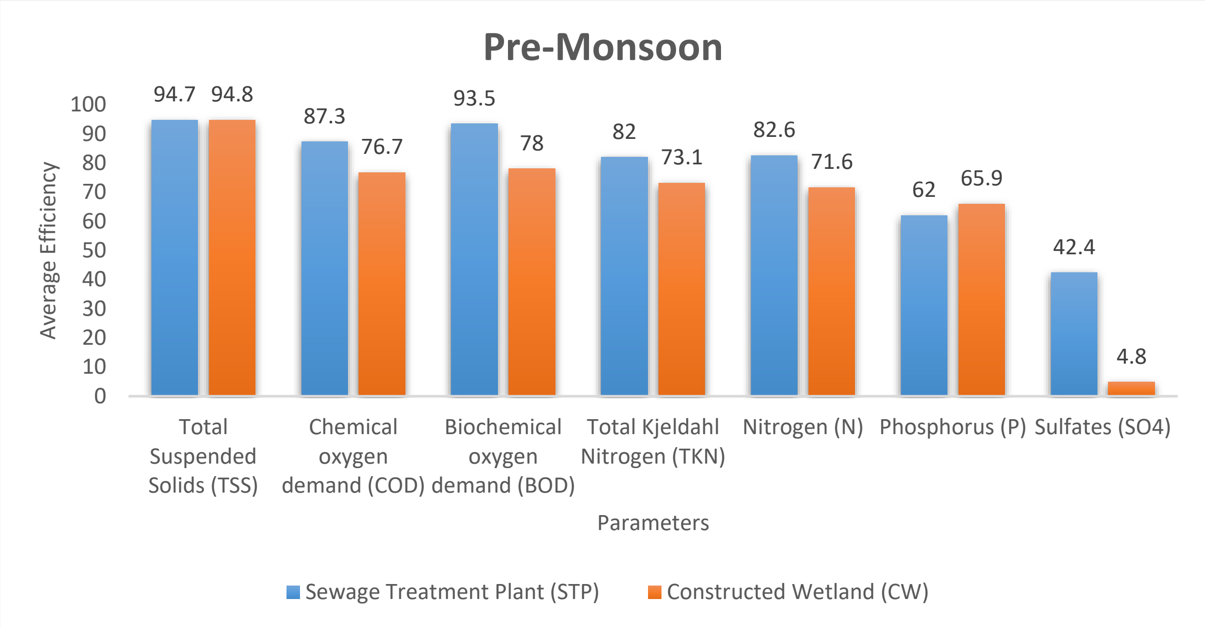

Figure 4.17: Average efficiency comparison of Pre-Monsoon test results

Table 4.11 indicate the average efficiency comparison of the Pre-monsoon results. The TSS value in case of STP comes out to 94.8 which is indicates STP is highly efficient and reliable.

Table 4.11: Average efficiency comparison of Pre-Monsoon with variables test results

Parameter	Sewage Treatment Plant (STP)	Constructed Wetland (CW)
Total Suspended Solids (TSS)	94.8	94
Chemical oxygen demand (COD)	87	77.8
Biochemical oxygen demand (BOD)	93.3	78.2
Total Kjeldahl Nitrogen (TKN)	81.7	72.1
Nitrogen (N)	77.8	69.5
Phosphorus (P)	66.5	74.7
Sulfates (SO_4)	24.6	5.1

Whereas CW process is found equally effective as the testing results represents 94 percentile efficiency. When it comes to COD results, the efficiency of CW found almost 10 percent lower than the STP but still results are found under the desirable limit. The effectiveness of the CW is further decreased to 15 percentiles in case of BOD.

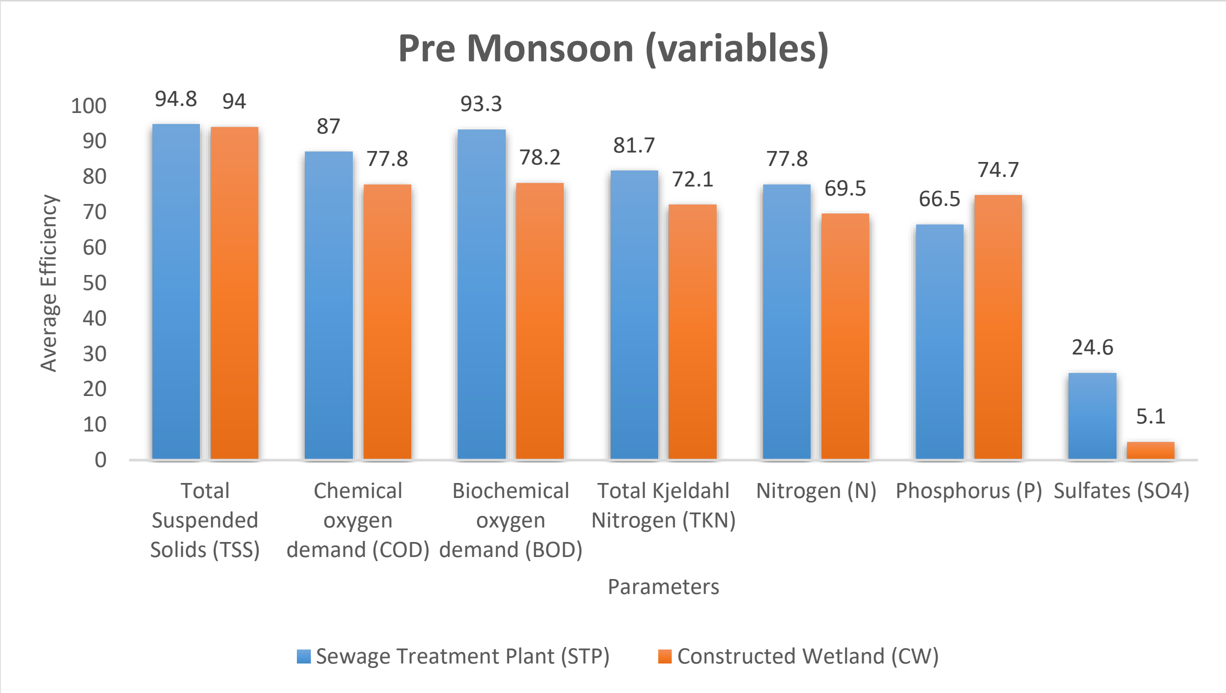

Figure 4.18: Average efficiency comparison of Pre-Monsoon with variables test results

Table 4.12: Average efficiency comparison of Post-Monsoon test results

Parameter	Sewage Treatment Plant (STP)	Constructed Wetland (CW)
Total Suspended Solids (TSS)	94.6	94.5
Chemical oxygen demand (COD)	87.1	79.6
Biochemical oxygen demand (BOD)	93.5	79.7
Total Kjeldahl Nitrogen (TKN)	82.2	71.6
Nitrogen (N)	82.4	69.3
Phosphorus (P)	60.9	72.5
Sulfates (SO_4)	45.3	0.3

Figure 4.19 represents the average efficiency comparison during the post-monsoon session. In case of TSS there is not much difference has been found in the efficiency of STP and CW

as the value comes out to be 94.6 percentile and 94.5 percentile respectively. COD and BOD are found similar as it was found during the pre-monsoon session hence it represents that the negligible impact of the temperature variation.

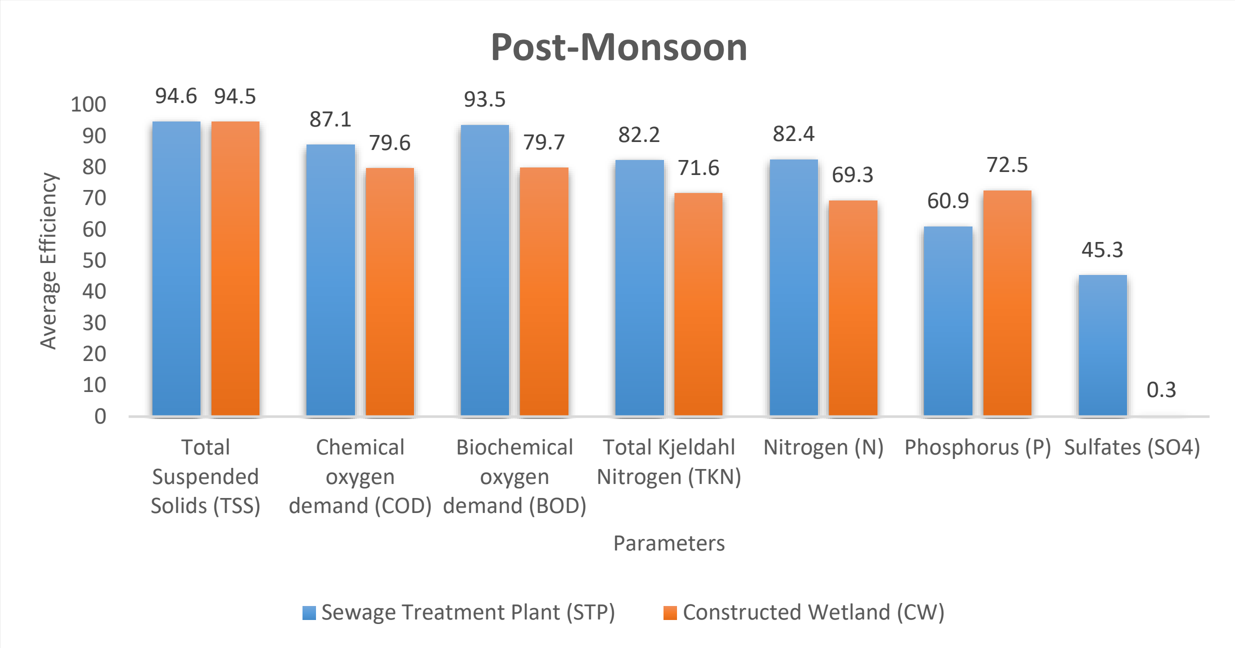

Figure 4.19: Average efficiency comparison of Post-Monsoon test results

The higher amount of the presence of TKN can lead to the excess growth of plants in natural water body. The CW testing results shows the value of TKN with 71.6 percentiles efficiency comes under permissible limit. Hence the CW is recommended for treatment of wastewater.

Table 4.13: Average efficiency comparison of Post-Monsoon with variables test results

Parameter	Sewage Treatment Plant (STP)	Constructed Wetland (CW)
Total Suspended Solids (TSS)	94.8	93.8
Chemical oxygen demand (COD)	87.1	79.5
Biochemical oxygen demand (BOD)	93.1	77.1
Total Kjeldahl Nitrogen (TKN)	82.3	71.7
Nitrogen (N)	82	69.7
Phosphorus (P)	62.8	74.1
Sulfates (SO_4)	42.4	0

Figure 4.20 indicates that's variation in the discharge does not have much impact of the treatment efficiency of CW since most of the parameter like TSS, COD and BOD shows

similar kind of results as shown during constant discharge. The average efficiency of removing Phosphorus from the wastewater in case of constructed wetland increased to 74.1 percentile as compared to STP which was 62.8 percentile.

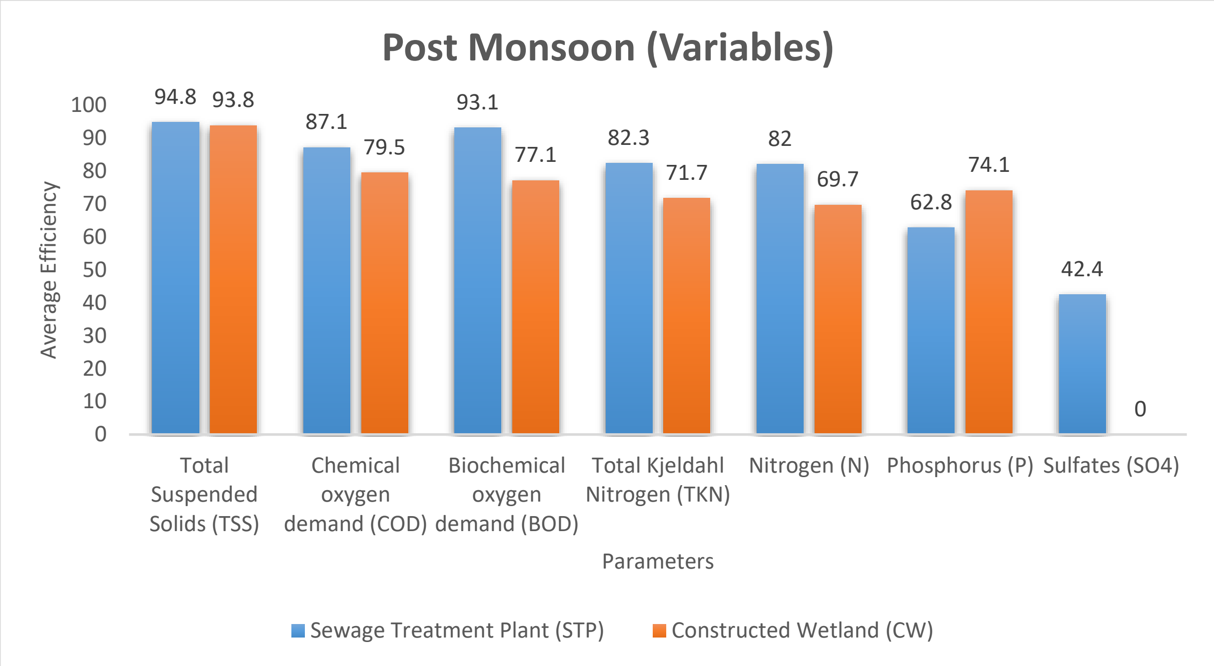

Figure 4.20: Average efficiency comparison of Post-Monsoon with variables test results

Considering the above analysis, it indicates that constructed wetlands are efficient structure to deal with wastewater as except of SO_4, all other values comes under the permissible limits set by CPCB. In case of Phosphorus, the efficiency of treating the wastewater found higher as compared to the STP. As shown in the results, the working of the CW did not get effected due to the change in the temperature or discharge. Here it is also important to mention that CW's are low cost structure and electricity requirement is almost negligible as compared to the STP hence it will reduce the cost of treatment. Moreover, presence of the CW seems more environment friendly and provide more esthetic looks. The efficiency of the constructed wetland can be further increased upto 30 percentile (e (UN-HABITAT, 2008) by providing the preliminary and primary treatment process in constructed wetland which has been designed as follows.

4.6 Design of Preliminary/Primary treatment of Constructed wetland

The current population of Bambianwali village is 2040 (as per 2011 population count) with 414 houses in the village, hence by using population forecasting method, the population comes out to be 3500.

4.6.1 Preliminary Treatment:

Design of screen: Following are the data considered for design of screens:

Population: 3500

Wastewater flow: 80 liters per day per person.

Average volume of waste water, Q : $3500 \text{ x } \left(\frac{80}{1000}\right)$ = 280 m^3 /day

Peak flow: $\frac{280000}{24*60*60}$ = 3.24 cum/sec

Let us assume velocity through screen cannot allowed to exceed 0.8 m/sec

Hence, Net area of screen opening: $\frac{3.24}{0.8}$ = 4.05 m^2

Provided,

Width of rectangular steel bars: 4 cm, clear spacing between bars: 5 cm

The gross area of the screen required: $4.05 * \frac{6}{5}$ = 4.86 m^2

Assuming the bars placed at 60 degrees to horizontal, hence

Gross area of the screen needed: $4.86/\sqrt{\frac{3}{2}}$ = 5.61 m^2

Hence, coarse screen of 5.61 m^2 area is required.

4.6.2 Primary treatment:

Design of septic tank: Following are the data considered for design of septic tank:

Two chambers of septic tank

Hydraulic retention time (HRT): 1.5 days (assume) = 36 hours.

Required volume of the septic tank: Q x HRT

: $280 * 1.5$ = 420 m^3

Volume of the first compartment of the septic tank: 2/3 of required volume

: $\frac{2}{3} \text{x } 420$ = 280 m^3

Volume of second compartment of the septic tank: 1/3 of required volume

: $\frac{1}{3} \text{x } 420$ = 140 m^3

- Depth of septic tank: 3 m (assume)
- Width of septic tank: 7 m (assume)

Hence, Length of the first compartment: Volume/ (Depth x Width)

$$: 280/(2.7\ x\ 7)$$

$$: \frac{280}{18.9} = 14.8\ m$$

Length of the second compartment: Volume/ (Depth x Width)

$$: 140/\ (2.7\ x\ 7)$$

$$: \frac{140}{18.9} = 7.4 \text{ m}$$

Free board of 0.3: 3 – 0.3 = 2.7 m

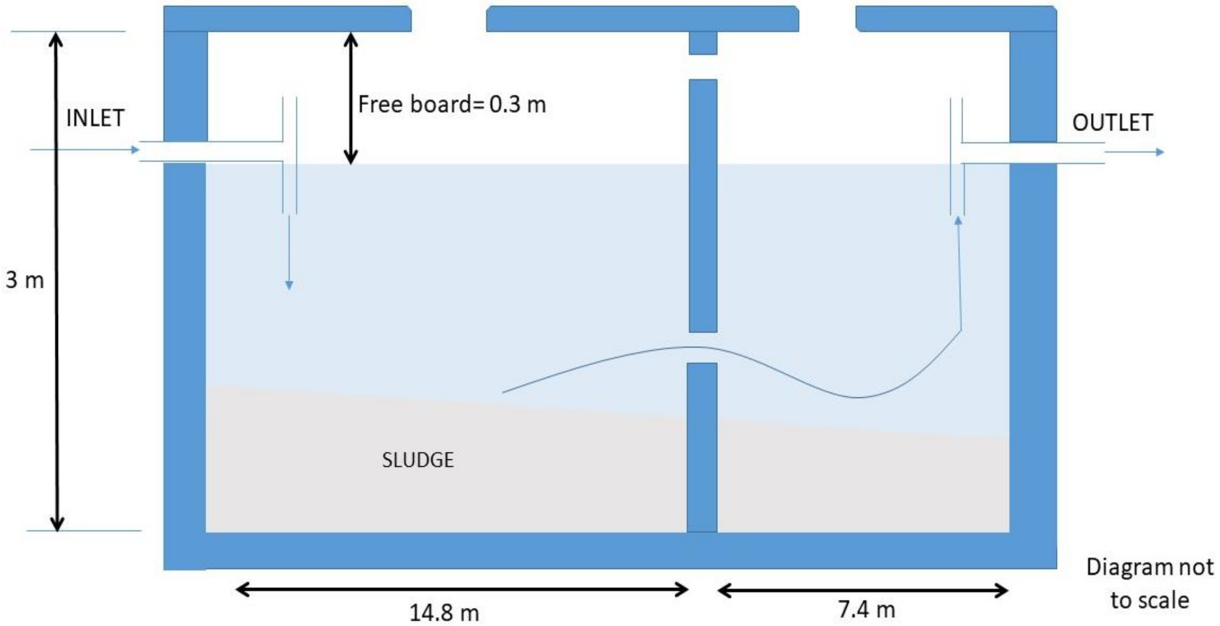

Figure 4.21: Schematic cross-section of a two component septic tank

Check HRT after sludge accumulation

Sludge accumulation rate: 70 liters/person/year (assume)

Desludging interval: 1 year

Sludge volume: Sludge accumulation rate x number of user's x desludging interval

$$: \frac{70\ x\ 3500\ x\ 1}{1000} = 245 \text{ m}^3$$

Available volume for the wastewater in septic tank: Total volume – Sludge volume

$$: 420 - 245 = 175 \text{ m}^3$$

HRT after sludge accumulation: Available volume for wastewater in septic/ Average volume of wastewater: $\frac{175}{280}$ = 0.625 days

Since, 0.625 days= 15 hours i.e., HRT > 12 hours. Hence, design is OK.

4.6.3 Sizing of the bed

Average volume of the wastewater, Q : 3500 x $\left(\frac{80}{1000}\right)$ = 280 m^3 /day

BOD_5 contribution: 40g BOD_5 /Pe.d.

BOD_5 concentration: 40 x $\left(\frac{1000}{80}\right)$ = 500 mg/l.

Let's assume 30 percentile BOD_5 is removed by primary treatment unit then

Ci = 350 mg/l

Effluent BOD5 concentration, Ce = 30 mg/l

K_{BOD} = 0.15 m/d for wetland (recommended)

The wetland has been designed by using Kickuth equation:

$$\left(\frac{\text{Qd (ln Ci} - \text{ln Ce)}}{\text{KBOD}}\right)$$

Where, Ah = Surface area of bed (m^2)

Qd = average daily flow rate of sewage (m3/d)

Ci = influent BOD5 concentration (mg/l)

Ce = effluent BOD5 concentration (mg/l)

K_{BOD} = rate constant (m/d)

Substituting the value: $\left(\frac{\text{Qd (ln Ci} - \text{ln Ce)}}{\text{KBOD}}\right)$

: $\left(\frac{280\ (\ln 350 - \ln 30)}{0.15}\right)$

: 4585.9 m^2

Specific area per person: $\left(\frac{4585.9}{3500}\right)$

: 1.31 m^2

The bed cross-section area has been decided by using Darcy's law:

$$\left(\frac{\text{Qs}}{\text{Kf}\ (\frac{\text{dH}}{\text{ds}})}\right)$$

Where, Ac = Cross sectional area of the bed (m2)

Qs = average flow (m3/s)

Kf = hydraulic conductivity of the fully developed bed (m/s)

dH/ds = slope of bottom of the bed (m/m)

Substituting the value: $\left(\frac{\text{Qs}}{\text{Kf}\ (\frac{\text{dH}}{\text{ds}})}\right)$

: $\left(\frac{0.0032}{2 \text{ x } 10{-}3\ (0.01)}\right)$

: 160 m^2

Assuming the depth of wetland 1.2 m (recommended), the width of the wetland will be 133.3 m

Length of the wetland: $\frac{\text{Plan area}}{\text{Width of wetland}}$

$$: \frac{4585.9}{133.3} = 14.3 \text{ m}$$

Hence, Length of wetland: 14.3 m
Width of wetland: 133.3 m
Depth of wetland: 1.2 m

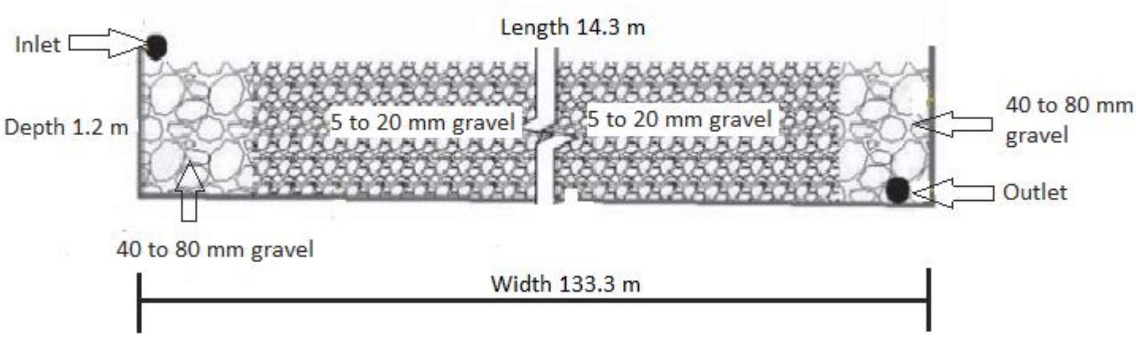

Figure 4.22: Layout plan of constructed wetland

4.7 Cost Analysis

The average Operation and Maintaince (O & M) cost of the wetland is about NRs. 20,000 annually for wastewater flow of 30 m^3 /day in year 2001. (as per constructed wetland manual, United Nations Human Settlements Programme, 2008). The present inflation rate in Nepal is 4.09% and the inflation rate in year 2001 was 2.69%. Therefore, net increase in inflation is 1.4%. Increasing the cost by 1.4 times will be the present O & M cost, which is NRs. 28, 000.

Yearly wastewater flow: wastewater average daily flow x Number of days in a year

: 30 x 365 = 10950 m^3 or 10950000 litre.

Hence, O & M cost per liter of wastewater: $\frac{28,000}{10950000}$ = Rs. 0.002 per litre.

Chapter 5: Summary and Conclusions

The present research was carried out on waste water samples collected both before and after the onset of the monsoon to deal with organic and inorganic materials, nutrients, pathogens and total solids for its treatment and discharge into Sutlej river. Sewage treatment effectiveness was evaluated using various parameters including pH, Temperature, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). To deal with the removal of pathogens and solid waste, Constructed Wetlands (CW) approach was used. The BOD content helps in the better growth of aquatic life, whereas nitrogen content reduces the growth of plants and algae in the treated water. Controlled sulphur and phosphorous content improves the life of plumbing system and eutrophication respectively. The following conclusions were drawn after studying two approaches CW and STP for the treatment of wastewater.

1. The pre-monsoon treated STP wastewater testing results indicated an adequate decrease in the pH, Temp, TKN, N, P, and SO_4 and a significant reduction in case of TSS, COD, BOD.
2. The Post-monsoon treated wastewater testing results indicated that its average temperature is lower than the Pre-monsoon wastewater. However, not much effect of the parameters like TNK, N, P and SO_4 is observed as all the testing results at outlet of STP were found under the limits.
3. In the case of CW, the observed values of the variables were under the permissible limits as per CPCB after the treatment. An adequate change (3-4 times reduction) is observed in the pH, Temp, COD, BOD, TKN, N, P, and SO_4 after the treatment. A significant change (19 times reduction) was resulted in case of TSS values.
4. After the complete investigation, the cost analysis of the STP method found 0.01 Rs/ltr. and on the other hand, CW method was calculated and observed to be 0.002 Rs/ltr for the treatment of the waste water.

It is reasonable to assume that CW is the superior method for treating wastewater. Although the shift in values for the various parameters in the case of STP and CW was almost similar, here cost analysis plays a determining role. When compared to the STP method, the CW method's cost analysis shows a whopping 5.5-fold reduction in expenditures making it more economical method.

Future Scope: Based on the current study, it has been found out the CW are more cost effective as compared to the STP. However, for future scope a laboratory scale model of constructed wetland system can be fabricated to study the removal efficiency of different parameters of raw sewage. The properties and characteristics of the soil and aggregates used in the CW could be further studied. Role of wetland plants and use of ornamental flowering plants in constructed wetlands for sewage treatment after primary treatment needs to be studied.

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List of Publications

1. Singh, J., & Swain, J. B. (2022). Evaluation of Constructed Wetland for Domestic Wastewater Treatment in Rural Areas. *Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering*, *44*(4), 58-65. (**Scopus** indexed)
2. Singh, J., & Swain, J. B. Evaluation of domestic wastewater treatment plant in rural areas Indian geotechnical and geoenvironmental engineering conference (Accepted for publication, **Scopus** indexed)
3. Singh, J., & Swain, J. B Evaluation of domestic wastewater treatment plant in rural areas International Conference on Materials for Emerging Technologies-2021 (Accepted for publication, **Scopus** indexed)