Design, Validation and Analysis of Wastewater Treatment Technologies using GPS-X Modelling and Simulation Program

By

Saba Ali

NUST2018MSEE00000273396

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Environmental Engineering

Institute of Environmental Sciences and Engineering (IESE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

2022

Approval Certificate

Certified that the contents and form of the thesis entitled

"Design, Validation and Analysis of Wastewater Treatment Technologies using GPS-X Modelling and Simulation Program"

Submitted by

Ms. Saba Ali

Has been found satisfactory for partial fulfillment of the requirements of the degree of Master of Science in Environmental Engineering.

Supervisor: ....
Assistant Professor
Dr. Waqas Qamar Zaman
IESE, SCEE, NUST

GEC Member: …………………………………
Dr. Sher Jamal Kahan
Professor
IESE, SCEE, NUST

GEC Member: ………………………………..
Dr. Musharib Khan
Assistant Professor
IGIS, SCEE, NUST

Acceptance Certificate

It is certified that final copy of MS/MPhil Thesis written by Ms. Saba Ali (Registration No: 00000273396) of IESE (SCEE) has been vetted by the undersigned, found complete in all respects as per NUST Statues/Regulations, is free of plagiarism, errors, and mistakes, and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Supervisor: …………………………

Dr. Waqas Qamar Zaman

Dated: ……………………………….

Head of Department: ………………………

Dated: ……………………………

Principal: ………………………………….

Dated: ………………………..

Declaration Certificate

I declare that that this research work titled "Design, Validation and Analysis of Wastewater Treatment Technologies using GPS-X Modelling and Simulation Program" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources as been properly acknowledged/referred.

Student Signature: ……………………………..

Student Name: …… Ms. Saba Ali..……

Date: ….………………………….

Plagiarism Certificate

This thesis has been checked for plagiarism. Turnitin endorsed by supervisor is attached.

Signature of student:…… Ms. Saba Ali……..

Signature of Supervisor: ………..…………..

To my most solid support- my parents.

They have always encouraged me and believed in me.

Acknowledgements

All praise be to Allah for His countless blessings- that have made it easy for me to achieve this milestone. I am very much grateful to my supervisor, Dr. Waqas Qamar Zaman, for his illuminating guidance. His guidance, help, and support has given me great insight and elevated to carry out this work. His appreciation, constructive suggestions, criticisms, and encouragement has made the research work and thesis write-up better.

I would like to extend my gratitude to Dr. Sher Jamal Khan and Dr. Musharib Khan, for ensuring their support and availability. Big thanks to Engr. Aamir Khan for his continuous assistance and support from the right beginning. My appreciation also goes to the entire faculty, the staff of IESE, and all my classmates for the support and guidance, they provided me during research.

Most importantly, nothing would have been achievable without my most loving friends and family. Thank you, Ammi and Abu, for being my most solid support and for believing in me; Engr. Farhan Khalid, for standing by my side; and Engr. Mareeha Gull, for streamlining things for me, in challenging times.

Table of Contents

List of Tables

List of Figures

List of Abbreviation

BOD	Biological Oxygen Demand
CAS	Conventional Activated Sludge
CAS-N	Conventional Activated Sludge Pre-denitrification
COD	Chemical Oxygen Demand
HRT	Hydraulic Retention Time
MBR	Membrane Bioreactor
MF	Microfiltration
MLSS	Mixed Liquor Suspended Solids
MPS	Mean Particle Size
NF	Nano Filtration
NH4 +1 -N	Ammonium-Nitrogen
NS	Not Significant
PAOs	Phosphorous Accumulating Organisms
pH	Potential Of Hydrogen
PSD	Particle Size Distribution
RSM	Response Surface Methodology
SMBR	Submerged Membrane Bioreactor
SRT	Sludge Retention Time
TDS	Total Dissolved Solids
TMP	Trans-Membrane Pressure
TP	Total Phosphorous
TR	Trans-Membrane Pressure Rate
TSS	Total Suspended Solids
UF	Ultrafiltration
SOR	Surface Overflow Rate
HRT	Hydraulic Retention Time
OLR	Organic Loading Rate
MLSS	Mixed Liquor Suspended Solids
DO	Dissolved Oxygen
AT	Aeration Tank
FM	Food to Microorganism

List of Symbols

A	Filtration duration
Avg	Average Mins Minutes
B	Relaxation duration
C	Chemical enhanced backwashing duration
μ	Viscosity of permeate
J	Operational flux
Q	Wastewater flow

List of Units

LMH	Liter per meter square per hour
s	Seconds
m^3/d	Cubic meter per day
m^3	Cubic meter
MGD	Million gallon per day
d^{-1}	Per day
Kg/d	Kilogram per day
Kg/hr	Kilogram per hour
hr	Hour
d	Day
m	Month
yr	Year
m^3/hr	Cubic meter per hour
ppm	Parts per million
lpcd	Liter per capita per day
m	Meter
kgO_2/hr	Kilogram of Oxygen per hour
Nm^3/hr	Newton cubic meter per hour
Nm^3/min	Newton cubic meter per minute

Abstract

Water scarcity has become a worldwide problem, due to climate change and population outburst. Wastewater reuse and recycling are the ways to overcome these problems. Pakistan is ranked as one of the most water stressed countries in the world. While the fraction of wastewater being treated is very small. Therefore, the study was conducted to model a new WWTP facility, for a proposed housing society in the capital city Islamabad. The projected design flow rate of the WWTP was 101,618 m^3/d. MBR and ASP facilities were modeled and compared using GPSX Hydromantic Software. The performance of the facilities was further simulated for a period of 365 days. The parameters assessed were BOD, COD, and TSS. Additionally, the installation cost of equipment and operational cost of the plant were estimated. The estimated removal efficiency as modelled by GPSX was 80-99%, for both technologies, during the steady and unsteady states. This is much higher than the empirical value i.e., 50%. The removal efficiency in terms of quality parameters were: 95.4% and 86.8% for BOD, 92.1% and 8.3% for COD, and 98.9% and 88.7% for TSS, for MBR and ASP respectively. Results illustrated that the total project cost of MBR and ASP are 38 million PKR/year and 28 million PKR/year, respectively. Despite, being costlier in comparison with ASP, MBR utilizes smaller footprint and provides better removal efficiency; thus, more beneficial technology.

1 Introduction

1.1 Background

Water is the most essential commodity of life. Anthropogenic factors i.e., population outburst, agricultural activities, industrial expansion, etc., and natural factors i.e., climate change have led to water scarcity worldwide. Pakistan has also become a water scarce country. Form 1996-97, the water availability has decreased from 1,299 m^3 per capita to 1,100 m^3 per capita in 2006. Which is further expected to reduce to less than 700 m^3 per capita by 2025. (Khalid & Khan, 2020) Wastewater reuse and recycling are the ways to encounter water scarcity and demand. While 80% wastewater remains untreated and is discharged, worldwide; (Mateo-Sagasta, Raschid-Sally, & Thebo, 2015) and a very small fraction of waster is treated in Pakistan.

Islamabad city is facing acute water deficiency in its sectors and water tankers are required to meet the basic needs. The city has only one domestic wastewater treatment plant at I-9 Markaz of capacity 17 MGD. This capacity is a minor fraction of entire city's sewage. The city also experiences water shortfall to an extent where water tankers are needed to supply water for domestic usage.

Therefore, the study aims to design wastewater treatment technology for a new Housing Society in Islamabad, near Motorway, for a projected maximum design flow rate of 101,618 m^3/d.

1.2 Objective of the study

The objectives of the study are:

1. To develop model/spreadsheet for the comparative performance evaluation of ASP and MBR technologies.
2. To verify the designed treatment technologies at Steady and Non-steady state using GPS-X Hydromantic Software.

1.3 Scope of the Study

The study covers the following aspects:

1. Empirical design of both ASP and MBR treatment technologies.
2. Model development using GPS-X software for the treatment processes.
3. Simulation of steady and non-steady conditions for both the systems.

4. Operational and Equipment Installation cost estimation for both technologies using MS Excel and GPS-X Software.
5. Estimation of BOD, COD, and TSS removal efficiency to evaluate the performance of both technologies.

2 Literature Review

2.1 Background

Water is the most essential commodity for the sustenance of life. Clean water and adequate water availability has become a global concern, as 2.2 billion people lack clean drinking water and 4.4 billion lack safe sanitation facilities (Verstraeten & Vanclooster, 2021). Anthropogenic factors (population outburst, agricultural activities, and industrial expansion) and natural factors (climate change) have resulted in an overall water scarcity and disturbance in hydrological cycle. These water-related issues require sustainable usage of water, and treatment, conservation, and reuse of wastewater.

However, 80% of water worldwide is discharged untreated (Mateo-Sagasta et al., 2015). Less than 40% wastewater is treated in developed countries (Ungureanu, Vlăduț, & Voicu, 2020). In Pakistan, over 12.5 million tonnes domestic sewage is produced annually (Javed et al., 1997), of which a very negligible fraction of wastewater undergoes treatment, prior disposal. Only Karachi and Islamabad have biological treatment processes, which treat <8% wastewater of these cities (Murtaza & Zia, 2012).

2.2 Water Scarcity in Pakistan

Pakistan from water-surplus country has become water-scarce country. The water availability has reduced from 1,299 m^3 per capita in 1996-97 to 1,100 m^3 per capita in 2006, which is further expected to reduce to <700 m^3 per capita by 2025 (Khalid & Khan, 2020).

2.2.1 Water Scarcity in Islamabad

In the city of Islamabad, water crisis exists to an extent that tanker system is needed, for the provision of water, at domestic level. The population of the city is increasing at a rapid growth rate of 5.7% per year, increasing the water shortfall. These issues can be encountered only if sustainable reuse of wastewater is practiced. Currently, the city has only one domestic wastewater treatment plant in I-9 Markaz of capacity 17 MGD; which is insufficient for the city sewage (Liu & Jiang, 2021).

2.3 Significance of Wastewater Reuse

The availability of clean water can be increased by reclamation and reuse of wastewater, through treatment. The treated wastewater finds its application in agricultural purposes, some industrial activities and other non-potable uses.

Because the demand of clean water is increasing for community health, environmental safeguard, reuse of wastewater in industry, and agriculture, a higher level of wastewater treatment is required (Al-Wardy, Alquzweenib, & Al-Saadi). Biological treatment technologies are more essential for the process efficiency they offer.

2.4 Significance of Biological Wastewater Treatment

Various physical, chemical, and biological wastewater treatment technologies have evolved significantly with the advancement of biological technologies. Biological treatment is most vital for the variety of contaminants it treats. It can remove organic pollutant, suspended particles, and a wide range of microorganisms. Biological treatments are most used for the treatment of domestic sewage because of their low cost and high removal efficiency. ASP and MBR are generally more efficient and cost effective biological treatments methods; therefore, most common for the treatment of municipal sewage, in Pakistan. (Y. Ali, Pervez, & Khan, 2020)

2.5 Activated Sludge Process

ASP is a complex microbial system for the treatment of wastewater. Several different heterotrophs and autotrophs co-habitat for the removal of organic matter. Microorganisms remain suspended in wastewater, where they grow and metabolize. (Orhon, 2015)

ASP comprises of a single bioreactor, a settling tank, a sludge recycling line, and a sludge wastage line. The bioreactor is an aerated basin. Here, suspended microorganisms consume organic matter, by catabolism and anabolism. The settling tank is a secondary clarifier, where activated sludge settles under gravity. The treated effluent may undergo further treatment or may be discharged in a receiving waterbody. Major portion of the sludge returns to bioreactor through sludge recycling line. Excess sludge is wasted through sludge wastage line at the bottom. (Hreiz, Latifi, & Roche, 2015)

2.5.1 Configurations of Activated Sludge Process

ASP allows efficient removal of carbonaceous and nitrogenous organic removal. Denitrification is achieved under anoxic conditions. In large WWTPs aerobic and anoxic conditions are carried out in separate reactors. Therefore, the configurations of ASP are pre-denitrification and post-nitrification. In pre-denitrification, the anoxic tank is placed upstream of anaerobic reactor. While in the post-denitrification configuration, the anoxic tank is present downstream of the aerobic reactor. Furthermore, for the efficient removal of both nitrogen and phosphorus the configuration comprises of anoxic, anoxic and aerobic reactors. (Hreiz et al., 2015)

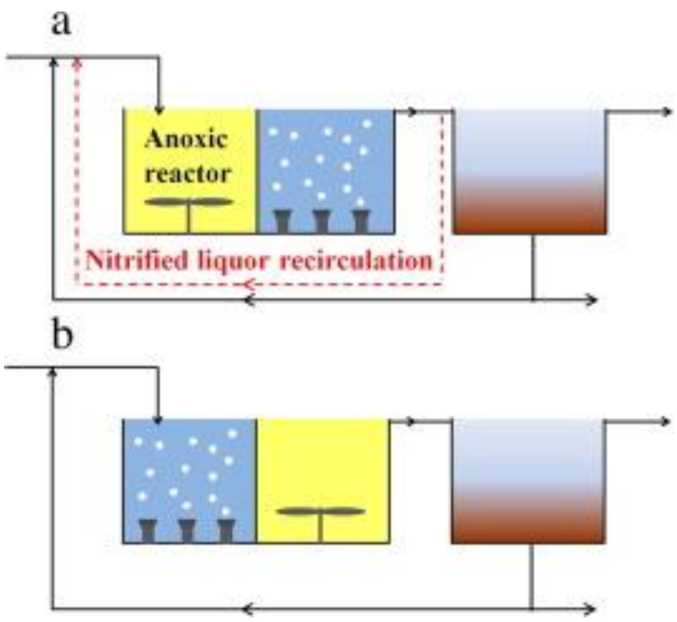

Figure 1 Configurations of Activated Sludge Process (Hreiz et al., 2015)

2.5.2 Benefits of Activated Sludge Process

ASP has multiple benefits over other technologies. It is an efficient process that allows up to 90% removal of SS, BOD, and micro-organisms. Thus, the extent of treatment produces an effluent of high quality which is nearly clear and prevents fly and odor problem. The retention time is low; therefore, it requires a small land area. The overall installation cost is less than that of trickling filters. The head loss is also comparatively very small. The sludge produced has a higher fertilizer value as compared to the other methods. (Gautam)

2.6 Membrane Bioreactor Process

A full scale MBR was first installed in North America, in 1970. It was then developed in Japan, in 1980. (Baker, 2012) MBR comprises of two processes: ASP and membrane filtration. Microorganisms consume wastewater as a substrate, for enhanced metabolism and growth. UF or MF membrane is used for the separation of biologically treated wastewater. Activated biomass, RAS, produced in the process is recycled back to aeration tank. (Drews, 2010)

2.6.1 Configurations of Membrane Bioreactor Process

Based on configuration, MBR is of two types i.e., submerged and side stream MBR. In submerged MBR membrane is immersed in the reactor and in side stream MBR membrane is located outside the bioreactor. (Besha et al., 2017)

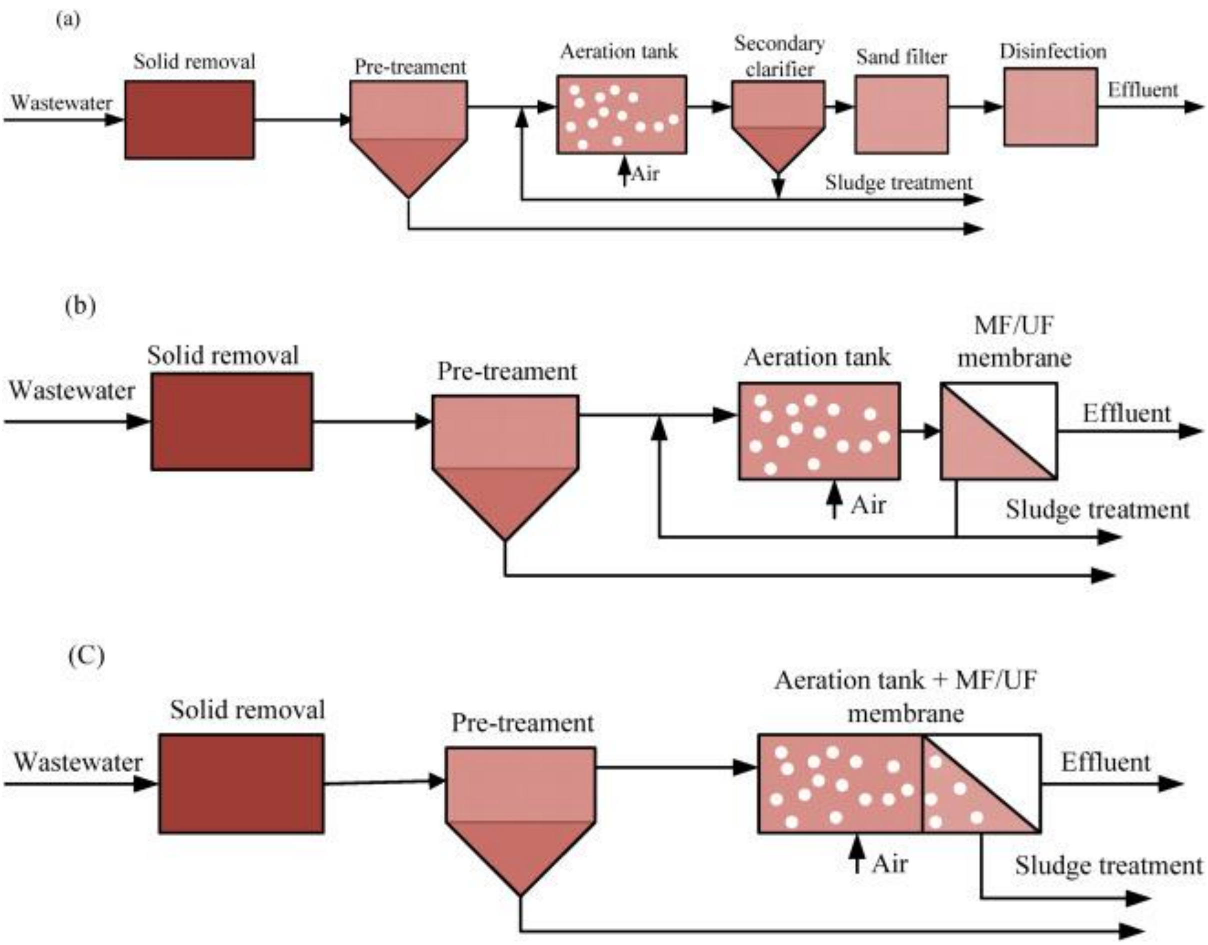

Figure 2 Configurations of Membrane Bioreactor (Besha et al., 2017)

2.6.2 Benefits of Membrane Bioreactor Process

MBR poses high nutrient and organic removal efficiencies, for the treatment of domestic and industrial wastewater. Over conventional ASP, it has additional benefits of low sludge wastage, small footprints, compact space requirements, and high robustness. (Shin & Bae, 2018)

The standards of effluent quality have become more stringent. For that, MBR is of benefit, and it has additional advantages too. MBR system has an easy operation and maintenance. The effluent quality is good enough to be discharged into the surface water and reuse. Since the technology does not require secondary clarifier and post-treatment, the footprint is considerably low. high concentration of biomass undergoes exothermic degradation, raising the temperature of the reactor, which resists the effect of cold climate. The amount of sludge is considerably low. the tightly closed system prevents spread of odor. (Visvanathan, Aim, & Parameshwaran, 2000)

2.7 Comparison between ASP and MBR

MBR poses high nutrient and organic removal efficiencies, for the treatment of domestic and industrial wastewater. Over conventional ASP, it has additional benefits of low sludge wastage, small footprints, compact space requirements, and high robustness. (Shin & Bae, 2018)

ASP is an effective technology to be used for domestic and municipal sewage. However, it is sensitive to physico-chemical changes. Hence, the effluent often has high turbidity and SS level. But unlike ASP, MBR has a membrane-based separation of biomass, rather than gravity. Hence, they completely remove SS. The effluent quality is also better in terms of organic matter, nutrients, less degradable micro pollutants, and heavy metal. It meets high discharge standards; the final effluent can be discharged in surface waters or used for irrigation, without any disinfection. MBR operates at prolonged SRT and high MLSS which makes the structure compact with low sludge production. (Besha et al., 2017)

The disadvantages of MBR are related to high investment cost and relatively difficult operation and maintenance. The major problem is of membrane fouling which requires frequent cleaning and replacement. To prevent fouling and aerate MLSS higher energy is required for aeration. Although MBR can remove some micro pollutants0 but all such pollutants can not be removed simply and effectively. **(Besha et al., 2017)**

2.8 GPS-X Hydromantic Modelling Software

Operations of WWTPs can mathematically be modelled through specialized software such as GPS-X, STOAT, SIMBA, WEST, and BioWin. GPS-X, developed by Hydromantic Environmental Software Solutions Inc., one such software facilitates with a modular, multi-purpose modelling environment for the simulation of wastewater treatment. It has a well-developed user interface that allows dynamic modelling and simulation. With several advancements overtime, researchers investigate the GPS-X program's ability to model and simulate WWTPs, partially or wholly, simulation and optimization of completely mixed systems. (Hydromantis, 2022)

2.9 Applications of GPS-X Hydromantic Modelling Software

GPS-X allows the improvement of design and operating efficiency for both, an existing plant and the one to be developed. Its various applicable areas are: (1) Determine the impact of increased OLR on a WWTP; (2) Analyze plant capacity under different physical conditions; (3) Evaluate options for converting or expanding an existing plant to meet new guidelines; (4)

Compare and analyze alternatives for retrofitting an existing technology; (5) Compare various BNR process configurations; (6) Investigate dynamic wet-weather performance and determine best bypass or step-feed procedures; and (7) Assess different diffused aeration designs. (Hydromantis, 2022)

2.10 Past Studies on GPS-X Hydromantic Modelling Software

GPS-X has been used for several modelling and simulation studies. In a recent study, it was used to design simulation of WWTP, in Al-Hay City. The results showed significant and satisfactory control performance of the Plant. (Jasim, 2020) In another study, it has been used to design and compare the performance of ASP and MBR (Tikrit WWTP), in which over-sized reactors were formed using the guidelines. Therefore, the volume could be reduced by 55% for CAS, 35% for CAS-N, and 55% for MBR according to the ASM-type model. (Arif, Sorour, & Aly, 2018) GPS-X can also be used with CapdetWorks for cost analysis. The previous study was expanded to analyze CAS, CAS-N, and MBR for economic factors. The cost of MB, in comparison with CAS and CAS-N, turned out to be 57% and 42% higher, respectively. (Arif, Sorour, & Aly, 2020) In a similar study, conducted on Zergandeh Treatment Plant, Tehran, it was observed that Contact stabilization was found to be more cost-effective in comparison with CAS and step aeration technologies. (Abbasi, Ahmadi, & Naseri, 2021) However, the low treatment cost is related to the low treatment efficiency. (Arif et al., 2020)

A major study was conducted o0n the WWT of Al-Muamirah City, Iraq. GPS-X was used to model oxidation ditch. It was found that the plant running below capacity reduces removal efficiency, due to the decrease in HRT and increase in SOR and OLR. (Al-Wardy, Alquzweenib, & Al-Saadi, 2021)

The proposed study aims to model a WWTP for new proposed housing scheme, in Islamabad, for a projected maximum design flow rate of 101,618 m^3/d. It is important to overcome the crisis associated with water scarcity. No such study has been conducted to validate theoretically generated efficiencies from software models and empirical values, before the establishment of WWTP.

3 Materials and Methodology

The detailed methodology has been given below.

3.1 Selection of Wastewater Parameters

Domestic wastewater characteristics were adopted from literature, for Islamabad. (M. Ali, Rousseau, & Ahmed, 2018; Fatima & Khan, 2012; Murtaza & Zia, 2012) These values were comparable with those provided in Metcalf and Eddy. The table below shows the values adopted.

Table 3.1 Wastewater Parameters (Metcalf, Eddy, & Tchobanoglous, 1991)

Parameter	Value	Unit
TSS	400	mg/l
BOD	190	mg/l
COD	430	mg/l

3.2 Empirical Design of Wastewater Treatment Technologies

The Wastewater treatment plant is designed for the New Housing Society, near Islamabad Motorway. The design flow rate is calculated as:

Table 3.2 Design Flow Rate Calculation

Parameter	Symbol	Value	Unit	Reference
Projected Population	P	273,167	No.	120 lpcd
Max Average Flow	Q_{avg}	32780	m^3/d	For the projected population
Peak Factor		2		
Peak Flow	Q_{peak}	65560	m^3/d	
Storm water Flow	Q_{storm}	32780	m^3/d	50% of peak flow (Metcalf et al., 1991)
Infiltration	$Q_{infiltration}$	3278	m^3/d	10% of Avg Flow (Metcalf et al., 1991)
Design Flow Rate	**Q**	**101,618**	**m^3/d**	$Q_{peak} + Q_{storm} + Q_{infiltration}$

Number of trains = 12

Flow rate for each train = 8,468 m^3/d

3.2.1 Empirical Design of an Activated Sludge Process

The CAS design includes equalization basin, aeration tank, secondary clarifier, primary clarifier and sludge drying beds. The design procedure was adopted from **Metcalf & Eddy.**

Table 3.3 Empirical Design of Equalization Tank for Activated Sludge Process

Equalization Tank		
Parameter	**Value**	**Unit**
Flow	352.85	m^3/hr
Retention Time	4	hrs
Volume	1411.4	m^3
SWD	5.5	m
Area	256.62	m^2

Table 3.4 Empirical Design of Primary Clarifier for Activated Sludge Process

Equalization Tank		
Parameter	**Value**	**Unit**
Flow	352.85	m^3/hr
Velocity	1.25	m/hr
Area	282.28	m^2
Diameter	18.96	m
Adopted Diameter	19.00	m

Aeration Tank					
Aeration Tank					
Flow		352.85	m^3/hr		
Flow		8468.4	m^3/day		
Parameters		**Value**	**Units**		
At the Inlet of ETP					
BOD		190	mg/l		
BOD Load		1608.996	Kg/d		
	At the Inlet of Aeration Tank				
%age removal in Primary		15.00	%		
BOD		161.5	mg/l		
BOD Load		1368	Kg/d		
	Pollution Load Reduction in Aeration Tank				
BOD at the Outlet		0	mg/l		
%age removal in AT		100.00	%	**Overall Reduction**	**85**

			in A.T(%age)
BOD Removed	161.5	mg/l	
BOD Load to be Removed in AT	1368	Kg/d	
	SET Design Basis		
FM Ratio	0.20	per day	Ranges from 0.2 to 0.6 for ASP
MLSS	2422.5	mg/l	Ranges from 2000 to 4000 for ASP
	Designed Aeration Tank		
Required Volume of the Aeration Tank	2822.80	m^3	
Retention Time	8.00	Hrs	
Side Water Depth	5.50	m	
Area of Aeration Tank	513.24	m^2	
	Anoxic Chamber		
Retention Time	1	Hrs	
Volume of Anoxic Chamber	352.85	m^3	
	Air Calculation (Alternative Just for Comparison)		
BOD load to be removed in Aeration Tank	1368	Kg/d	
Kg of O2 Required per Kg BOD load	1.2	Kg O_2/Kg BOD load	Ranges from 0.9 to 1.3 (Metcalf &Eddy)
Density of Air	1.21	Kg/m^3	
Percentage of O2 in Air	0.21		21% oxygen in air
Diffusers Efficiency	0.12		12% Adopted (Specified by Manufacturer)
Required Air	53823	Nm^3/day	
Required Air	2243	Nm^3/hr	
> Specific Gravity = 1 Kg/L = 1 g/cm3 = 1000 Kg/m3			
> Concentration = mg/l = g/m3 = ppm			

Table 3.5 Empirical Calculations of MLSS for Activated Sludge Process

MLSS Calculation for Required Retention Time at Specific FM ratio		
Parameter	**Value**	**Unit**
Flow	352.85	m^3/hr
BOD to be removed in AT	161.5	mg/l
BOD Load to be removed in AT	1367.6466	Kg/d

Required Retention Time	8	Hrs
Volume of Aeration Tank	2822.8	m^3
Selected FM Ratio	0.2	per day
Required MLSS	2422.50	mg/l

Table 3.6 Empirical Calculation of FM Ratio for Activated Sludge Process

FM Ratio Calculation for Required Retention Time at Specific MLSS		
Parameter	**Value**	**Unit**
Flow	352.85	m^3/hr
BOD to be removed in AT	161.5	mg/l
BOD Load to be removed in AT	1367.6466	kg/d
Required Retention Time	50	hrs
Volume of Aeration Tank	17642.5	m^3
Selected MLSS	3205.71	mg/l
Required FM Ratio	0.024	d^{-1}

Table 3.7 Number of Aeration Tanks for ASP

Number of Aeration Tanks		
Parameter	**Value**	**Unit**
Total Volume of AT	2823	m^3
No. of Aeration Tanks	1	Nos.
Volume of One AT	2823	m^3
Flow in One AT	352.85	m^3/hr
RT of each AT	8	hrs

Table 3.8 Empirical Air Requirement for Activated Sludge Process

Air Requirement for Aeration Tank		
Parameter	**Value**	**Unit**
Feed Flow	352.85	m^3/ hr
BOD	161.5	ppm
BOD Load	1367.6466	kg/day
BOD Load	56.985275	kg/hr
Kg O_2 Req. per Kg BOD Load	1.2	kg O2 / kg BOD Load
O_2 Demand	68.38233	Kg/hr

AOR = SOR * (((β*Ω*CT – DO field) / $Csat_{20}$)*θT) – 20*α

AOR Average	68.38233	
Alpha	0.7	
Beta	0.95	
Altitude	20	
DO field	3	
Temp.	35	
Omega	0.9982	
Csat T	6.8	
Theta	1.024	
Csat T	9.1	
Aerostrip O2 Transfer Eff.	30%	
Θ^{T-20}	1.43	
SOR	**180.29**	Kg O_2 /hr
Air Requirement	2,365	Nm^3 /hr
	39.42	Nm^3 /min

Table 3.9 Empirical Air Requirement for Equalization Tank

Air Requirement for Equalization Tank		
Parameter	**Value**	**Unit**
Flow	352.85	m^3/hr
Retention Time	4	hrs
Volume	1411.4	m^3
Mixing Air Req. Factor	0.7	Nm^3-hr/ m^3 of wastewater
Mixing Air Required	987.98	m^3/hr

Table 3.10 Empirical Blower Selection for Activated Sludge Process

Blower Selection		
Parameter	**Value**	**Unit**
Total Air Required	3353.04	m^3/hr
Total Air Required	55.88	m^3/min
Selected Blower's Capacity	19.1	m^3/min
	1146	m^3/hr
No. of Working Blowers	3	No.
Total Air Flow	3438	m^3/hr
Standby Blower	1	No.
Total No. of Blowers	4	Nos.

Diffusers Quantity For Aeration Tank		
Total Air Flow in A.T	2450	m^3/hr
Air Flow per Diffuser	5	m^3/hr
No. of Diffusers Req.	490	Nos.
No. of Diffusers Selected	500	Nos.

Secondary Clarifier		
Flow	352.85	m^3/hr
No. of Secondary Clarifiers	**1**	m/hr
Flow for one Clarifier	352.85	m/hr
Velocity	0.66	m/hr
Aera	534.62	m^2
Dia	26.10	m
Adopted Dia	26.00	m

Sludge Calculations					
Flow	352.85	m^3/hr	8468.4	m^3/day	
Parameters	**Concentration**	**Units**	**Load**	**Units**	**Any Remarks**
Inlet Parameters					
BOD	190	mg/l	1608.996	kg/d	
COD	430	mg/l	3641.412	kg/d	
TSS	400	mg/l	3387.36	kg/d	
Outlet Parameters					
BOD	80	mg/l	677.472	kg/d	
COD	150	mg/l	1270.26	kg/d	
TSS	200	mg/l	1693.68	kg/d	
Primary Sludge					
Chemical Sludge					
Alum/ PAC (20-150 ppm)	50	mg/l	423.42	kg/d	One of these will be dosed as Coagulant
FeCl3 (2-5 ppm)	0	mg/l	0	kg/d	
Anionic Polymer (1-2 ppm)	2	mg/l	16.9368	kg/d	Dosed as Flocculant
Solids Sludge					
Solids removed			1693.68	kg/d	
Total Primary Sludge			2134.0368	kg/d	As 100%

			Conc.
	2.1340368	**m^3/d**	As 100% Conc.
Secondary Sludge			
Biological Sludge			
Y_{obs} 0.37			
Biological Sludge	344.66388	Kg/d	As 100% Conc.
	0.34466388	**m^3/d**	As 100% Conc.
Total Sludge			
Total Sludge	2.47870068	**m^3/d**	As 100% Conc.
	82.623356	**m^3/d**	As 3% Conc.
Sludge Pumping Hours	5	Hrs	

Sludge Drying Bed Area		
Sludge Volume	82.62336	m^3/d
Sludge on SDB	57.83635	m^3/d
SWD of SDB (12 Inches)	0.305	m
Area Required for one day sludge	189.70	m^2
No. of SDB	3	Nos.
Total Area Required for SDB	569.11	m^2

Sludge Pumps		
Primary Sludge Transfer Pump	211.71	m^3/hr
Secondary Sludge Transfer/Recir. Pump	211.71	m^3/hr
Sludge Handling Pump	16.525	m^3/hr
Selected Sludge Handling Pump	20	m^3/hr

3.2.2 Empirical Design of Membrane Bioreactor Reactor

The design of membrane bioreactor consists of Primary equalization basin, aeration chamber and membrane reactor. The Influent is allowed to settle in Primary Clarifier (Sedimentation Tank). This unit removes suspended solids by providing sufficient settling time to influent. All the settled sludge will be collected by gravity into a Sludge Holding Tank for further process. Influent will further enter into the Anoxic Chamber. The anoxic chamber shall be provided prior to Aeration Tank for proper mixing of return sludge (RAS) with raw wastewater and its denitrification. Influent then flow by gravity to Biodegradation Aeration Tank. Bacterial growth shall be generated by providing air in Aeration Tank by Air Blowers through Air Diffusers. Bacteria are generated in a sufficient amount in the Aeration Tank to reduce the BOD. The bacteria act upon the organic matters present in the wastewater, contributing the pollution load, and disintegrate the complex organic matter into simpler products such as carbon dioxide. The permeate is collected in effluent tank.

The design of an MBR Process is as:

MBR Design			
Flow	8,468.40	m^3/day	
Flow	352.85	m^3/hr	
BOD	161.5	g/m3	After Primary Treatment (15% Removal)
Bio-Reactor Design			
BOD Load	1,367.65	Kg/day	Load = Flow x Concentration
F/M ratio	0.20	kg/kg-day	
MLSS	5537.14	g/m^3	8,000 to 12,000 ppm in case of MBR
Volume of Bio-Reactor	1,234.98	m^3	F/M = BOD x Q / MLSS x V ==> **V = BOD x Q / MLSS x FM**
Retention Time	3.50	Hrs	R.T = V/Q
MBR			
Module Type	BIO-CEL L-2		in Europe
Area of membranes in one module	480	m^2	Standard for the selected module
Net Avg. Flux	14.5	L/m^2-hr	Manufacturer's Recommended
No. of Modules Required	50.70	Nos.	No. of modules Required = Q / Area of membranes in one module x Filtration Flux
Selected No. of Modules	52	Nos.	
Filtration Tank Sizing			
Number of Modules per Filteration Line along length	26	Nos.	No any fixed range. Choose as per area availability & geometry
Total Number of Filteration Lines	2	Nos.	= Total no. of modules / No. of modules per filtration line
Number of Lines per Filteration Tank along width	1	Nos.	

Number of Filteration Tanks	2	Nos.	= Total Number of Filteration Lines / Number of Lines per Filteration Tank
Minimum Water Level	3	m	Manufacturer's Recommendation
Length of One Module	1.524	m	Manufacturer's Recommendation
Width of One Module	1.08	m	Manufacturer's Recommendation
Recommended length distance among modules/ wall	0.25	m	Manufacturer's Recommendation
Recommended width distance among modules/ wall	0.25	m	Manufacturer's Recommendation
Length of One Filtration Tank	46.374	m	
Width of One Filtration Tank	1.58	m	
One Filtration Tank Volume	219.8128	m^3	= length x width x water level
Selected One Filtration Tank Volume	220	m^3	
Total Filteration Tanks Volume	440	m^3	= Volume of one filtration tank * No. of filtration tanks
Air Requirement			
Design Cross Flow Aeration per Module	90	Nm^3/hr	Manufacturer's Recommendation for this specific module
Design Cross Flow Aeration per Line	2340	Nm^3/hr	= Air for one module x No. of modules in one filtration line
Design Cross Flow Aeration Total for MBR Modules	4680	Nm^3/hr	= Air for one filtration line x No. of filtration lines
Operating flux through one module in case of our flow	**14.14**	**L/m^2-hr**	Filtration Flux = Q / Area of membranes in one module x No. of modules

3.3 Model Development at GPS-X Software

Creating a GPS-X Model, the primary processes include model calibration, Model building, scenario development, simulation, and result interpretation.

Calibration of the model is the most difficult phase at the start of the model development, as the model simulation acquires all the physical parameters of the full-scale plant and must be comparable to the real one, it is mimicking to correctly evaluate its functioning Hydromantic Environmental Software Solutions. Since GPS-X creates dynamic process models based on a graphical depiction of unit processes, the first step was to create a graphical representation of WWTP for the Housing Society. The WWTP process flow diagram was built by selecting items (process unit icons) from the process table (GPS unit X's process library) and connecting them through flow pathways, as shown in **Figure 3.**

It is important to choose a library that is more appropriate for the entire WWTP facility. A library is a collection of wastewater treatment components with built in state variables. Each of GPSX's libraries contain default values and formulas for calculating state variables. Since there was an interest in modelling comprehensive - carbon, nitrogen, phosphorus, and pH, (mantis3lib), library is comprised of fifty-six (56) state variables that were chosen for this study. GPS-X program includes adding the parameters of characteristics of the influent wastewater entering the plant in detail. The characteristics are entered for both the systems accordingly to their respective reactors and pathways. This program was used to estimate both construction costs and annual operate and maintain costs according to the equipment and machinery used. The data was taken from the **PKAISTAN E-procurement.**

At initial step, the variable were entered to the library to adjust the influent parameter i.e., BOD5, COD and TSS. After addition of specification software modelling occurs for 365 and 100 successive days in order to get the results for steady and unsteady state. The model was simulated, and the data was transferred on excel sheet with the graph representation of BOD, COD and TSS to define the plant performance for both the states.

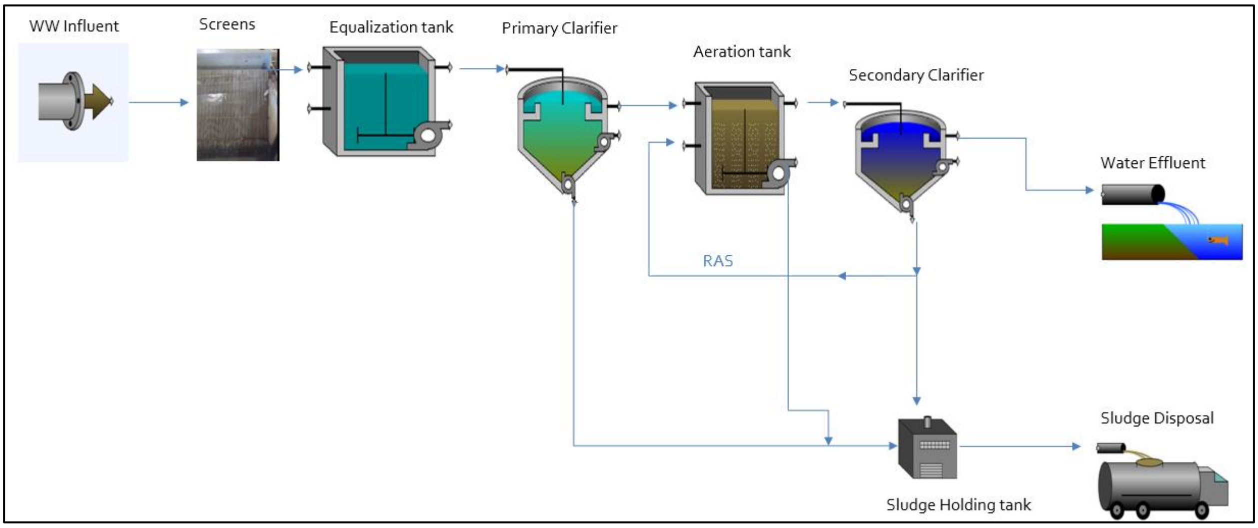

Figure 3-1: Layout of Activated Sludge Process for Wastewater Treatment

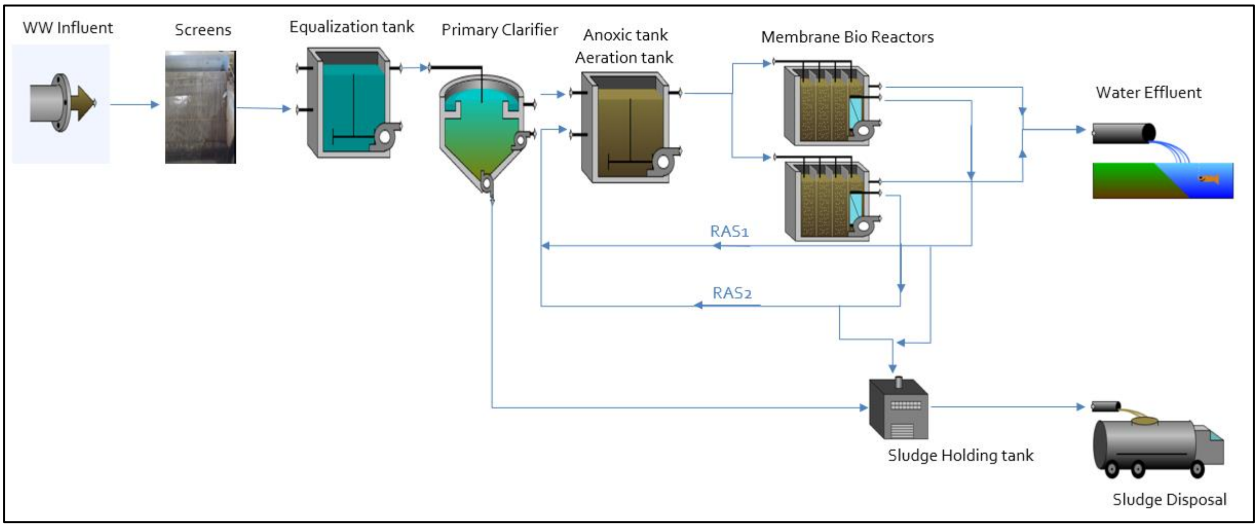

Figure 3-2: Layout of Membrane Bioreactor for Wastewater Treatment

4 Results and Discussion

The results of the study have discussed, in detail, below:

4.1 BOD Removal

Figure 5 shows the BOD Removal, for ASP and MBR, as calculated empirically and modelled by GPS-X. The Software simulated BOD_5 removal efficiency of 96.2% and 84.3% for MBR and ASP, respectively. Whereas the model spreadsheet development was restricted for the 50% removal efficiency. The effluent standard for BOD5 is 80 mg/l in comparison with the concentrations obtained from ASP and MBR are 29.81 and 7.2 mg/l respectively.

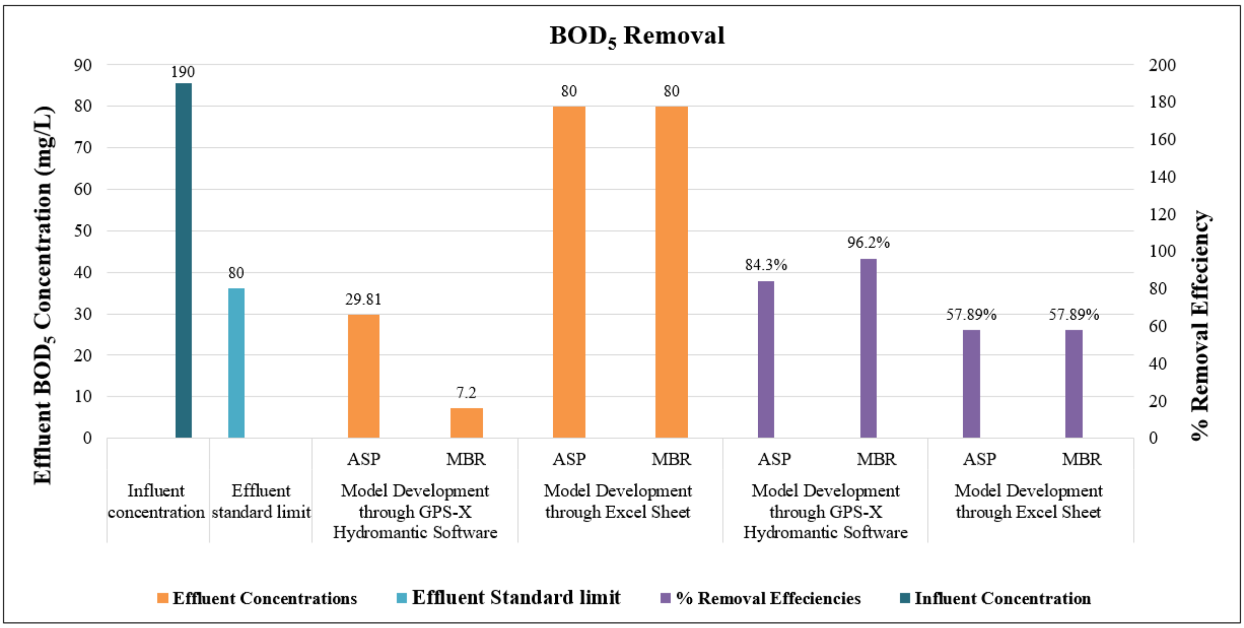

Figure 3 BOD Removal

4.2 COD Removal

Figure 6 shows the COD Removal, for ASP and MBR, as calculated empirically and modelled by GPS-X. The graphs shows that the software simulated the COD Removal efficiency of 97.14% and 89.65% for MBR and ASP, respectively. Whereas the model spreadsheet development was restricted for the 65.11% removal efficiency, in order to attain standard effluent concentration. The effluent standard for COD is 150 mg/l in comparison with the concentrations obtained ASP through and MBR are 44.7 and 12.3 mg/l respectively.

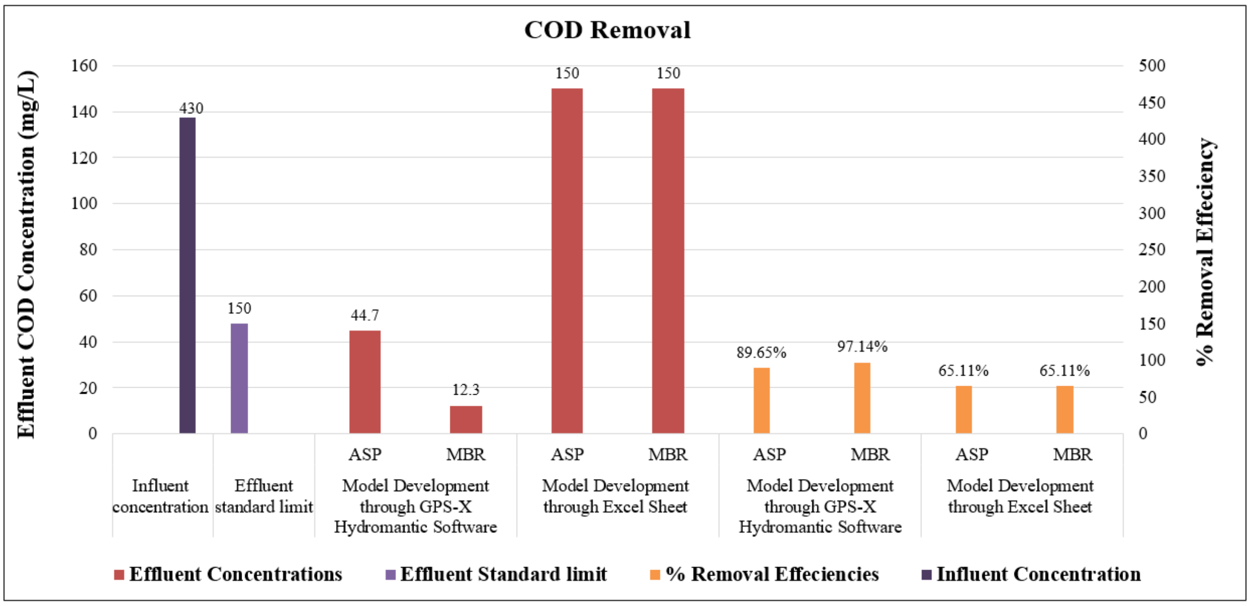

Figure 4 COD Removal

4.3 TSS Removal

Figure 7 shows the TSS Removal, for ASP and MBR, as calculated empirically and modelled by GPS-X. The graphs shows that the software simulated the TSS removal efficiency of 99.2% and 97.1% for MBR and ASP, respectively. Whereas the model spreadsheet development was restricted for the 50% removal efficiency, in order to attain standard effluent concentration. The effluent standard for TSS is 200 mg/l and concentrations obtained through ASP and MBR are 11.7 and 3.08 mg/l respectively.

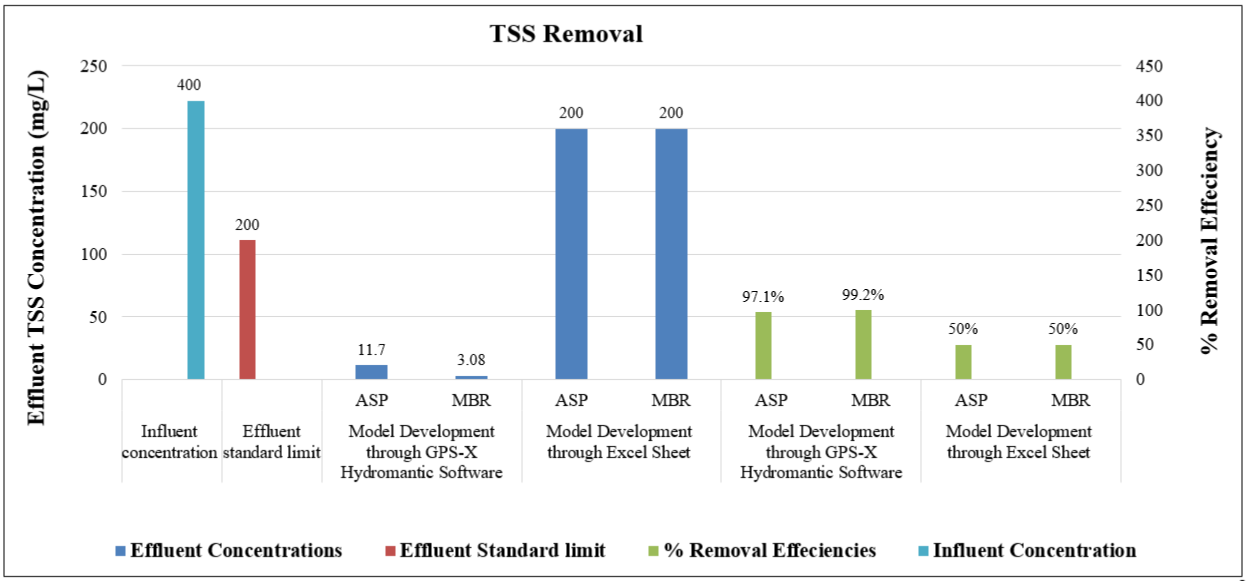

Figure 5 TSS Removal

4.4 Energy Consumption Cost

Figure 8 shows energy consumption cost for ASP and MBR treatment technologies. The electricity consumption cost for the operation of plants for one year is estimated to be 37.9 million PKR per year for MBR and 28.38 million PKR per year for an ASP. The additional cost in MBR is due to the membrane modules with rotatory drum installation. Whereas in ASP the Secondary clarifier cost is as same as the primary clarifier used in primary treatment.

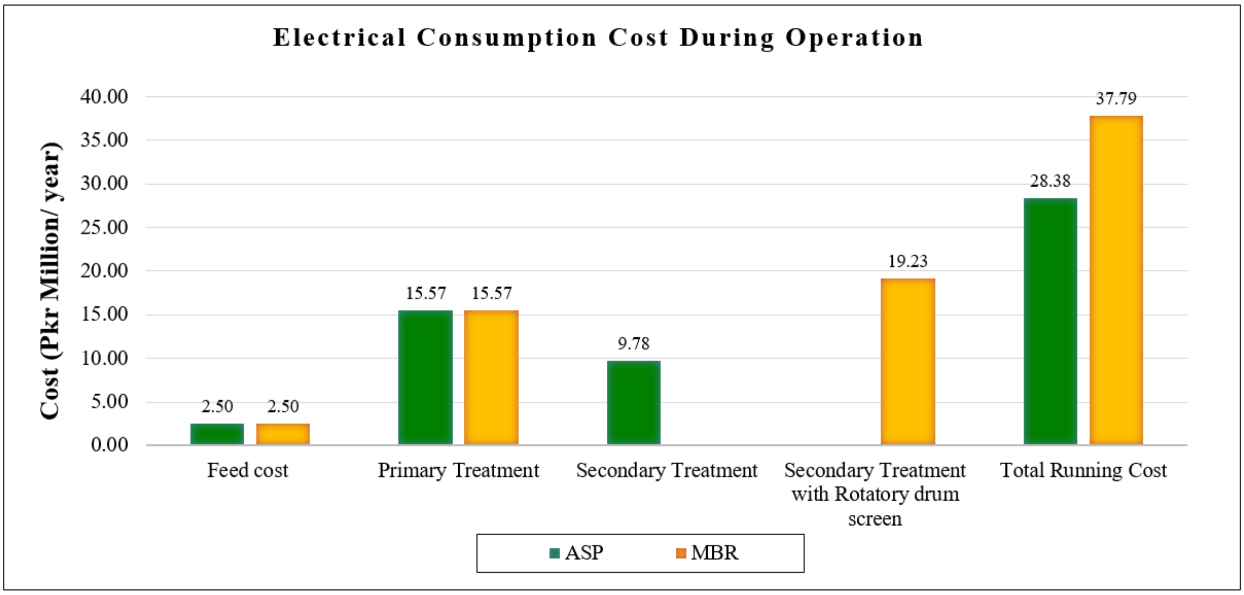

Figure 6 Energy Consumption Cost

4.5 Equipment and Installation Cost

Figure 9 shows the estimated equipment and installation cost, for ASP and MBR treatment technologies. The equipment and installation cost includes the cost of PVC piping, PH meter, MLSS meter, flow meters, dosing pumps, electric cables wiring, and mainly the installation cost of imported membrane modules. The graph represents that the MBR costs 16.5 million PKR whereas the ASP cost 11.6 for the phase 1.

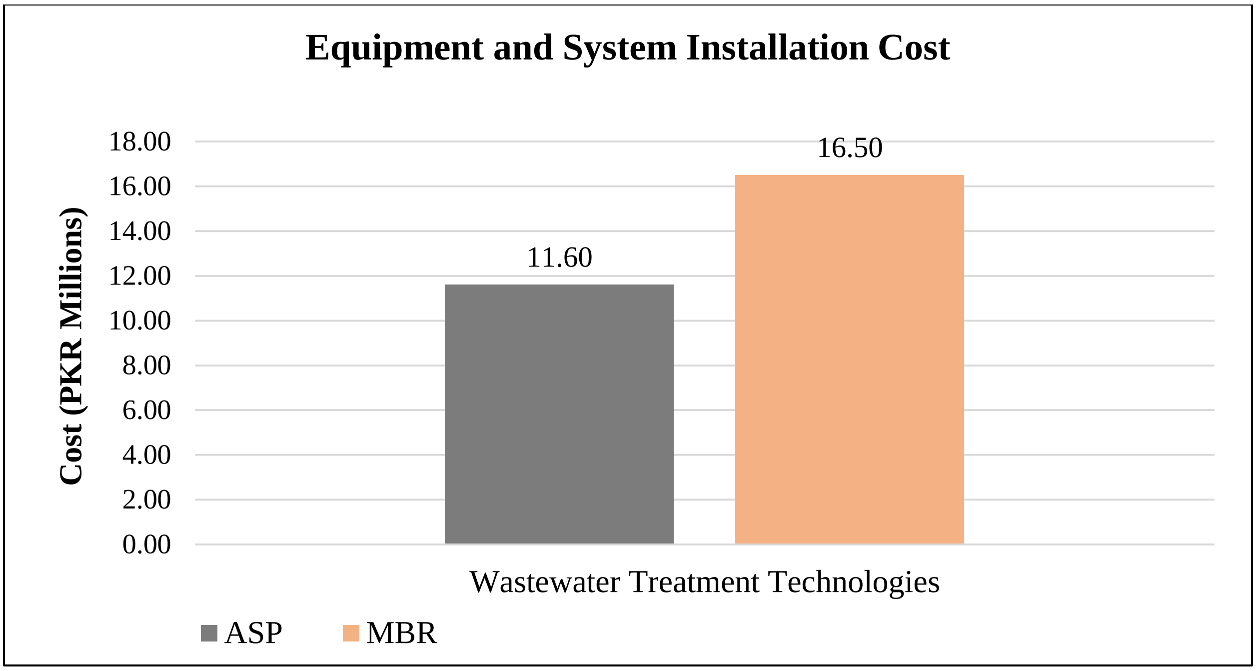

Figure 7 Equipment and Installation Cost

4.6 GPSX Output of Steady and Non-steady State Simulation

The modelled GPS-X plants designs were simulated at two conditions i.e., steady, and non-steady state.

During the non-steady state, the variables were not fixed, and the software simulated on the given constant set of variables, without any fluctuations as the plants are for the future development and there is no such present condition available.

Figure 10 shows the variation in ASP in non-steady state. A slight fluctuation at the initial days of its run to maintain the steady state by the given flow rate and design parameters can be seen. The results show that the plants will run under the desired value. All the parameters, BOD, COD, and TSS showed a decline in their respective concentrations, initially- to attain the stable condition. Once, they attained stability, their concentrations remained constant. Similarly, Figure 11 shows the non-steady state response for MBR; which showed same initial fluctuation as ASP, until it attained stability.

On the other hand, Figures 12 and 13 show the steady state response for ASP and MBR, respectively. Due to the absence of any variations in conditions no fluctuations on effluent concentration occurred. The concentration of each parameter has remained constant throughout the simulation.

The response observed for both technologies, in the stated conditions, are shown hereunder:

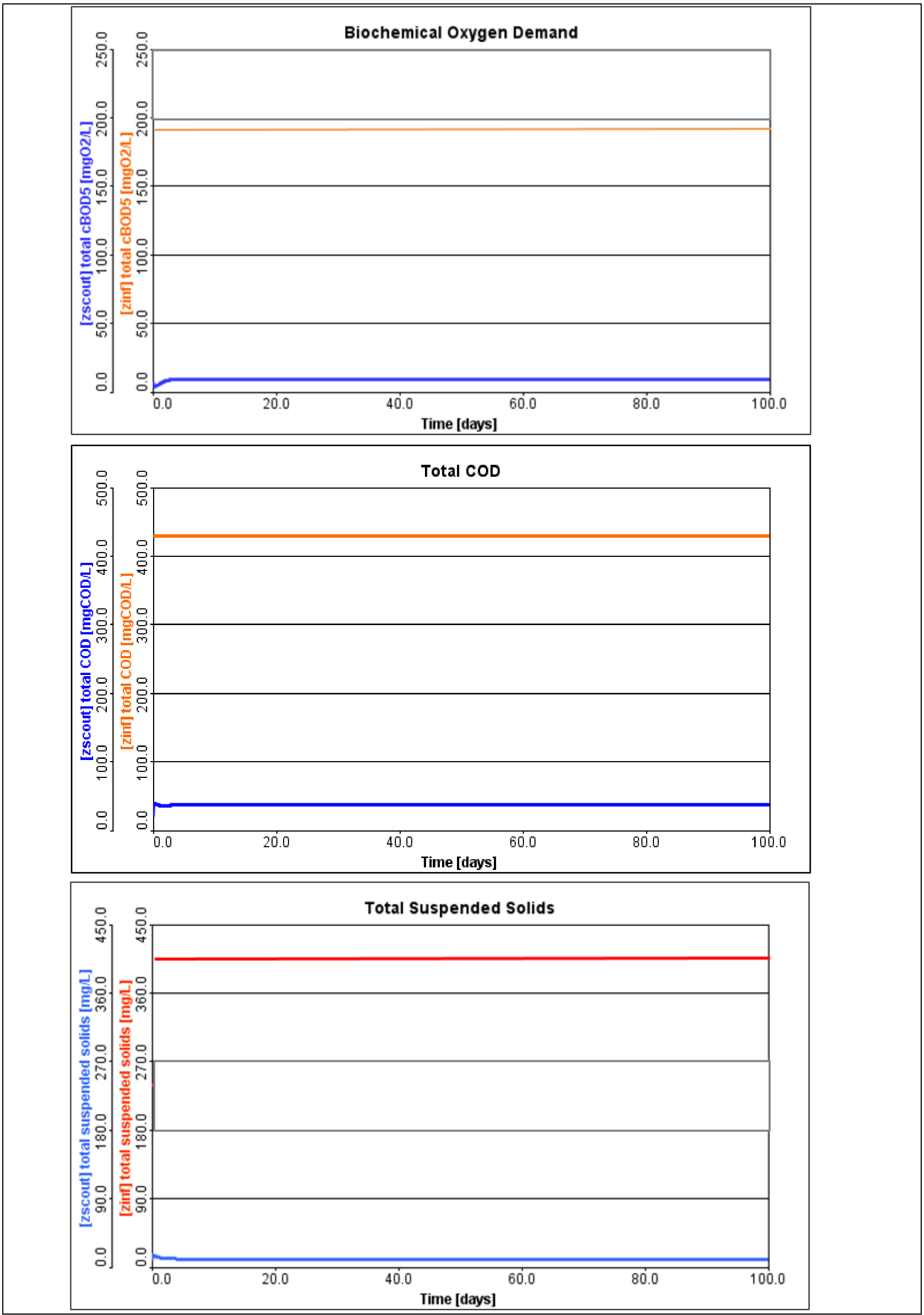

Figure 8 Non-steady State Response of Activated Sludge Process

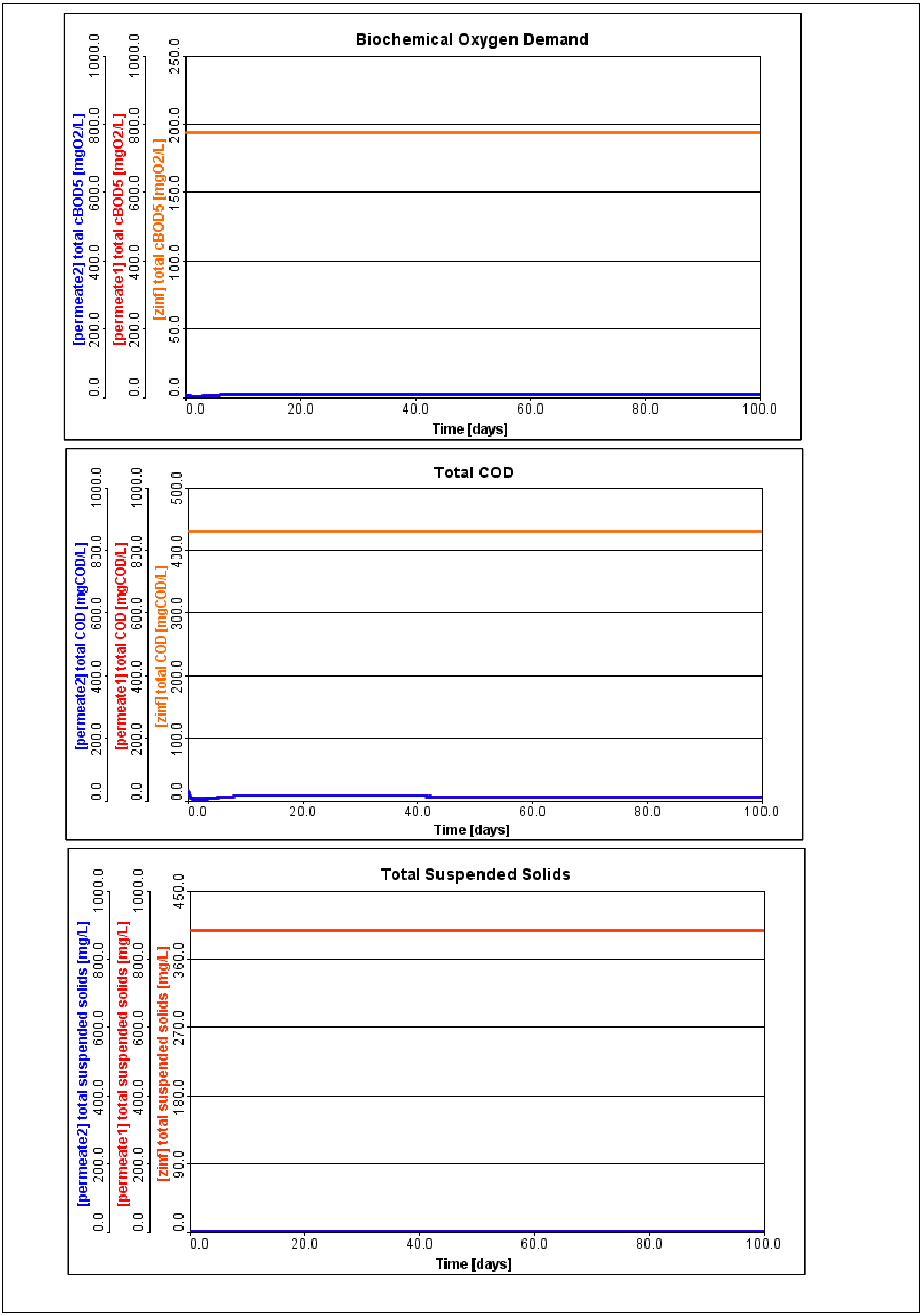

Figure 9 Non- steady State Response of Membrane Bioreactor

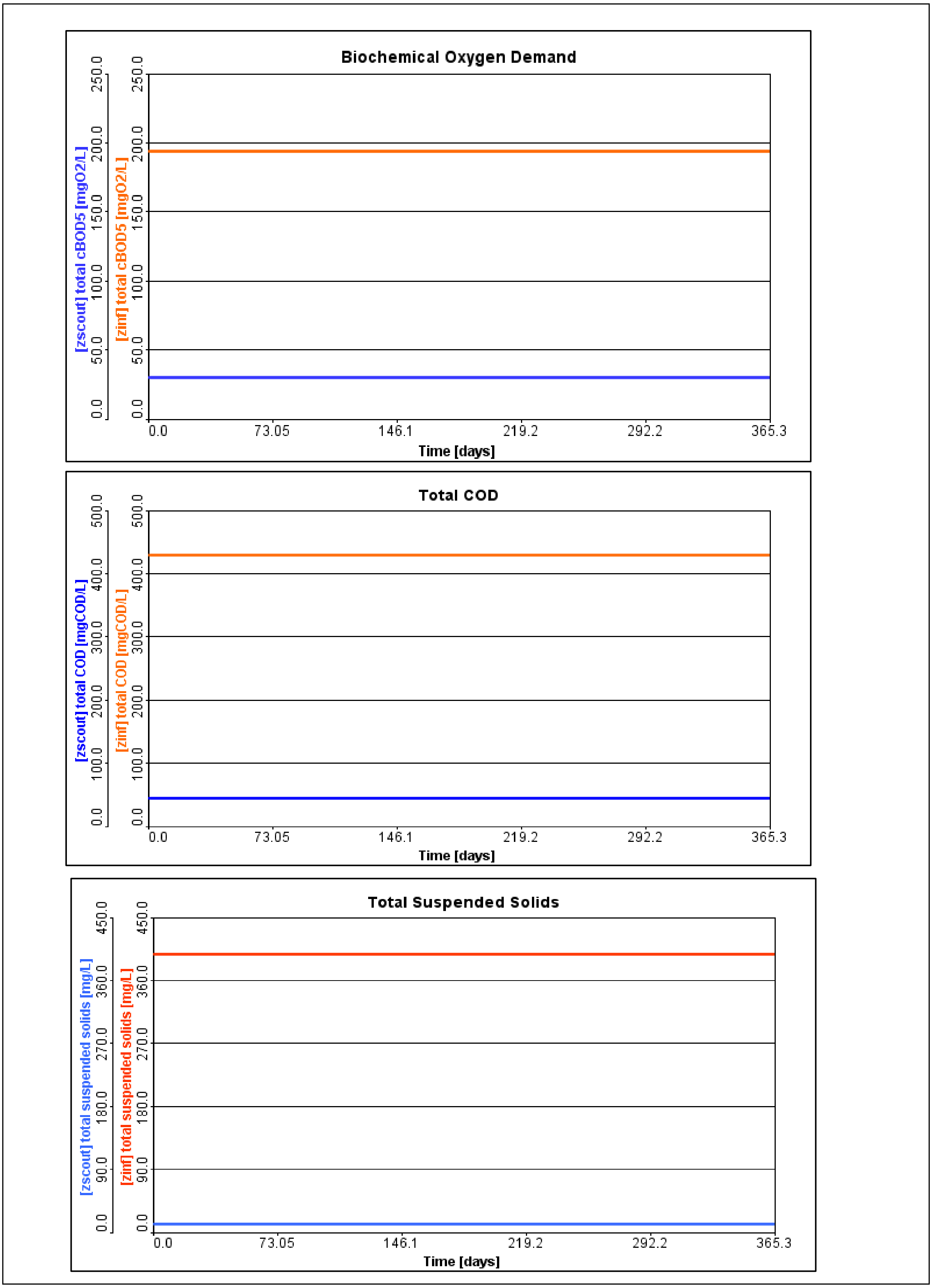

Figure 10 Steady State Response of Activated Sludge Process

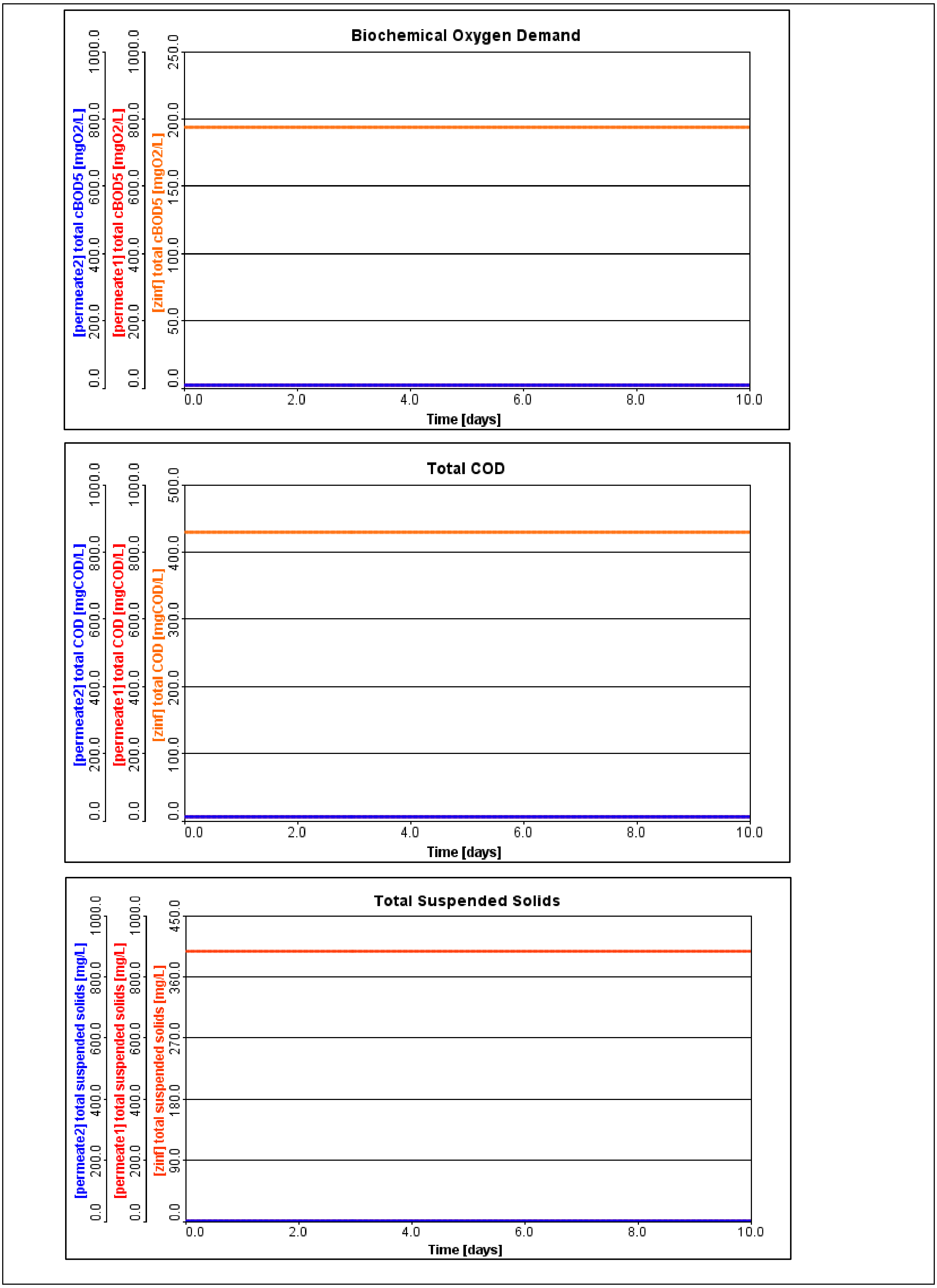

Figure 11 Steady State Response of Membrane Bioreactor

5 Conclusion

The results indicated that The MBR achieved high removal efficiencies and is the most suitable technology for future advancement. Although MBR is being a state-of the art technology but it is comparatively costly as the operational and equipment installation cost for MBR is 37.79 million Rupees and 16.50 million rupees for its first phase for a year which is greater than the ASP technology which is 28.38 million and 11.6 million.

The excel sheet model development was based on 50 and 60 % removal efficiencies and GPSX Software simulated the technologies on 84-99% removal efficiencies for the parameters; BOD COD and TSS.

The removal efficiencies for BOD COD and TSS were 84.3%89.6 and 97.1% for ASP using GPSx software and for MBR; 96.2%97.14% and 99.2% respectively. So the GPSx software gave more accurate results for the technologies studied. Therefore, efficiencies greater than the target ones are much suitable to run on GPSX

6 Recommendations

1. Variation in the Organic Loading rate (TN, TP, TSS, BOC, COD etc.,) can be modeled to evaluate the pollutants on design parameters.
2. Variation in Hydraulic Loading Rate can also be modeled through the software
3. Other Treatment Technologies such as Waste, Stabilization Pond, Oxidation Ditch, Forward Osmosis, and Sequencing Batch Reactors can be modelled too on GPSX Software to further ease the wastewater treatment Selection Process.
4. Physical parameters can be incorporated such as SRT, HRT and Temperature to better evaluate the plant performance.

7 References

Abbasi, N., Ahmadi, M., & Naseri, M. (2021). Quality and cost analysis of a wastewater treatment plant using GPS-X and CapdetWorks simulation programs. *Journal of environmental management*, *284*, 111993.

Al-Wardy, A. H., Alquzweenib, S. S., & Al-Saadi, R. J. Modelling and Simulation of Al-muamirah Wastewater Treatment Plant by GPS-X Software.

Al-Wardy, A. H., Alquzweenib, S. S., & Al-Saadi, R. J. (2021). Modelling and Simulation of Al-muamirah Wastewater Treatment Plant by GPS-X Software. *Kerbala Journal for Engineering Sciences, 1*(2).

Ali, M., Rousseau, D. P., & Ahmed, S. (2018). A full-scale comparison of two hybrid constructed wetlands treating domestic wastewater in Pakistan. *Journal of environmental management, 210*, 349-358.

Ali, Y., Pervez, H., & Khan, J. (2020). Selection of the most feasible wastewater treatment technology in Pakistan using multi-criteria decision-making (MCDM). Water Conserv Sci Eng 5 (3): 199–213. In.

Arif, A. U. A., Sorour, M. T., & Aly, S. A. (2018). Design and comparison of wastewater treatment plant types (activated sludge and membrane bioreactor), using GPS-X simulation program: case Study of Tikrit WWTP (Middle Iraq). *Journal of Environmental Protection*, *9*(6), 636-651.

Arif, A. U. A., Sorour, M. T., & Aly, S. A. (2020). Cost analysis of activated sludge and membrane bioreactor WWTPs using CapdetWorks simulation program: Case study of Tikrit WWTP (middle Iraq). *Alexandria Engineering Journal*, *59*(6), 4659-4667.

Baker, R. (2012). Gas separation. *Membrane technology and applications, 2*, 301-351.

Besha, A. T., Gebreyohannes, A. Y., Tufa, R. A., Bekele, D. N., Curcio, E., & Giorno, L. (2017). Removal of emerging micropollutants by activated sludge process and membrane bioreactors and the effects of micropollutants on membrane fouling: A review. *Journal of environmental chemical engineering*, *5*(3), 2395-2414.

Drews, A. (2010). Membrane fouling in membrane bioreactors—Characterisation, contradictions, cause and cures. *Journal of membrane science*, *363*(1-2), 1-28.

Fatima, S., & Khan, S. J. (2012). Evaluating the treatment performance of a full scale Activated Sludge Plant in Islamabad, Pakistan. *Water Practice and Technology, 7*(1).

Gautam, V. Activated Sludge Process of Sewage Treatment | Waste Management. Retrieved from https://www.engineeringenotes.com/waste-management/activated-sludge-process/activated-sludge-process-of-sewage-treatment-waste-management/40150

Hreiz, R., Latifi, M., & Roche, N. (2015). Optimal design and operation of activated sludge processes: State-of-the-art. *Chemical Engineering Journal*, *281*, 900-920.

Hydromantis. (2022). GPS-X. Retrieved from https://www.hydromantis.com/GPSX-innovative.html

Jasim, N. A. (2020). The design for wastewater treatment plant (WWTP) with GPS X modelling. *Cogent Engineering*, *7*(1), 1723782.

Javed, T., Qureshi, R., Ahmad, S., Sajjad, M., Mashiatullah, A., & Sha, Z. (1997). An overview of environmental pollution status and waste treatment technology used in Pakistan.

Khalid, P. D. I., & Khan, M. A. (2020). Water Scarcity-A Major Human Security Challenge to Pakistan. *South Asian Studies*, *31*(2).

Liu, Y., & Jiang, Y. (2021). Urban growth sustainability of Islamabad, Pakistan, over the last 3 decades: a perspective based on object-based backdating change detection. *GeoJournal, 86*(5), 2035-2055.

Mateo-Sagasta, J., Raschid-Sally, L., & Thebo, A. (2015). Global wastewater and sludge production, treatment and use. In *Wastewater* (pp. 15-38): Springer.
Metcalf, L., Eddy, H. P., & Tchobanoglous, G. (1991). *Wastewater engineering: treatment, disposal, and reuse* (Vol. 4): McGraw-Hill New York.
Murtaza, G., & Zia, M. H. (2012). *Wastewater production, treatment and use in Pakistan.* Paper presented at the Second regional workshop of the project ‘safe use of wastewater in agriculture.
Orhon, D. (2015). Evolution of the activated sludge process: the first 50 years. *Journal of Chemical Technology & Biotechnology, 90*(4), 608-640.
Shin, C., & Bae, J. (2018). Current status of the pilot-scale anaerobic membrane bioreactor treatments of domestic wastewaters: a critical review. *Bioresource technology, 247*, 1038-1046.
Ungureanu, N., Vlăduț, V., & Voicu, G. (2020). Water scarcity and wastewater reuse in crop irrigation. *Sustainability, 12*(21), 9055.
Verstraeten, E., & Vanclooster, M. (2021). *Collection and analysis of historical data for empirically assessing water pollution risks of Walloon catchments.* Paper presented at the International virtual conference Interdisciplinary approaches for adressing the 21 century water challenges.
Visvanathan, C., Aim, R. B., & Parameshwaran, K. (2000). Membrane separation bioreactors for wastewater treatment. *Critical reviews in environmental science and technology, 30*(1), 1-48.