Statistical Monitoring of a Biological Wastewater Treatment Process

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Abstract

Background: Wastewater/Sewage influent & effluent quality and effluent reutilisation can be assessed with the help of various statistical and multivariate tools. Nowadays, these tools have proved to be efficient method for the quality assessment and management of various wastewater treatment technologies. **Objective:** The present study is carried out on the influent and effluent of Dr. Sen Nursing Home Sewage Treatment Plant (STP), New Delhi, India based upon BIOFOR which is a biological treatment technology. The basic objective of the study is to carry out statistical monitoring of all the physiochemical parameters and to identify treatment process performance, the interdependencies between the variables. **Methods:** The raw sewage (influent) and treated sewage (effluent) data of the STP was subjected to paired t-test, Principal Component Analysis (PCA) and Biodegradability Index (B.I). All the Statistical Analysis was performed using SPSS 22.0 and MS-Excel. **Findings:** The paired sample t-test proved that all the physicochemical parameters vary significantly in the influent and effluent ($p < 0.05$) indicating that the technology is effectively functioning for the treatment of raw sewage. PCA reduced the dimensionality of wastewater data (influent and effluent) into three factors which accounted for 68.05% and 72.053% respectively of the total variance in the dataset. The study also utilized the Biodegradability Index which was applied to both influent and effluent data and the results obtained revealed that the technology is very much efficient in treating influent with production of effluent of high quality. **Application:** BIOFOR technology can be considerable coupled with another conventional sewage treatment technologies giving low performance (which are currently used in different STPs of New Delhi) to increase their effectiveness and get the optimum results.

Keywords: BIOFOR, Correlation Matrix, Principal Component Analysis (PCA), t-test, Biodegradability Index

1. Introduction

1.1. Background

Municipal Corporation usually takes care of the various sewerage treatment plants (STP's). In Delhi the same has been taken up by Delhi Pollution Control Board (DPCC) as well as Delhi Jal Board (DJB). Multivariate techniques are used worldwide as they are efficient in assessing the potential parameters affecting the wastewater treatment technologies and further helping deciding the performance and management related to wastewater/sewage or water quality [1-2]. Statistical analysis was carried in a treatment plant and the concentration data was considered in the influent from an external source [3]. A study was also carried out in USA which presented a multivariate analysis of the physicochemical parameters of municipal wastewater. The objective of this study was to establish simple and reliable predictive models to correlate target variables with specific measured parameters [4].

The relationship within the physiochemical parameters of the influents do affect the quality of the effluent coming out from a STP. To foresee the same statistical evaluation of wastewater characteristics at the Inlet – Outlet of an Activated Sludge Process was done in Pune, India [5]. A study on how suspended solids concentration affects nitrification rate in microalgal-bacterial photobioreactors without external aeration was conducted in Italy and the results obtained revealed that assessment of the optimal TSS concentrations makes possible to concentrate the microbial biomass in a photobioreactor while ensuring high kinetics and a low footprint [6]. In an another study conducted in US the relationship between suspended solids and nutrients with variable hydrologic flow regimes were evaluated results proved that inflow dynamics drive changes in the salinity regime, suspended solids, and act to maintain nutrient concentrations[7]. Similarly, study on the efficiency of sequential batch reactor (SBR) - based sewage treatment plant was carried out J&K, India [8]. Study conducted in Iraq established an empirical correlation between biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) of the sewage flowing in Al-Diwaniyah wastewater treatment plant. Results proved that they were highly correlated with each other [9]. Likewise, Correlation between Biochemical Oxygen Demand and Chemical Oxygen Demand for Various Wastewater Treatment Plants in Egypt to Obtain the Biodegradability Indices [10]. Recently a case study was presented regarding sewage treatment highlighting the drawbacks and positive aspects of the same for Indian contest [11].

Researcher have worked upon the wastewater quality monitoring. A study on the quality of raw and treated wastewater was carried out using the principal component on weighted index (PCWI) which was defined as a sum of principal component scores weighted according to their eigenvalues and the results obtained revealed that unlike other weighted indexes, the PCWI is composed of independent variables with minimal information noise and objectively determined weights [12]. In a case study, evaluation of biological wastewater treatment process using Mahalanobis distances in original and principal component space and it was concluded that in contrast to complexity and different magnitudes of the original wastewater parameters, the logMD charts provided a simple and effective tool for the evaluation of biological wastewater treatment process [13].

1.2 Research Gaps

As per the literature reviewed so far it is being observed that in case of statistical or multivariate analysis that the researchers have taken either influent parameters or only the effluent parameters during their course of the investigation. Hence, to get better results and desired output in terms of statistical monitoring and performance, both influent and effluent analysis must be considered and the same is not being reported in the literature reviewed. Although, performance evaluation has been reported for the Delhi STPs [14-15]. But for BIOFOR technology which is the most recent technology the statistical analysis has not been reported yet in terms of PCA.

1.3 Objectives of the Study

The literature reviewed and the research gap obtained thereafter has arose two main objectives of the study. First objective of the study is to have a statistical monitoring of the recent and robust technology taking in account both influent and effluent physiochemical parameters of the study. Second objective is dimensionality reduction of the parameters to identify treatment process performance, the interdependencies between the variables. Hence, both these objectives will link the research gaps mentioned above.

1.4 Significance of the Study

Sewage treatment plants contributes toward the betterment of the society as they clean the sewage and the reutilisation of the sludge as manure is very helpful for the agricultural land. This study is significant as in New Delhi some of the STPs working on the conventional technology are not producing the desirable effluent for example Timarpur STP of Delhi which is not disposing its effluent as per the Central Pollution Control Board (CPCB) and Delhi Pollution Control Committee (DPCC) norms [16]. Now this STP is being closed for the same reason. Hence, a BIOFOR technology can be coupled with any of the conventional technology which will enhance the performance of the STP.

2. Methodology

2.1 Study Area

Dr. Sen Nursing Home STP, New Delhi is being taken during the investigation of the course. It is 28° 09'52.2"N 77°14'25.0"E as per the ordinates. This plant is based upon the BIOFOR technology, and the capacity of the plant is 20MLD. “The treatment process used here is Physico-chemical Treatment. This involves pre-treatment viz. fine & coarse screening/aerated degriting: 1 operation unit, oil & grease trap: 1 operation unit, Biological aerated filters: 8units & sludge dewatering on filter press: 2 units [17]. Figure 1. Depicts the details of the various STPs in the vicinity of Delhi. Figure 2. Shows the flow diagram to depict the working of Dr. Sen Nursing Home STP.

2.2 Sampling sites, Frequency and Duration of samplings

Sampling for the parameters was conducted at the inlet (influents) and outlet (effluents) of Dr. Sen Nursing Home STP based upon BIOFOR technology on monthly basis from the year 2014 to 2019 as per American public health association-APHA 1998 standards [18]. Composite sampling method is being used for sample collection.

2.3 Physiochemical parameters analysed and test method adopted

Parameters considered for the study were pH, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Oil and Grease, Ammonical

Nitrogen and Phosphates. The various testing methods adopted for testing of different physiochemical parameters and instruments for the same are depicted in Table 1.

2.4 Statistical Analysis

2.4.1. Paired sample t- test

This is a statistical technique used to determine whether there is a difference in mean values of two sets of observations or not. In the present study paired t-test was conducted to check whether there is a difference in the influent and effluent values. For testing significant difference between means of influent and effluent data, the differences (D) of the values were calculated:

$$D = \overline{x_1} - \overline{x_2}$$

It is assumed that D has a normal distribution and $\overline{D} = \sum \frac{D}{n}$ and t-value is calculated as

$$t = \frac{\overline{D} - \mu_D}{S_D/\sqrt{n}}, \text{ where } S_D = \sqrt{\frac{n\sum D^2 - (\sum D)^2}{n(n-1)}} \text{ and } S_{\overline{D}} = \frac{S_D}{\sqrt{n}}$$

If the t-value calculated is more than the critical t-value, then it is concluded that there is a significant difference in the mean values of two dependent samples (influent and effluent). In the present study statistical significance is determined using p-value. The cut-off value for determining statistical significance is chosen as 0.05 or less. If the computed p-values are less than 0.05, it is concluded that the means of two samples are unequal and the difference is significant and if the p-values are more than the cut-off (i.e., 0.05) it is concluded that difference is not significant.

2.4.2. Biodegradability Index

The biodegradability index (BI) is an indicator of the toxicity of the wastewater and is defined as the ratio between BOD and COD. Its value varies from zero to unity. Typical values for the ratio of BOD/COD for untreated municipal wastewater are in the approximate range 0.3 to 0.8 as shown in Table 2. If the ratio is equal or greater than 0.5 the wastewater is easily treatable by biological treatment. If the ratio is below 0.3, either the wastewater may have some toxic components or acclimated microorganisms may be required for degradation. This ratio decreases to 0.11 – 0.31 for the treated sewage [19-20].

2.4.3. Correlation Analysis

It is a technique that measures statistical association between variables. In the present study Pearson correlation coefficient is used to know the inter-variable relations between the parameters. Pearson's correlation coefficient (r) lies between $-1 \leq r \leq 1$. When r takes value greater than 0.7 it is considered as a strong positive correlation and if $r \leq -0.7$ then it is interpreted as strong but negative correlation. If $0.5 \leq r \leq 0.7$ then moderate positive correlation, $-0.7 \leq r \leq -0.5$, then moderate negative correlation [21].

2.4.4. Principal component analysis or PCA

PCA is a dimensionality reduction method that is used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one (called principal components or factors) that contains most of the information of the large set. Factors/Principal components are constructed as linear combinations of the initial variables in such a way that the factors are uncorrelated and most of the information within the initial variables is condensed into the first components i.e., the first factor accounts for the **largest possible variance** in the data set. The second factor is calculated in the same way, with the condition that it is uncorrelated with the first factor, and it accounts for the next highest variance. This continues until a total of p factors have been calculated which is equal to the original number of variables. Few factors are retained for the interpretation which is done using Kaiser Criterion which suggests that components having eigen value greater than one is considered essential and are retained in the analysis. Varimax rotation is used to increase the participation of the variables with higher contribution and reducing that of the variables with lesser contribution at the same time [22-24]. Statistical Analysis was performed using MS-Excel and SPSS 22.

3. Results and Discussions

3.1. Variations

Paired sample t-test was applied to both influent and effluent data values. T-test results signifies that there is a significant difference between influent and effluent values of the following parameters: TSS, BOD, COD, Ammonical Nitrogen and phosphate (with p-value < 0.05). However, no significant difference was found in pH values. Overall, the t-test suggests that there is an influence of the treatment technology on the parameters of wastewater.

3.2. Biodegradability Index (B.I.) BOD/COD

B.I. was calculated for influent (untreated) sewage and effluent (treated) sewage and the results are displayed in Table 3. From the results it is observed that BOD/COD ratio of influent ranged between 0.22-1.14 with an average of 0.38 indicating that this sewage is easily degradable by biological processes inculcated in the BIOFOR technology. The range for effluent is 0.22- 0.44 with an average of 0.311 which indicates that the technology is working efficiently with respect to the production of good quality effluent.

3.3. Correlation between the physicochemical parameters

Pearson correlation coefficient was used to measure the linear relation between various physicochemical parameters. The results in Table 4 indicates that there is a strong and positive correlation between TSS and Ammonical Nitrogen ($r = 0.571$) in the influent data. From Table 5, it is observed that BOD is strongly correlated with COD ($r = 0.745$) and moderately correlated with TSS ($r = 0.542$) for the effluent parameters. This is due to the reason that assessment of the optimal TSS concentrations makes possible to concentrate the microbial biomass in a photobioreactor while ensuring high kinetics and a low footprint.[6]. Also, inflow dynamics drive changes in the salinity regime, suspended solids, and act to maintain nutrient concentrations [7].

Further, the decrease in TSS could be attributed to sedimentation process undergoing during the treatment this is indicated by the fact that BOD and COD usually exhibit linear positive correlation in nature. Moreover, there exists a definite correlation between the COD and BOD under certain conditions and by determining the COD, the information about the BOD of the wastewater can be derived, but it is highly waste dependent [9]. Naturally, these variables are highly correlated due to their overall representation of organic components in the wastewater. BOD is moderately correlated with TSS (0.542). This is due to the fact that there is no direct relation between TSS and BOD. However, some sense is also required based on the type of your wastewater (domestic or industrial, or from commercial buildings) or grey water, taking into consideration the level of treatment [12, 13].

3.4. Principal Component Analysis (PCA)

Before the influent and effluent data was subjected to multivariate technique (PCA)the following assumptions were checked.

Step 1: Checking linearity

Linearity assumption can be seen from the Pearson correlation matrix in Table 4 & 5 of the influent and effluent data.

Step 2: Suitability of data

Kaiser- Meyer-Olkin (KMO) is used to measure how suited data is for PCA. The test measures sampling adequacy for each variable in the model and the complete model. The KMO value over 0.5 is considered acceptable. Bartlett's test of Sphericity is used to test the null hypothesis that the correlation matrix is an identity matrix. A significant statistical test (usually less than 0.05) shows that the correlation matrix is not an identity matrix (rejection of the null hypothesis). The validity of PCA can be seen from KMO Value = 0.664> 0.5 and Bartlett test significance value = 0.032 < 0.05 (Table 6).

Step 3: Total variance explained

The eigenvalues represent the total amount of variance that can be explained by a given principal components/factors. Table 7 & 9 shows lists of Eigen values associated with each principal component for both influent and effluent data. Eigen values in terms of percentage of variance explained is also displayed in Table 7 & 9 and corresponding cumulative percentages shows that first three factors explained 68.053% of the total variance in influent data (Table 7) and 72.027% of the total variance in the effluent data (Table 9). Also, from the scree plot (Fig 3 & 4) there is bend elbow after the third component for both influent and effluent data inferring those three components should be retained. Table 8 & 10 shows the rotated component matrix which is a matrix of the factor loadings for each variable onto each factor. Factor loading < 0.5, 0.70 – 0.5, > 0.70 are classified as weak, moderate and strong [22]. The first factor contributes 31.31% (Table 7) and 34.132 % (Table 9) in influent and effluent respectively. The first factor exhibits high load of TSS and Ammonical Nitrogen and moderate load of pH in the influent data (Table 8); which clearly indicates that all these parameters characterize organic and inorganic compounds occurring in municipal wastewater. There is a high loading of BOD, COD and a moderate loading of TSS in effluent because of characterizing the content of organic compounds which were persistent to the treatment process.

The second factor explains 21.154% and 21.13% (Table 7 & 9) of total variance in the influent and effluent values, respectively. Factor 2 loads highly with BOD, Oil & Grease and Phosphate in influent data (Table 8) indicating heavy organic loading from the nearby domestic and industrial areas. Factor 2 of effluent values load highly with pH and moderately with Oil & Grease (Table 10). Factor 3 contributes 15.59% and 16.768% of the total variance in influent and effluent values, respectively. Factor 3 has high negative loadings with COD in influent and positive loading with Ammonical Nitrogen and Phosphate in effluent. This is due to characterizing the content of organic compounds which were persistent to the treatment process and nitrification process occurring in the raw wastewater during the treatment process [12, 13].

4. Conclusion

The study revealed that there is a significant difference in the physicochemical parameters of influent and effluent, indicating the effective functioning of the BIOFOR technology in treating the raw sewage. By the means of PCA, three components were extracted for both influent and effluent data which accounted for 68.053% and 72.027% of the total data variance. The acquired three components from PCA indicates that the variations are mainly because of sewage coming from the different catchment areas supplemented by runoff water, dilution, diffusion and infiltration rate. Also, the higher values of BOD, TSS, COD and Ammonical Nitrogen is attributed to the intake of massive organic waste by an increase in the bacteriological activities. Based on biodegradability index the study revealed that the plant is suitable for the treatment of raw sewage and is capable of producing effluent of good quality which can be disposed off either into inland surface water or can be reutilised for irrigating the garden and lawns. BIOFOR technology can be coupled with any of the existing aerobic and anaerobic sewage treatment technologies which are currently used in New Delhi STPs. This will enhance the performance of these STPs.

5. Acknowledgement

We pay sincere thanks to Delhi Pollution Control Committee (DPCC) and Central Pollution Control Board (CPCB) for providing us relevant information regarding the various STPs in Delhi NCR. Without their help this study would have not been possible.

Table 1. Test Methods adopted for various Physiochemical parameters

S.No.	Name of the Parameter	Test Method Adopted.	Instruments Used
1	pH	Electrometric	pH Meter
2	Oil and Grease	Soxhlet Extraction	Soxhlet Apparatus
3	Total Suspended Solids	Membrane Filtration	Glass Fibre Apparatus

4	Biochemical Oxygen demand	Winkler's Titration	BOD Incubator
5	Chemical Oxygen Demand	Closed Reflux Titrimetric	Titrimetric Instruments
6	Ammonical – Nitrogen	Distillation Titrimetric	Titrimetric Instruments
7	Phosphate	Ascorbic Acid Spectrophotometry	Spectrophotometer

Table 2. Comparison of ratios of various parameters to characterize wastewater

Type of raw wastewater	**BOD/COD**
Untreated wastewater	0.29-0.79
Primary Sedimentation	0.41-0.59
Final Effluent wastewater	0.11-0.31

Table 3. Biodegradability Index of influent and effluent sewage

Year/ Month	**2014**		**2015**		**2016**		**2017**		**2018**		**2019**	
	Untreated	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**
Jan			0.33	0.25	0.28	0.25	0.55	0.44	0.32	0.37	0.31	0.33
Feb			0.33	0.35								
March	0.40	0.32	0.30	0.3								
April	0.43	0.42	0.22	0.23	0.31	0.28					0.34	0.37
May	0.36	0.32	0.34	0.31			0.33	0.36	0.34	0.27		
June	0.46	0.32										
July	0.3	0.24					0.35	0.34			0.32	0.30
August	0.33	0.29							0.32	0.30		
September	1.14	0.33	0.27	0.22								

October	0.39	0.26	0.30	0.24			0.31	0.35				
November	0.33	0.37	0.39	0.27	0.66	0.29			0.35	0.30	0.31	0.29
December												
Average												

Table 4. Correlation matrix for influent data

Correlation Matrix								
		pH	**TSS**	**BOD**	**COD**	**Oil & Greese**	**Ammonical Nitrogen**	**Phosphate**
Correlation	pH	1.000	-.156	.100	-.157	-.031	-.472	-.147
	TSS	-.156	1.000	.212	-.046	-.004	**.571**	.263
	BOD	.100	.212	1.000	.010	-.272	.161	**.444**
	COD	-.157	-.046	.010	1.000	-.059	.121	-.159
	Oil & Greese	-.031	-.004	-.272	-.059	1.000	-.088	-.337
	Ammonical Nitrogen	-.472	**.571**	.161	.121	-.088	1.000	.301
	Phosphate	-.147	.263	.444	-.159	-.337	.301	1.000

Table 5. Correlation matrix for effluent data

Correlation Matrix								
		pH	TSS	BOD	COD	Oil & Greese	Ammonical Nitrogen	Phosphate
Correlation	pH	1.000	.276	.054	.175	.201	-.151	.148
	TSS	.276	1.000	**.572**	.404	.294	.116	.242
	BOD	.054	.572	1.000	.745	.130	.013	.056
	COD	.175	.404	**.745**	1.000	.214	-.333	-.101
	Oil &Greese	.201	.294	.130	.214	1.000	-.294	-.033
	Ammonical Nitrogen	-.151	.116	.013	-.333	-.294	1.000	.243
	Phosphate	.148	.242	.056	-.101	-.033	.243	1.000

Table 6. KMO and Bartlett test for sampling adequacy

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.664
Bartlett's Test of Sphericity	Approx. Chi-Square	34.476
	df	21
	Sig.	.032

Table 7. Total variance explained for influent data.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.192	31.310	31.310	2.192	31.310	31.310	1.898	27.110	27.110
2	1.481	21.154	52.463	1.481	21.154	52.463	1.726	24.655	51.765
3	1.091	15.590	68.053	1.091	15.590	68.053	1.140	16.288	68.053
4	.840	11.996	80.049						
5	.651	9.303	89.353						
6	.427	6.098	95.451						
7	.318	4.549	100.000						
Extraction Method: Principal Component Analysis.									

Table 8. Rotated Component Matrix of influent data

Rotated Component Matrix[a]			
	Component		
	1	2	3
pH	**-.681**	.145	.351
TSS	**.736**	.166	.281
BOD	.074	**.767**	.100
COD	.067	.002	-.893
Oil & Greese	.113	**-.744**	.271
Ammonical Nitrogen	**.873**	.162	-.098
Phosphate	.326	**.713**	.219

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Table 9. Total variance explained for effluent data.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.389	34.132	34.132	2.389	34.132	34.132	2.127	30.380	30.380
2	1.479	21.130	55.262	1.479	21.130	55.262	1.465	20.931	51.310
3	1.174	16.768	72.029	1.174	16.768	72.029	1.450	20.719	72.029
4	.778	11.113	83.142						
5	.657	9.379	92.521						
6	.358	5.115	97.636						
7	.165	2.364	100.000						

Extraction Method: Principal Component Analysis.

Table 10. Rotated Component Matrix of effluent data

Rotated Component Matrix[a]			
	Component		
	1	2	3
pH	.039	**.759**	.229
TSS	**.684**	.307	.422
BOD	**.948**	-.038	.051
COD	**.854**	.181	-.285
Oil & Greese	.170	**.693**	-.161
Ammonical Nitrogen	-.034	-.500	**.697**
Phosphate	-.001	.173	**.790**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 4 iterations.

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Figure 1. Sewage Treatment Plants of Delhi NCR.

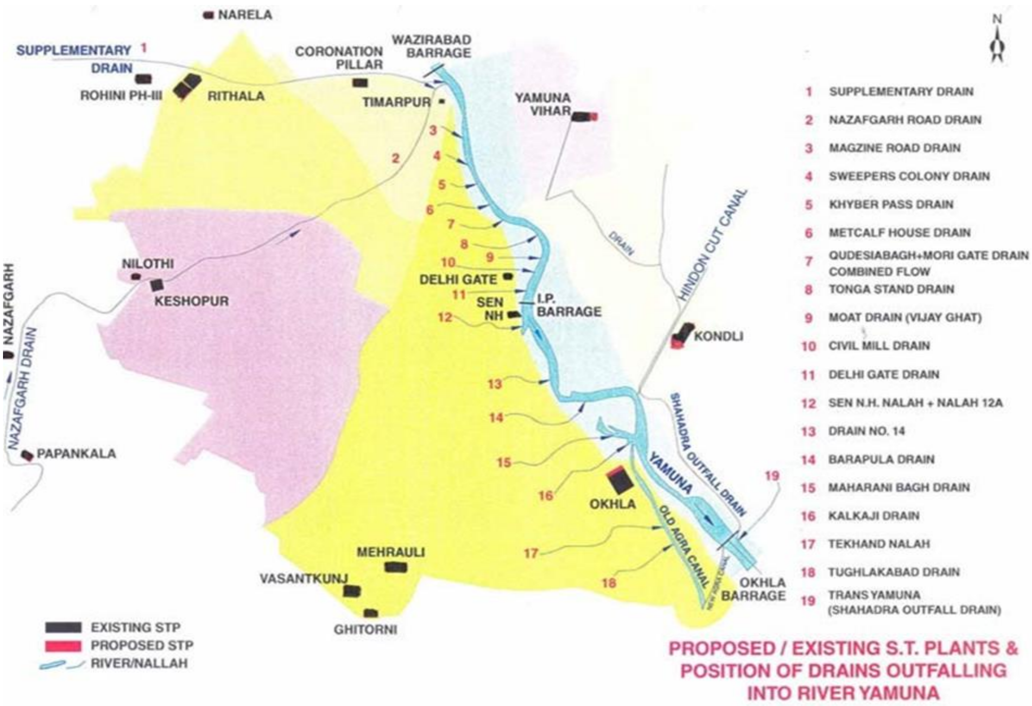

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Figure 2. Flow diagram to depict the working of Dr. Sen Nursing Home STP, New Delhi.

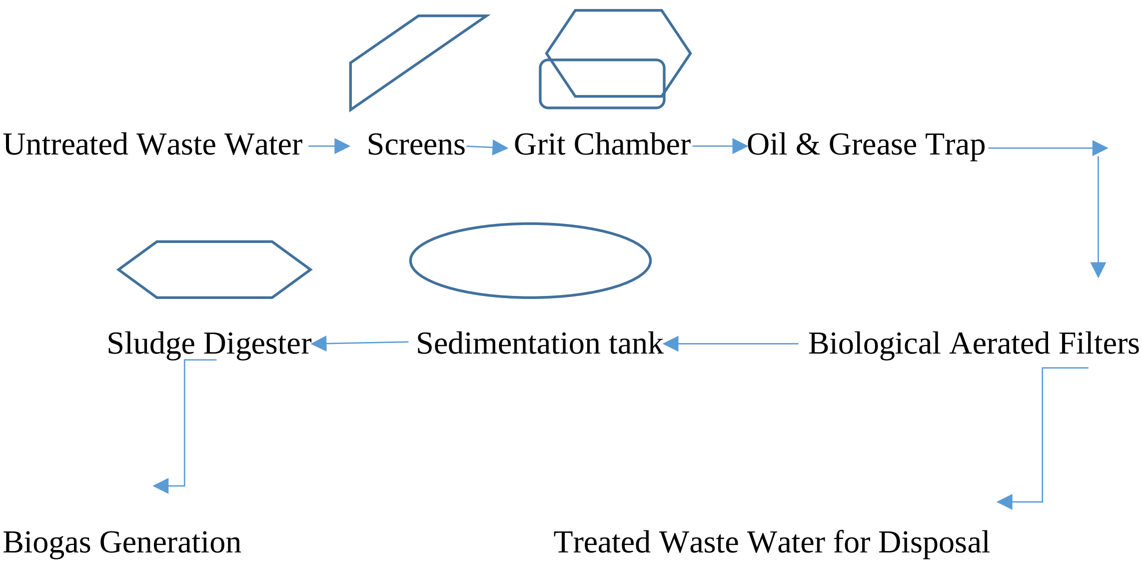

Fig. 1.4.1: Flow diagram for BIOFOR Technology

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