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Statistical Evaluation of Wastewater Characteristics at the Inlet – Outlet of an Activated Sludge Process

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ABSTRACT
Effluent to Influent concentration ratios for BOD, COD, TSS and Food-to-Microorganisms (F/M) ratio are measure of treatment plant efficiency. Daily observed inlet and outlet concentrations at ASP in a plant are plotted as time series for Pre-monsoon (January – May) and Post-monsoon (July – December, 2013) period. BOD vs TSS and BOD vs COD indicated that inlet concentrations are ~ 80 % reduced in treatment process. Correlation matrix indicated strong correlationbetween COD and TSS of post-monsoon raw sewage, while weak correlation among the rest. Principle Component Analysis (PCA) and Factor Analysis (FA) are used to characterize wastewater at the inlet and outlet of ASP. PCA & FA clustered wastewater quality parameters into strongly correlated groups - pH, COD and BOD as PC1 in pre-monsoon raw sewage while, DO and $F/M_{average}$as PC1 in post-monsoon raw sewage. All parameters (pH, TSS, COD, BOD, O&G) of treated effluent in pre-monsoon period are grouped into PC1. In post-monsoon period, for treated effluent, pH, DO, TSS and $F/M_{average}$are clustered as PC1.
Effluent BOD, COD and TSS are dependent variables with $F/M_{average}$ as independent variable for regression analysis. Regression fits developed with 2013 data for these effluent concentrations fit well with field samples (December 2013 – March 2014) and with routine monitored data (January – March, 2014), thus, validating the model. Effluent concentrations indicated 80 – 95% of removal efficiency. Thus, $F/M_{average}$ ratios obtained from regression fit can further be considered as design parameters for efficient functioning of ASP and can be used to design the inflow and outflow characteristics for any treatment plant with similar process conditions.
***Keywords*–**Principle Component Analysis (PCA), Factor Analysis (FA), Activated Sludge Process (ASP), Regression, F/M Ratio

I. INTRODUCTION

Domestic and industrial wastewaters have to undergo a well-defined treatment process prior to their release into local water bodies, mainly due to environmental, health and economic concern. Methods used in wastewater treatment processes depend on the extent of pollution, type of pollutant (organic, inorganic or toxic) and on further usage of treated effluent. Waste Water Treatment Plant (WWTP) classically provides a regulated outflow of water with limited quantity of contaminants in order to maintain an ecologically controlled environment. Regulated outflow is maintained by means of diverse unit operations applied to the incoming wastewater in a sequential manner until a cleaner outflow is achieved (Niku and Schoeder, 1981; Peavy et al., 1985; Singh et al., 2010).

Most common and efficient biological treatment process,Activated Sludge Process (ASP), employed extensively throughout the world both in its conventional and modified forms (first designed in 1913 in UK). Many field-scale(Dharaskar and Balkar, 2012) and local-scale experiments(Dharaskar and Patil, 2012) had been conducted to analyze ASP performance (Liu and Tay, 2001; Hoa, 2002) intreating domestic (Shahalam, 2004)-industrial recycles(Mardani, 2011),and in minimizing the effluent standards. Performance of ASP depends on Aerate Rate, Waste Sludge Rate and its concentration(Kumar et al, 2010; Ukpong, 2013), Sludge Retention Time, Recycle Sludge Rate, Food-to-Microorganisms (F/M) ratio (Metcalf and Eddy, 2003; Clara et al., 2004), Organic Loading Rate, Growth Pressures – pH, BOD, DO, nutrients, toxics, etc. Further, the standards to be maintained for reuse of treated effluent for different purposes are given byUkpong(2013).

Multivariate Statistical Process Control (MSPC), a process monitoring technique, referring to a set of advanced techniques which are used for the monitoring and control of both continuous(Bersimis et al., 2007) and batch processes (Aguado et al., 2007). Some of the MSPC techniques include Factor Analysis (FA), Cluster Analysis, Multidimensional Scaling, T2 Statistics and Principle Component Analysis (PCA). These methods interpret and link the results of the advanced process monitoring model for an ASP to the occurrence of significant events of interest in full scale process (Ren and Frymier, 2004), and subsequently, use that information for process operation improvement.

Primary objective of this research is to evaluate the performance of an ASP by identifying controlling quality parameters using these clustering techniques, which are rarely carried out for Indian WWTP.Further, a mathematical model is developed for further forecast of parameters.

II. MATERIALS AND METHODOLOGY

2.1 Study Area - Sewage Treatment Plant (STP)

Municipal wastewater treatment plant employing ASP process at Vithalwadi Sewage Treatment Plant (STP) in Pune, India is chosen for the current study. Entire Pune region is supported by seven treatment plants, out of which this Vithawadi STP treats the southern zone as shown in Figure 1(a), serving a catchment area of 14 km^2. Average capacity of the treatment plant is 32 MLD with peak capacity as 72 MLD. After treatment, the treated waste water finds its way into the river Mutha.

Raw Sewage Pumping Station (Coarse Screening, Wet Well, Raw Sewage Pumps), Sewage Treatment Plant (Primary, Biological Treatment, Chlorination and Disinfection), Sludge Handling (Thickner,Digester, Centrifuge) and Biological Treatment Unit (Aeration Tank, Retrievable Diffused Aeration System, Air Blowers, Secondary Settling tank Sludge Recirculation System) are the four majorcomponents of this STP, detailed in Figure 1 (b). ASP in Vithalwadi STP consisted of two Aeration Tanks (AT), each at a flow rate 16 MLD, diameters of 23.6 m and water depth of 8.1 m.

Major design quality characteristics of raw water are 150 – 200 mg/L, 250 – 300 mg/L and 200 – 250 mg/L for BOD, TSS and COS respectively. These concentrations have to be maintained at less than 20 mg/L after treatment. With this theoreticaldescription of Vithawadi STP, next section details the methodology adopted in data collection.

2.2 Data Collection

Waste water characteristics are studied by collecting data from the plant in two phases – regularly monitored STP Plant Data and Field Experimental Data. STP Plant data involved collecting data related to operational conditions – Flow (Q, m^3/day), MLSS, biological, andphysiochemical characteristics.Regularly monitoredprimary data of the treatment plant is collected from

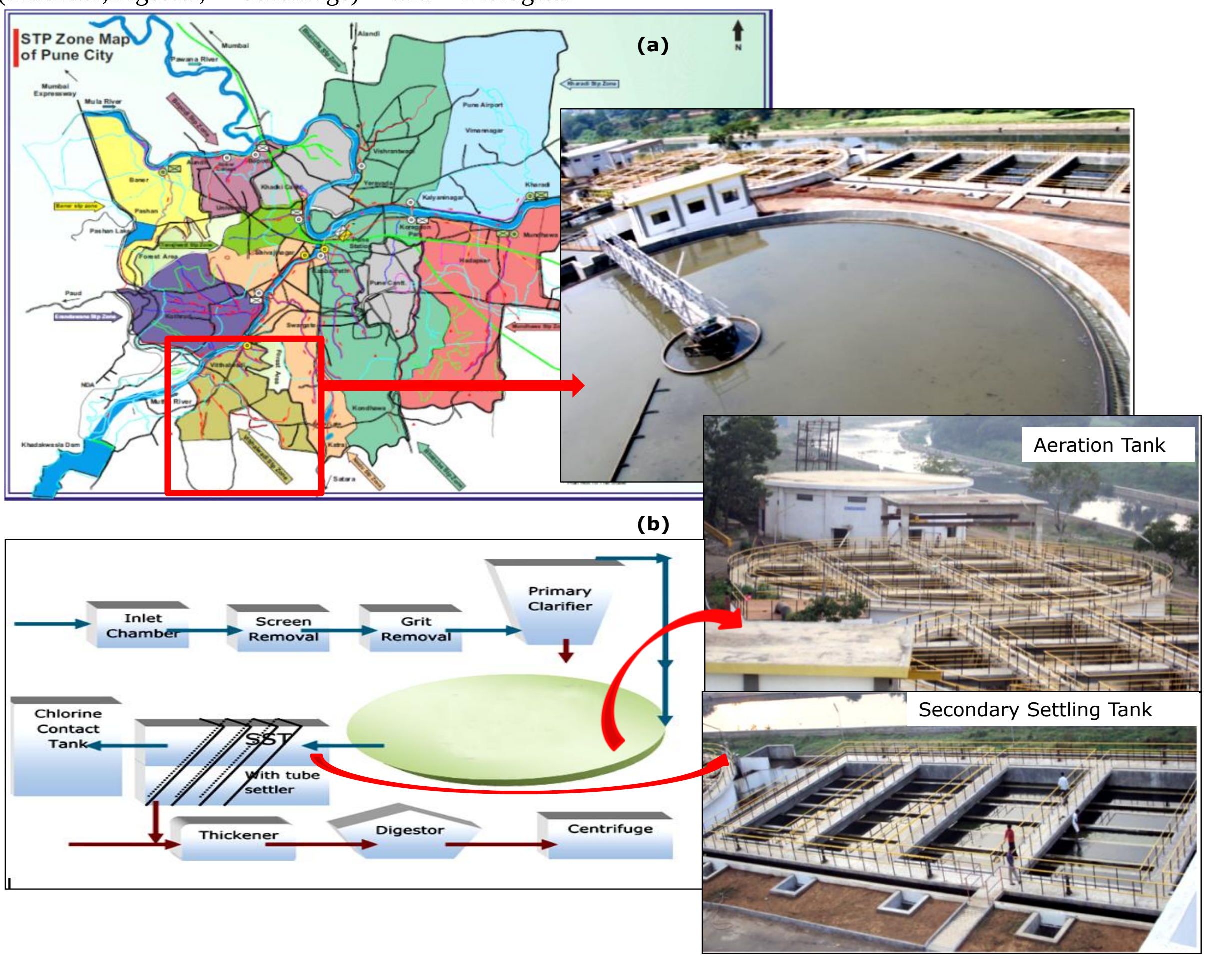

Fig. 1 Study Area Details - (a) Location Details of Vithalwadi STP (b) Functional Flow Diagram

January 2013 to March 2014. Data comprised of pH, BOD, COD, TSS, Oil and Grease (O&G) and DO, sampled at both inlet and outlet of the STP. Mixed Liquor Suspended Solids (MLSS) in the AT-1 and AT-2 are also sampled and analyzed daily at the plant by an attendant.

In order to verify and validate the primary data obtained from STP, wastewater samples are manually collected at 10 days interval December 2013 to March 2014, i.e., total of 11 sampling dates during these four months. On each sampling date, first sample is taken at the inlet of treatment plant, second one at the AT unit and the third one at effluent after SST. Hence, samples are collected on 11 sampling-dates at the three points adopting grab sampling. Clean 1L plastic bottles are used for samples at inlet, from AT and at the outlet and are analyzed on the same day. Standard experimental procedures such as 5-day BOD, $K_2Cr_2O_7$ for COD, etc are used identify BOD, COD, TSS, MLSS, pH, and O&G in the waste water.

III. PRELIMINARY DATA ANALYSIS

Regularly monitored operational plant data and sampled data are initially analyzed for temporal trends.Comparison of variations in the parameters (pH, TSS, BOD, COD, and MLSS) in AT observed at the inlet and outlet of the treatment plant is given as a part of Trend Analysis. One-year long daily monitored influent-effluent quality data is divided into “Pre-monsoon” (January – May 2013) and “Post-monsoon” (July - December 2013) periods. In addition, as mentioned in Section 2.2, field samples are collected every month from December 2013 to March 2014, on 11 different sampling dates. Time series plots for pre-monsoon and post-monsoon data are shown in Figure 2 (a) – Figure 2 (f) for different parameters. Grey shades in the figures indicate the outflow/ effluent discharges (Q, in MLD). Flow rate in the month of October and November is maintained at 32 MLD in order to check the efficiency of the treatment plant units.

pH: Pre-monsoon data indicated that pH varied from 6.6 – 7.2, with three low peaks in January, March and May. Presence of toxic chemicals (phenol, chlorinated hydrocarbons, heavy metals, halogens, acid and bases, etc.) from the household waste possibly inhibited the cell growth and substrate utilization at very low concentrations and possibly decreased the pH value. pH variations are observed to be same at both inlet and outlet of the plant as shown in Figure 2 (a). Peaks in pH in pre-monsoon are not observed in post-monsoon data, where pH is nearly constant at both inlet and outlet i.e. ~ 7.0.

TSS: Time series plots for both pre-monsoon and post-monsoon period for TSS are shown in Figure 2 (b). There are fluctuations in inlet TSS, during both seasonal periods, which could be due to the variations in the organic loading at the inlet of thetreatment. Among the two seasons, pre-monsoonTSS varied among 300 – 400 mg/L, while post-monsoon TSS is slightly lower at ~ 300 mg/L.

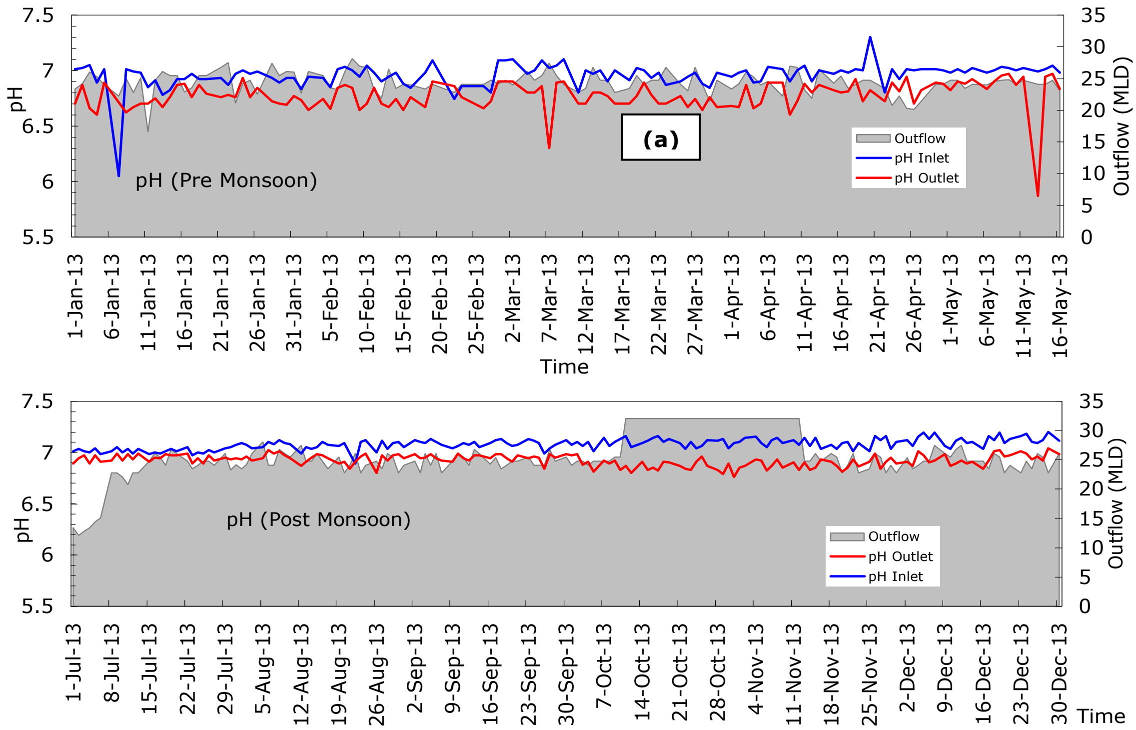

Figure 2 Time Series Plot for (a) pH

Treated effluent is observed to be very low, < 20 mg/L, indicating higher removal efficiency of plant.

DO: Oxygen supply in an AT should satisfy two needs - oxygen demand and residual DO. Oxygen rates of between 1.0 to 2.0 mg/L are best for maintaining efficient, healthy activated sludge organisms. An AT DO profile is necessary, which is studied in detail by running 3 to 4 times per year at different times of the day. Figure 2 (c) indicated a sudden decrease in DO in AT due to the maintenance problem of the air diffusers during the month of April 2013. But for this, pre-monsoon DO is at ~ 4 mg/L concentration. In post-monsoonperiod, the growth of microorganisms is high due towet climatic conditions - higher demand for DO andlower concentrations of DO is observed in the time series plot for post-monsoon period.

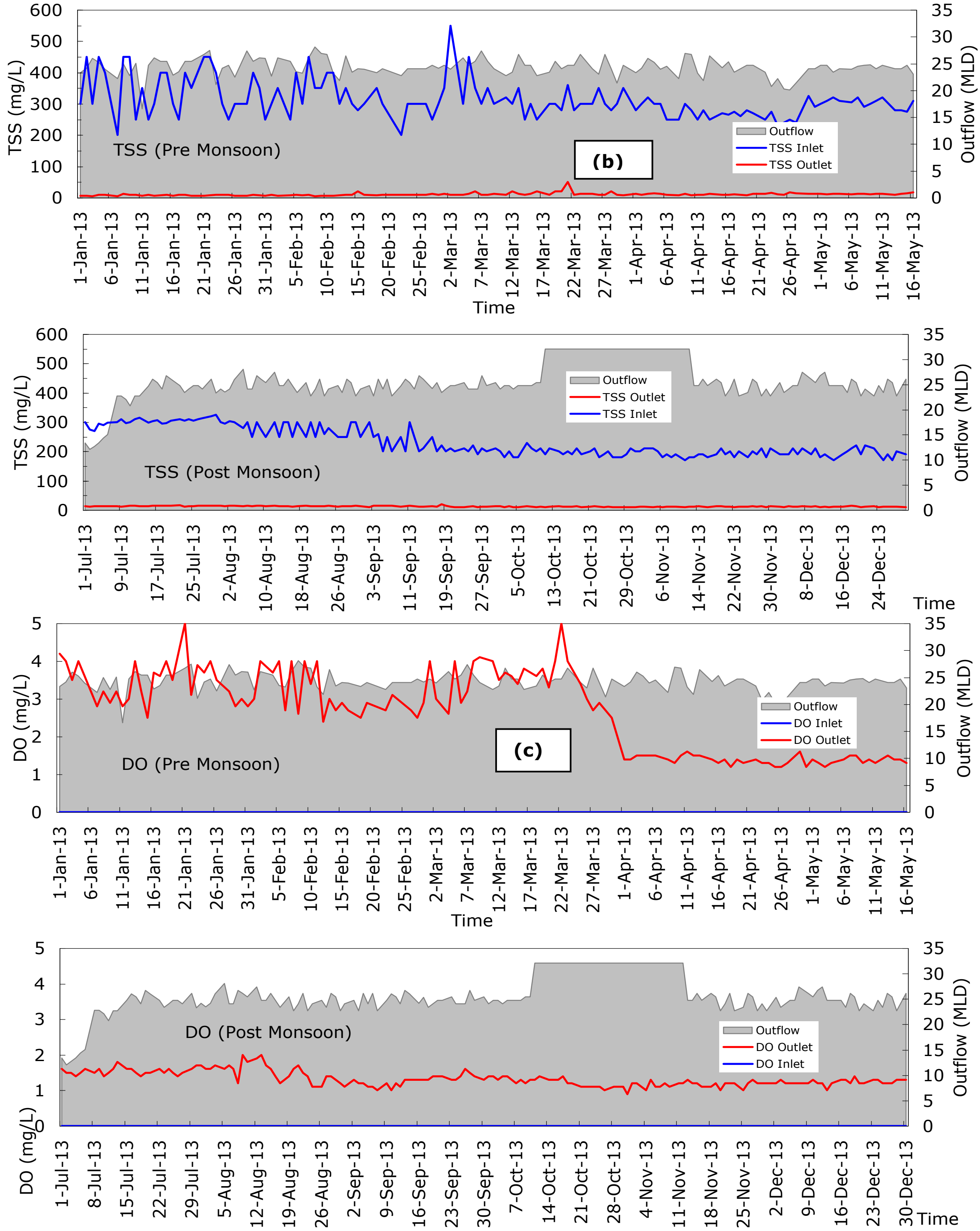

Figure 2 Time Series Plot for (b) Total Suspended Solids (TSS) (c) Dissolved Oxygen (DO)

BOD: DO requirements of the microorganisms in AT depends on influent BOD (food). As the influentBOD entering the AT increased, the amount of oxygen required to maintain a desired level of DO also increased, as observed by the fluctuations in Figure 2 (d) for pre-monsoon period at the inlet. Incomparison, the fluctuations in BOD concentration are observed to below in post-monsoon period at the inlet. Outlet BOD for both monsoon periods reduced from 100 – 150 mg/L to 10 – 15 mg/L.

COD: Fluctuations observed in COD for pre-monsoon period as given in Figure 2 (e) are similar those observed for DO (Fig. 2c) and BOD (Fig. 2d). Decrease in COD in post-monsoon period is observed, which is similar to the behavior of BOD and DO. Efficiency of the plant is further indicated by low COD outlet concentrations.

MLSS: Mixed Liquor Suspended Solids (MLSS) values as shown in Figure 2 (f), decreased during post-monsoon period from 4500 mg/L to 3000 mg/L.

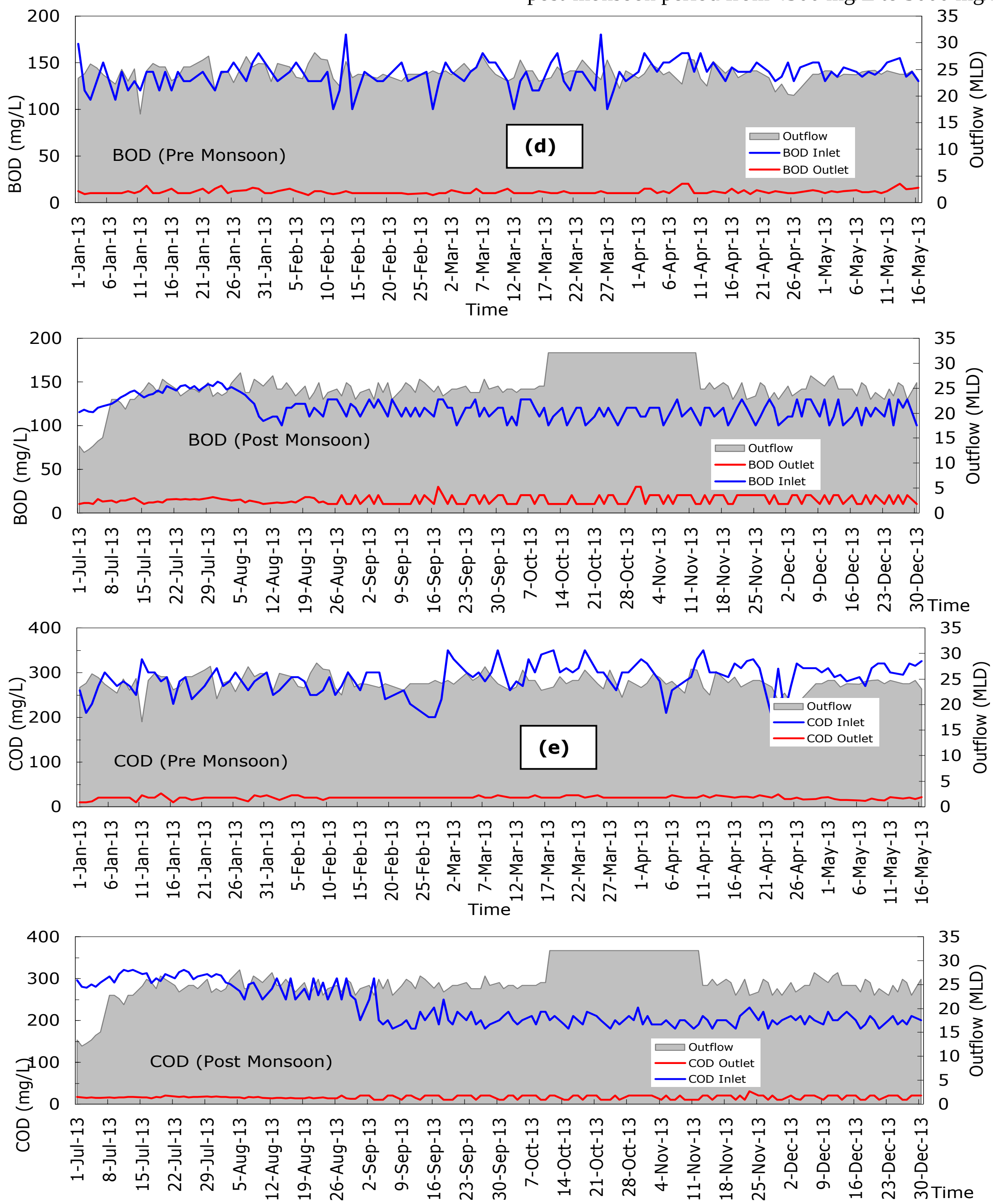

Figure 2 Time Series Plot for (d) Biological Oxygen Demand (BOD)(e) Chemical Oxygen Demand (COD)

MLSS concentration in AT decreased due to dilution of storm water at the inlet of the treatment plant.Similar was observed by Mohan and Ramesh (2006). ATs are emptied for repair of the pipelines in mid of August and September, and hence further lowered MLSS in this period. MLSS in AT stabilized later as shown by line plot in later 2013.

Food-to-Microorganisms (F/M) Ratio: Control over the microbiological population in an ASP is achieved by maintaining a constant Solids Loading Rate (SLR) or Food-to-Microorganisms (F/M) ratio. F/M ratio is defined as the ratio between the mass offood entering the plant and the mass of micro-organisms in AT. It is an important parameter relating to biological state of plant and independent of AT dimensions. Operation at adesired F/M ratio is dependent onthe control of MLSS in the system. BOD removal from Primary Settling Tank (PST) isassumed to be 30 % of inlet concentration. Thus,

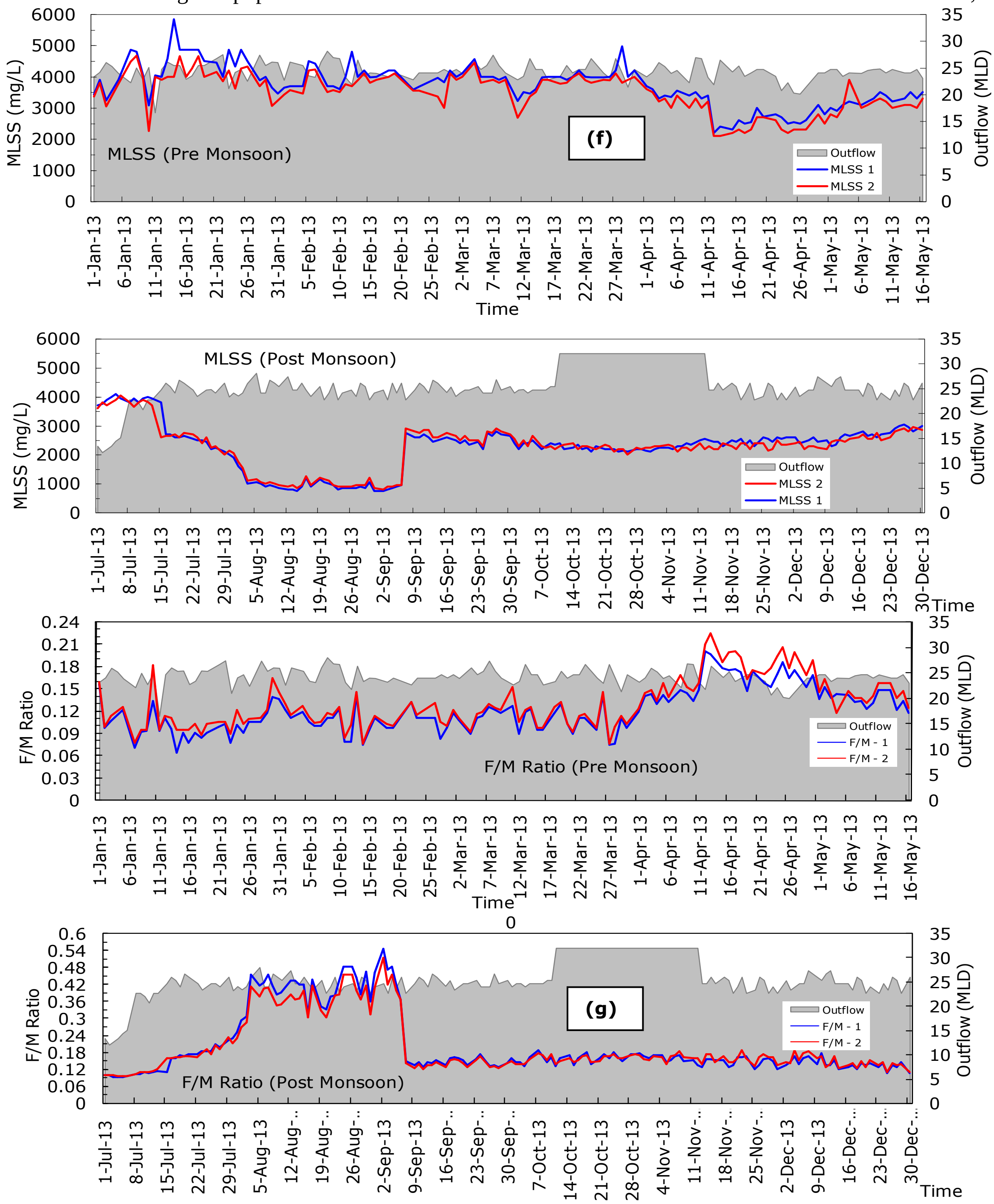

Figure 2 Time Series Plot for(f) Mixed Liquor Suspended Solids (MLSS) and (g) Food-to-Microorganisms (F/M) Ratio

BOD5 is considered as 70% of the raw influent BOD5 and F/M ratio equation is given as

$$F/M = (Q * 0.7 * BOD_5) / (V * MLSS) \ldots\ldots(1)$$

where, F/M is Food-to-Microorganisms ratio in AT (mg/L), Q is Flow rate at the inlet of AT (m^3/day), V is Volume of AT (m^3), MLSS is Mixed Liquor Suspended Solids (mg/L), BOD_5 is BOD at the inlet of AT (mg/L).

F/M ratios for the two ATs are calculated using Eq. (1) and shown as time series in Figure 2 (g). Minimal variations are observed in the pre-monsoon period, while higher ratios are observed in August due to possible pipe leakages during the monsoon. MLSS concentration in AT decreased due to dilution of the storm water at the inlet, which affected the F/M ratio of AT. With this preliminary trend analysis of primary data obtained from STP, identification of controlling parameters is performed in next section using statistical techniques.

IV. STATISTICAL ANALYSIS

Statistical analysis is performed to identify the relationship between various quality parameters of existing operational conditions and thus, to regulate the operations of ASP.

4.1 Correlation Matrix

Correlation matrix for the inlet parameters - pH, TSS, COD, BOD of raw sewage entering the treatment plant is developed as shown in Table 1 (a). DO and F/M ratio in AT are added in 'outlet' correlation matrix (Table 1b) inaddition to all theinlet parameters. Among pH, TSS, BOD, COD, F/M-1 and F/M-2, BOD is moderately correlated to F/M-1 (= 0.592). Rest all parameters are less correlated with

Table 1 Correlation Matrices for(a) Raw Sewage at Inlet in Pre-Monsoon

	pH	TSS	COD	BOD	F/M-1	F/M-2
pH	1					
TSS	0.159	1				
COD	0.241	-0.043	1			
BOD	0.233	-0.081	0.296	1		
F/M-1	0.278	-0.372	0.203	0.592	1	
F/M-2	0.226	-0.409	0.141	0.521	0.965	1

(b) Treated Sewage at Inlet in Pre-Monsoon

	pH	DO	TSS	COD	BOD	F/M-1	F/M-2
pH	1						
DO	-0.165	1					
TSS	0.077	-0.068	1				
COD	0.002	0.031	0.229	1			
BOD	-0.123	-0.191	-0.031	-0.011	1		
F/M-1	0.118	-0.642	0.014	-0.045	0.196	1	
F/M-2	0.105	-0.633	0.004	-0.042	0.205	0.965	1

(c) Raw Sewage at Outlet in Post-Monsoon

	pH	TSS	COD	BOD	F/M-1	F/M-2
pH	1					
TSS	-0.505	1				
COD	-0.539	0.847	1			
BOD	-0.242	0.559	0.554	1		
F/M-1	-0.064	0.426	0.352	0.171	1	
F/M-2	-0.055	0.413	0.339	0.182	0.994	1

(d) Treated Sewage at Outlet in Post-Monsoon

	pH	DO	TSS	COD	BOD	F/M-1	F/M-2
pH	1						
DO	0.249	1					
TSS	0.373	0.432	1				
COD	0.006	0.055	-0.074	1			
BOD	-0.027	-0.151	-0.132	0.052	1		
F/M-1	0.168	0.168	0.344	-0.103	-0.072	1	
F/M-2	0.161	0.233	0.333	-0.122	-0.067	0.994	1

factor less than 0.5. TSS has negative correlation with all parameters. Further, correlation matrix for treated sewage at outlet in the same pre-monsoon season, Table 1 (b), indicated weak correlation among all the parameters. Further, Table 1 (c) and Table 1 (d)indicated the correlation matrices for post-monsoon data at both inlet and outlet of the treatment plant respectively. BOD and TSS are highly correlated (0.85) at the inlet, while there is no strong correlation among any parameters at the outlet in post-monsoon. Correlation coefficient values are observed to be low for all the four cases pre-monsoon and post-monsoon at the inlet and outlet (Table 1).Hence, statistical analysis is further adopted in the next section to identify the controlling parameters.

4.2 PCA and FA for Wastewater Characteristics

Multivariate process monitoring techniques are used in treatment plant economy to analyze all the processes with large number of variables into consideration. Principle Component Analysis (PCA) approach uses all the original variables to obtain a smaller set of new variables, known as Principal Components (PCs). Number of PCs required to explain the data depends on the degree of correlation between the data set - the greater the degree of correlation between the original variables, smaller the number of new variables required (Al-Ghazzawi and Lennox, 2008; Refaat, 2007).

Factor Analysis (FA) is another statistical way of estimating data interdependence, where some of the variables are overlapping on each other (Hair et al., 1987). An assumption explicit to this common factor is that the observed variation in each variable is attributable to the underlying common factors and to a specific factor (often interpretable as measurement error). In contrast, there is no underlying measurement model with PCA; each PC is an exact linear combination (i.e. weighted sum) of the original variables with no underlying measurement. Therefore, if the error in FA model is assumed to have the same variance then FA becomes equivalent to PCA (Lattin et al., 2003).

Variance, Eigen Values and Scree Plot:

Raw sewage and treated effluent characteristics in terms of pH, BOD, COD, TSS, DO and F/M are now analyzed using PCA and FA to normalize the parameters. Percentage of total variability explained by each Eigen value in PCA analysis is shown as Scree plot in Figure 3.The plot explained variation in Eigen values against the number of factors in the order of extraction.

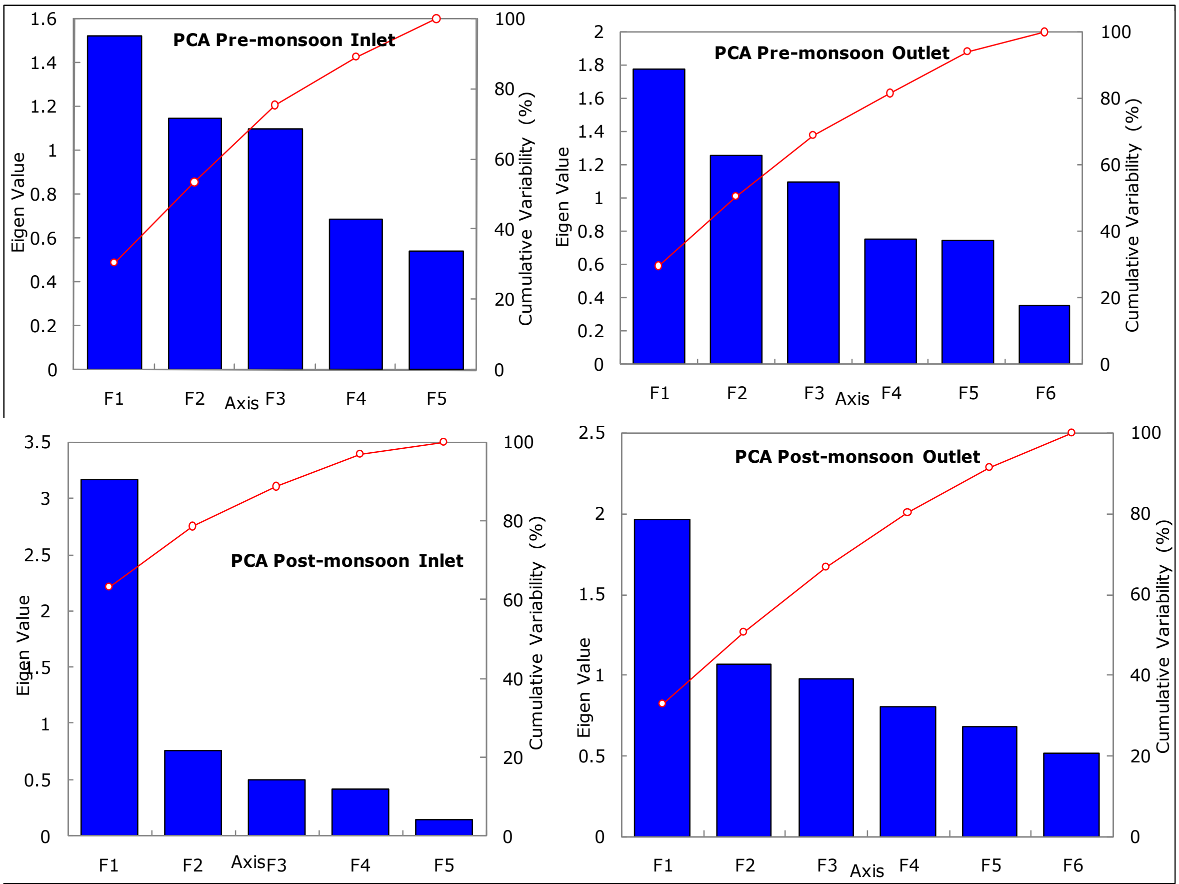

Figure 3 Scree Plot for PCA Analysis of Raw and Treated Sewage

Eigen vectors computed using both PCA and FA techniques are shown in Table 2. The table showed that PC1 and F1 respectively of both PCA and FA have highest total variance. Eigen factor >0.5 inboth PCA and FA are dominant parameters to be considered for further analysis. From Table 2, two PCs with Eigen value > 1 are retained as compared to one FA factor retained.

Factor Loadings in PCA and FA:

Loadings represent correlations between PCA and FA factor loadings under each of these factors are given in Table 3. Factor loadings are classified as "strong" (bold), "moderate" and "weak" corresponding to absolute loadings being > 0.70, 0.70 - 0.50 and < 0.25 respectively. Absolute value of the loadings is an indicator of the participation of variables in PCs and FAs, in Table 3, the maximum contribution reached by each original variable is highlighted.

At the inlet of the treatment plant for Pre-monsoon period, PC1 constituting of pH, BOD and COD are highly inter-correlated (Table 3a), whereas PC1 is found to be uncorrelated with inlet TSS. This correlation can be explained on the basis of a normal operating condition of the WWTP, attributing to a particular behavior of the particulate matters. At the outlet of the treatment plant for pre-monsoon period PC1 is participated by DO in AT, which is i.e., during post-monsoon period at the outlet of the treatment plant. pH is negatively correlated as observed at the inlet for the post-monsoon period. On the other hand, DO, TSS and F/M ratio are positively correlated at the outlet in post-monsoon.

Similar analysis done using FA is shown in Table 3 (b), as mentioned earlier. At the inlet of the treatment plant, in pre-monsoon season, pH, BOD and COD formed one component F1. It is similar to results of PCA analysis of Table 3 (a). After treatment in pre-monsoon season, DO and F/M form first group F1, while TSS and COD form second group F2. Patterns observed in all the four tables of

Table 2 Eigen Values obtained from PCA and FA

Type of data	PCA					FA		
	PC1	PC2	PC3	PC4	PC5	F1	F2	F3
Pre-monsoon								
Inlet	1.523	1.148	1.099	0.688	0.542	0.958	0.596	0.461
Outlet	1.853	1.242	0.956	0.899	0.712	1.474	0.856	0.083
Post-monsoon								
Inlet	3.167	0.762	0.506	0.417	0.149	2.871	0.245	0.125
Outlet	1.944	1.085	0.955	0.916	0.615	1.476	0.397	0.086

Table 3 (a) PCA Factor Loadings for Different Conditions

Raw Sewage at Plant Inlet in Pre-Monsoon

Factors →	PC1	PC2	PC3	PC4	PC5
Eigen Value→	1.944	1.085	0.955	0.916	0.615
pH	**-0.585**	-0.392	0.112	0.564	0.291
DO	**0.786**	0.301	0.021	-0.022	0.053
TSS	**0.751**	-0.108	0.170	0.147	0.539
COD	-0.120	**0.783**	0.118	0.577	-0.081
BOD	-0.320	0.154	**0.866**	-0.339	0.077
$F/M_{average}$	**0.551**	-0.439	0.386	0.357	-0.474

Treated Sewage at Plant Outlet in Pre-Monsoon

Factors →	PC1	PC2	PC3	PC4	PC5
Eigen Value→	3.167	0.762	0.506	0.417	0.149
pH	**-0.671**	0.630	0.275	-0.279	0.013
TSS	**0.897**	0.060	-0.115	-0.336	-0.257
COD	**-0.917**	0.013	-0.046	-0.276	0.286
BOD	**0.691**	0.597	-0.204	0.353	0.002
O&G	**-0.772**	-0.073	0.611	0.160	-0.032

Raw Sewage at Plant Inlet in Post-Monsoon

Factors →	PC1	PC2	PC3	PC4	PC5
Eigen Value→	1.523	1.148	1.099	0.688	0.542
pH	**0.704**	-0.106	0.479	-0.279	0.431
TSS	0.011	0.474	**0.803**	0.240	-0.269
COD	**0.689**	0.379	-0.301	-0.378	-0.384
BOD	**0.723**	-0.061	-0.253	0.639	0.,036
O&G	-0.169	**0.875**	-0.265	0.045	0.367

Treated Sewage at Plant Outlet in Post-Monsoon

Factors →	PC1	PC2	PC3	PC4	PC5
Eigen Value→	1.853	1.242	0.956	0.899	0.712
pH	0.451	0.162	**-0.761**	0.262	0.456
DO	**-0.829**	0.007	-0.228	0.317	0.183
TSS	0.105	**0.804**	-0.194	-0.027	0.213
COD	-0.078	**0.744**	0.430	0.079	-0.242
BOD	0.440	-0.114	0.309	**0.817**	0.583
$F/M_{average}$	**0.867**	-0.050	0.083	-0.237	-0.253

Table 3 (b) FA Factor Loadings for Different Conditions

Raw Sewage at Plant Inlet in Pre-Monsoon

Factors →	F1	F2	F3
Eigen Value→	2.871	0.245	0.125
pH	-0.585	0.349	-0.021
TSS	0.908	0.089	0.201
COD	0.919	0.001	0.062
BOD	0.610	0.323	-0.118
O&G	0.697	-0.107	-0.258

Treated Sewage at Plant Outlet in Pre-Monsoon

Factors →	F1	F2	F3
Eigen Value→	1.474	0.856	0.083
pH	0.258	-0.089	-0.389
DO	-0.680	-0.010	0.033
TSS	0.101	-0.878	0.118
COD	-0.039	-0.256	0.194
BOD	0.242	0.051	0.335
F/$M_{average}$	0.935	0.089	0.019

Raw Sewage at Plant Inlet in Post-Monsoon

Factors →	F1	F2	F3
Eigen Value→	2.871	0.245	0.125
pH	-0.585	0.349	-0.021
TSS	0.908	0.089	0.201
COD	0.919	0.001	0.062
BOD	0.610	0.323	-0.118
O&G	0.697	-0.107	-0.258

Treated Sewage at Plant Outlet in Post-Monsoon

Factors →	F1	F2	F3
Eigen Value→	1.476	0.397	0.086
pH	-0.415	-0.166	0.239
DO	0.869	0.298	-0.229
TSS	0.593	-0.241	0.120
COD	-0.047	0.221	0.076
BOD	-0.186	0.044	0.193
F/M average	0.402	-0.414	-0.035

Table 3 (b) are respectively same as those observed in tables of Table 3 (a). In conclusion, both the statistical analyses indicated that component 1 comprising of pH, BOD and COD, component 2 comprising of O&G and TSS for raw sewage. On the other hand, treated sewage cluster with DO & F/M as component 1, TSS & COD as component 2, pH as component 3, BOD as component 4.

4.3 Multivariate Regression Model

Based on the preliminary statistical analysis (PCA and FA) performed in previous section, large scale plant data and its correlation matrix is reduced to its underlying dimensions, variables of which cluster together in a meaningful way. As a next step, Regression model to relate effluent BOD (dependent variable) with all other characteristic parameters (independent variables) is this section; similar to previous studies in the waste water domain (Box et al., 1978; Urbain et al., 1993; Sponza 2002; Joseph and Malina 1999).

Multiple regression analysis is used to determine the correlation between effluent BOD, COD and TSS with F/M of wastewater using the plant data. Resulting regression model fit equations are given below as Equations 2 (a) to Equations 2 (h):

Pre-monsoon:

$BOD = 9.48 + (37.52 * F/M_{avg})$……………(2a)

$COD = 20.46 - (11.74 * F/M_{avg})$……..……(2b)

$TSS = 10.83 + (3.24 * F/M_{avg})$…..………..(2c)

$DO = 5.48 - (51.99 * F/M_{avg})$…..…………(2d)

Post-monsoon:

$BOD = 15.39 - (7.45 * F/M_{avg})$………......(2e)

$COD = 16.83 - (10.56 * F/M_{avg})$..………..(2f)

$TSS = 11.51 + (14.10 * F/M_{avg})$…………(2g)

$DO = 1.23 + (1.14 * F/M_{avg})$…..………...(2h)

Maximum error or deviation in the fit and observed data is least for post-monsoon TSS, apart from DO and then second least for pre-monsoon BOD. Thus, Effluent BOD, effluent COD and effluent TSS can be predicted based on these regressions fit equations for any given inflow conditions (i.e. F/M ratio).

V. RESULTS AND DISCUSSION

Establishment of constant relationships among the various measures of organic content depend primarily the nature of the wastewater and its source. In AT, contact time is provided for mixing and aerating influent wastewater with microbial suspension, referred as MLSS/MLVSS. Hence, it is necessary that F/M ratio is maintained in the specified range of 0.1 - 0.18 in AT for extended aeration process.

5.1 Model Efficiency Using Experimental Data

Wastewater and activated sludge samples are collected on 11 sampling dates during (December 2013 - March 2014) at the inlet and outlet of STP and are analyzed for wastewater characteristics, biological properties in the environmental laboratory of COEP (College of Engineering, Pune). Each of the 44 samples (2 samples per day on 11 sampling-dates at each of the inlet and outlet) are analyzed for 5 parameters - pH, BOD, COD, TSS, including wastewater composition and MLSS in the AT. Averaged BOD, COD with TSS, DO, MLVSS for these 11 dates are shown in Table 4. It is observed from the table that inlet DO is zero, inlet & outlet pH are almost same. Outlet BOD is almost 1/5th of the inlet BOD, while outlet COD is 50% of inlet COD and outlet TSS is 1/6th of inlet TSS.

Laboratory experimental results presented in Table 4 are compared with the plant data results for December 2013 – April 2014 period. Routine analysis of waste water characteristics from STP plant is compared with experimental data in the time series of Figure 4. Figure 4 (a) indicated the variations in pH and TSS at the inlet and outlet of the plant for December 2013 – April 2014 period. TSS is observed to reduce drastically in the plant data at inlet. But, the experimental data in January 2014 – April 2014 is in line with December 2013 – January 2014 observations and does not show any drastic decrease (Fig. 4a). Drastic decrease in TSS of plant data could possibly be due to some deviations in plant operations or for any other reason. Variations in outlet DO observed by regular plant data are in coherence with experimental data, as shown by Figure 4 (b). Outlet concentrations of BOD from both regular observations and focused experimental data are more similar than the inlet BOD concentrations. Times series plot for December 2013 to March 2014 for MLSS and COD are given in Figure 4 (c). Experimental MLSS data is observed to be highly in line with regular monitored plant data. Some deviation is observed in inlet COD experimental data and secondary plant data, while this deviation is less in outlet COD. Hence, all time series plots of Figure 4 indicate coherence between secondary plant data and experimental data for December 2013 to March 2014 period, validating the accuracy ofexperimentation.

5.2 Model Validation

Regression equations developed as a part of the statistical analysis is verified with experimental data. Using inlet BOD, MLSS at both AT tanks i.e., MLSS 1 and MLSS 2, obtained by experimental data (Table 4), outlet BOD, outlet TSS, outlet COD and outlet DO are computed based on regression fit equations (Eq. 3a to Eq. 3h). These model fit values are plotted as time series (empty open circles in Fig. 4) in comparison with secondary plant data (straight line in Fig. 4) and experimental laboratory data (filled circles in Fig. 4). Figure 4 (a) indicated that outlet TSS estimated from model are in line with secondary plant data and slightly lower than experimented data. Similarly, outlet DO in Figure 4 (b) shows higher outlet DO as per experimental data and slightly lesser outlet DO as per model fit. Outlet BOD clearly shows coherence between plant data and model estimate (open circles of Fig. 4). Similar coherence is observed in outlet COD in Figure 4 (c). In summary, fluctuations in the laboratory data at the inlet indicated the variations in the organic loading at the inlet of the plant. Further, there are no variations at the outlet of the plant and the estimated values obtained from the regression fit equations are thus in coherence with plant outlet data.

5.3 Removal Efficiency of Treatment Plant

Regression model efficiency is checked in previous section, while the efficiency of plant in reducing wastewater quality is explained in this section. Difference between respective inlet and outlet concentrations indicated the reduction in BOD, COD and TSS. These reduced concentrations are expressed as percentage of inlet concentrations in removal efficiency expressions. Hence,

Removal Efficiency = Reduction / Inlet Conc.
= (Inlet Conc. - Outlet Conc.) / (Inlet Conc.) ……………...(3)

where, concentrations include BOD, COD, TSS in mg/L

BOD, COD and TSS Removal Efficiency:

BOD, COD and TSS Reductions and Removal Efficiencies are computed for both regularly monitored plant data (2013 and 2014 data) and for

Table 4 Mean Experimental Data for December 2013 – April 2014 Period

Date	BOD (mg/l)		COD (mg/l)		TSS (mg/l)		pH		DO (mg/l)		MLSS 1 (mg/l)	MLSS 2 (mg/l)
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	AT 1	AT 2
2-Dec	117.5	31.50	176.44	39.22	250	40.0	7.08	7.00	NIL	1.5	3200	3000
10-Dec	132.5	32.50	156.16	39.04	230	35.0	7.12	7.10	NIL	1.8	2900	2800
19-Dec	147.5	37.50	160.00	40.00	200	40.0	7.28	7.25	NIL	1.8	3000	2800
30-Dec	150.0	37.50	156.80	39.20	180	30.0	7.10	7.02	NIL	1.6	2800	2750
30-Jan	147.5	26.65	132.88	37.44	205	32.5	6.98	6.97	NIL	1.7	3000	2900
10-Feb	136.5	33.75	183.80	38.76	215	30.0	7.20	7.15	NIL	1.4	2500	2600
20-Feb	135.0	23.75	176.40	39.20	250	35.0	7.24	7.13	NIL	1.1	2600	2650
01-Mar	112.5	35.00	175.52	38.76	200	37.3	7.01	7.00	NIL	2.0	2650	2800
10-Mar	181.3	36.25	176.25	39.20	210	34.0	7.08	6.93	NIL	1.3	2300	2200
20-Mar	129.4	37.75	154.40	38.60	260	50.0	7.39	7.03	NIL	1.3	2000	2150
30-Mar	111.3	30.00	172.80	38.40	200	20.0	6.77	6.74	NIL	1.2	1850	1950

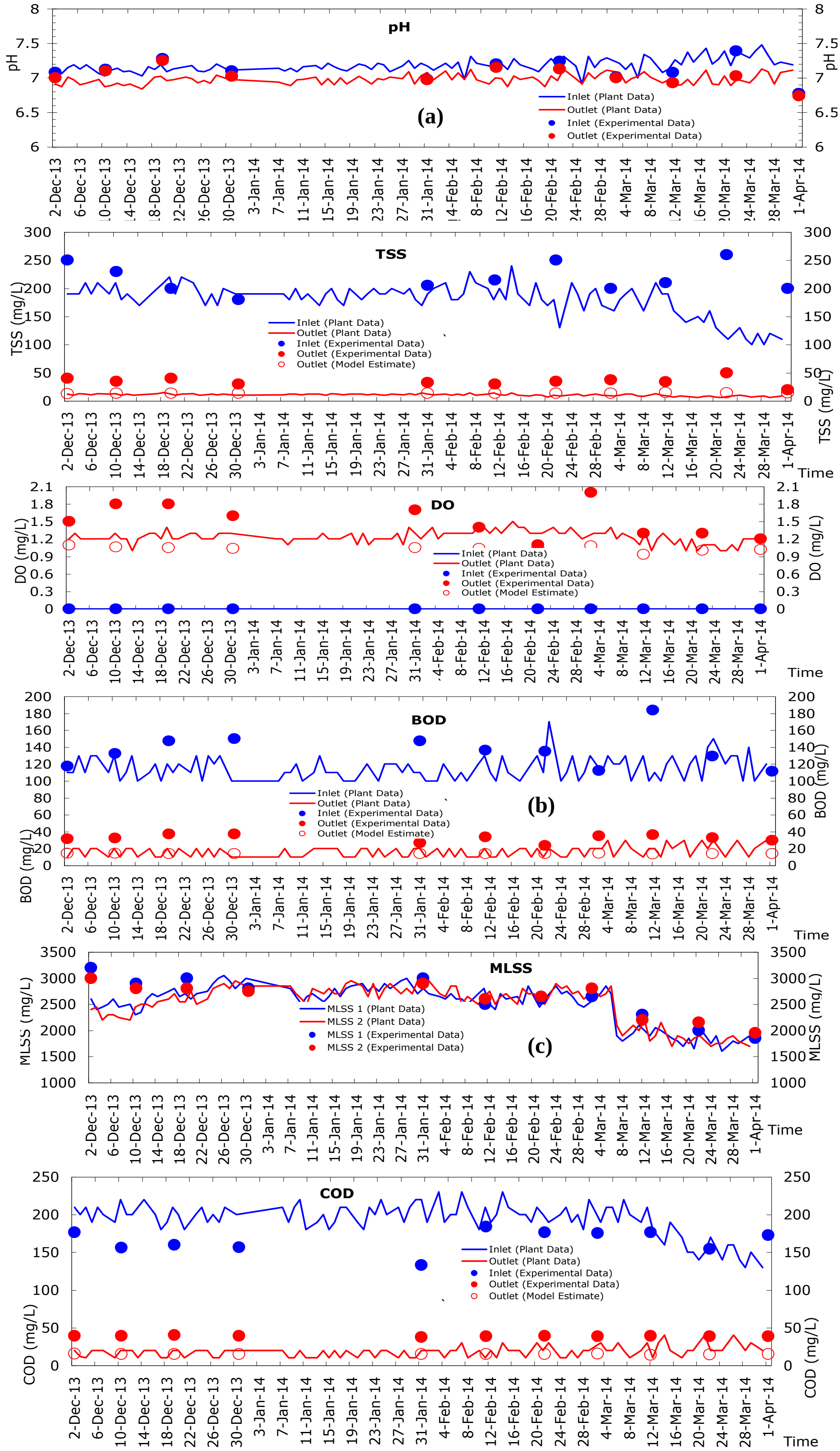

Figure 4 Variations in (a) pH & TSS (b) DO & BOD (c) MLSS & COD during Experimental Period at Inlet and Outlet

experimental data using above equation (Eq. 3). These efficiencies are computed for pre-monsoon and post-monsoon data separately. Mean and standard deviation of concentration reductions and removal efficiencies are given in Table 5. From the table, plant data indicated 85 – 93 % of reduction i.e., 85 – 93 % of removal efficiency in outlet concentrations during 2013 and 2014 period. Experimental data on the other hand, indicates 70 – 79 % reduction.Standard deviation in % reduction is low (~ 2 %) in plant data, while ~ 20 % deviation in experimental data.

Process Loading Index (PLI):

Principal factors responsible for loading variations are the established habits of community residents, which cause short-term (hourly, daily and weekly) variations. Seasonal conditions cause long-term variations, while industrial activities cause both long-term and short-term variations. Various activated sludge processes including Conventional ASP, Extended ASP, Contact stabilization and Aerated lagoons depend on the process loading rate of the influent wastewater which indirectly have effect on the F/M ratio. Process Loading Index (PLI) is defined as the ratio of Inlet COD to MLSS. PLI is computed for MLSS 1 and MLSS 2 (for both AT tanks) and plotted with respect to inlet F/M ratios (Figure 5).

Table 5 Reduction and Removal Efficiencies for STP and Experimental Data

Data Series	2013 Plant Data		2014 Plant Data	(2014) Experimental Data
	Pre - Monsoon	Post - Monsoon	Pre - Monsoon	Pre - Monsoon
BOD				
Reduction (mg/L)	125.86 ± 14.4	104.71 ± 13.9	98.65 ± 12.7	96.72 ± 31.1
% Reduction	91.6 ± 1.7	87.2 ± 7.9	85.6 ± 5.3	71.2 ± 20.3
COD				
Reduction (mg/L)	267.45 ± 32.2	214.23 ± 47.5	174.93 ± 25.3	122.61 ± 34.8
% Reduction	93.1 ± 1.3	92.3 ± 7.6	90.1 ± 4.8	71.9 ± 20.6
TSS				
Reduction (mg/L)	303.73 ± 61.7	218.65 ± 48.4	169.08 ± 27.4	170.21 ± 47.5
% Reduction	96.4 ± 1.7	93.8 ± 7.4	94.1 ± 0.9	78.4 ± 23.6
PLI Rate				
MLSS 1	0.079 ± 0.02	0.126 ± 0.08	0.078 ± 0.01	0.062 ± 0.02
MLSS 2	0.086 ± 0.02	0.122 ± 0.08	0.078 ± 0.01	0.062 ± 0.02

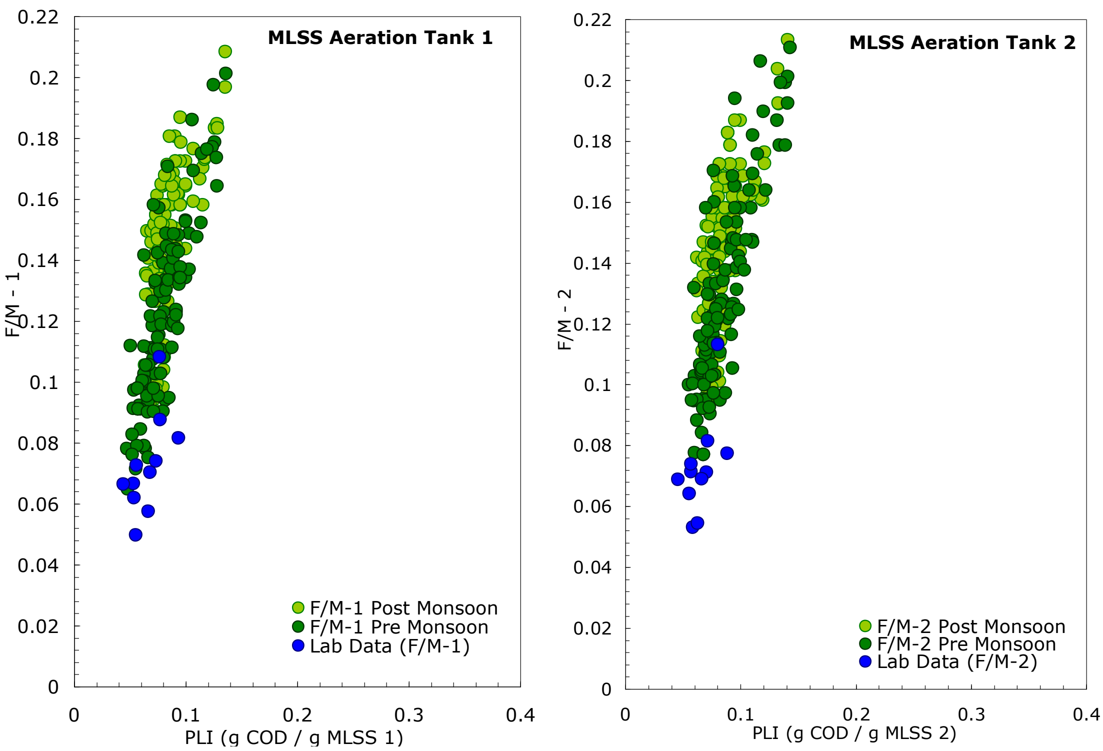

Figure 5 Variations in F/M Ratio with PLI Loading

From the figures plotted for both MLSS values, it is observed that PLI is less for lower F/M ratio. Further, a strong correlation between F/M ratio and PLI loading is observed in the figure for both plant and field experimented data.

VI. CONCLUSIONS

Current study involved preliminary data analysis of waste water characteristics at the inlet and outlet of a treatment plant. Plant data is supported with experimental data i.e., waste water samples collected at the plant and analyzed for their characteristics. Temporal series of regularly monitored plant data indicated correlation with seasonal effects and hence are classified as pre-monsoon and post-monsoon. Correlation Matrix indicated weak correlation among the parameters – pH, BOD, TSS, COD but,strong correlation with F/M ratio. Statistical analysis, PCA and FA, is performed to identify the trends and interdependence among dominant parameters. pH, COD and BOD are statistically identified to be strongly correlated at the inlet while TSS and COD are correlated at the outlet. At the outlet of treatment plant, F/M ratio is strongly correlated to DO.

In the next stage, F/M ratio is used as independent variable and outlet BOD, COD and TSS are considered as dependent variables to derive regression fit equations. Model developed is validated by estimating effluent BOD, COD and TSS for experimented inlet F/M ratios. Apart from model efficiency, plant efficiency is also verified by computing reductions, removal efficiencies and PLI for BOD, COD and TSS. 80 – 95 % of removal of BOD, COD and TSS is achieved by the plant, while experimental data indicated ~ 70% of removal of effluent concentrations. BOD, COD and TSS removal percentages from experimental data is lesser than the recorded plant data. This is possibly due to improper aeration (oxygen) provided in AT, which results in poor settling characteristics of biomass produced, causing bulking sludge condition or possibly return sludge rate is not maintained.

F/M ratio in the plant should be maintained at the values obtained from the regression fits to regularize effluent BOD, effluent COD and outlet TSS. F/M ratios are maintained by increasing or decreasing MLSS levels in AT to suit inlet BOD loads. Regression model build can thus be used for a treatment plant having similar treatment processes. Hence, preliminary statistical analysis performed in the current study should be supported with few more experiments to thoroughly identify the controlling factors and to further optimize functionality of ASP.

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