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ORIGINAL ARTICLE

Study on the efficiency of sequential batch reactor (SBR)-based sewage treatment plant

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Abstract

The present study was carried out to evaluate the performance of 16.1 MLD sewage treatment plant (STP) located at Brari Nambal (J&K), India. The STP is based on sequential batch reactor (SBR) technology. Wastewater (influent and effluent) samples were analyzed for 14 different physicochemical parameters. Significant variation ($P<0.05$) was recorded within and among the wastewaters in pH ($F_{11},_{1}=7.49$, 26), electrical conductivity ($F_{11,1}=12.13$, 49.94), calcium ($F_{11,1}=8.58$, 91.66), magnesium ($F_{11,1}=4.68$, 132.37), chloride ($F_{11,1}=10.18$, 74.85), sodium ($F_{11,1}=11.31$, 192.64), potassium ($F_{11,1}=5.98$, 52.22) and chemical oxygen demand ($F_{11,1}=4.16$, 267.65), whereas among the wastewaters in total suspended solids ($F_1=165.21$), total dissolved solids ($F_1=150.40$), biological oxygen demand ($F_1=307.89$), ortho-phosphate ($F_1=624.54$), total phosphorous ($F_1=336.85$) and nitrate nitrogen ($F_1=68.10$). Significant negative correlation exists between TSS and EC ($r=-0.796$; $P<0.01$) and Cl and Ca ($r=-0.646$; $P<0.05$), whereas significant positive correlation between BOD_5 and Ca ($r=0.579$; $P<0.05$), COD and TSS ($r=0.728$; $P<0.01$) and ortho-phosphate and pH ($r=0.791$; $P<0.01$). Maximum decrease was recorded in TP (68.37%) followed by NO_3-N (64.88%), COD (63.79%), BOD (59.38%), OP (55.94%), TDS (44.82%) and least in TSS (38%) among parameters which are of prime concern. Six principal components (PCs) have been identified by factor analysis which explained 90.30% of total variance, representing alkaline factor, salts/ions factor, household/water usage factor, dissolved salts factor, soaps/detergents factor and catchment factor. Thus, least reduction in concentration of ortho-phosphate, TDS and TSS is concern when the effluent is disposed off in a water body which is already under the stress of nutrient enrichment/pollution.

Keywords Effluent · Influent · Sequential batch reactor · Sewage treatment plant

Introduction

Wastewater discharged from residences, institutions and commercial establishments is termed as sewage. The composition of wastewater is a reflection of the life styles and technologies practiced in the producing society (Edwin et al. 2014; Gray 1989). Normally, domestic/municipal wastewater is composed of 99.9% water and remaining 0.1% suspended, colloidal and dissolved solids, mainly organic in nature, as it consists of larger proportion of carbon compounds such as human excreta, paper, vegetable matter and microorganisms (Gautam et al. 2013). Three quarters of organic carbon in sewage are present as carbohydrates, fats, proteins, amino acids and volatile acids. The inorganic constituents include large concentrations of sodium, calcium, potassium, magnesium, chlorine, sulfur, phosphate, bicarbonate, ammonium salts and heavy metals (Chen et al. 2018: Horan 1990; Lim et al. 2011). In order to minimize the environmental and health hazards (Singh et al. 2015; Jafarinejad 2017; Khudair and Jasim 2017; Kominko et al. 2018), these constituents need to be brought down to permissible limits. Therefore, removal of the nutrients, organic contaminants and pathogens from wastewater is of paramount importance in order to prevent eutrophication, oxygen depletion and toxicity (Najar and Khan 2011, 2012, 2013; Najar 2017; Ajala et al. 2018). Further, there are some strict criteria for discharging effluents containing nitrogen and phosphorus, especially in environmentally sensitive areas.

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Sequencing batch reactor (SBR) as compared to traditional or conventional treatments is an easily obtainable, on timescale, highly operational, flexible technology for newer and varied pollutants (Popple et al. 2016; Dutta and Sarkar 2015); Kulkarni 2013). The SBR systems have many advantages such as lower operational cost, less bulking and higher flexibility to combine nitrification and denitrification phases into one reactor (Lim et al. 2011) with good removal efficiency for nitrogen, phosphorus and chemical oxygen demand (Khan et al. 2017; Ding et al. 2011).

Evaluation on performance of treatment plants is required to assess the existing effluent quality and/or to meet treatment requirements (Sekhar et al. 2014). The efficiency of sewage treatment plants can be evaluated by measuring the concentration of pollutant in the influent and effluent (Metcalf and Eddy 2003). Keeping in view of the above facts, the present investigation was carried to study the efficiency of sewage treatment plant by analyzing the different physiochemical characteristics of influent and effluent.

Materials and methods

The study was carried out at Brari Nambal STP located at Srinagar, Jammu and Kashmir, India, located within the geographical coordinates of 34°08 69N, 74°8139E, with a total capacity of 16.10 MLD. The STP is based on sequential batch reactor (SBR) technology. Disposal site for treated sewage (effluent) is Brari Nambal (small fresh water body and was previously part of Dal Lake). The catchment area of the STP includes Saida Kadal, Hathi-Khan, Gorepora, Naidyar, Jogilanker, Miskeenbagh, Daulatabad, Naqashpora, Baba dawood Khaki Bridge, Brari Nambal, Khonakhun area, Nehru Park, Dalgate and Bishembar Nagar.

Collection and analysis of wastewater samples

Wastewater samples were collected on a monthly basis from inlet and outlet of the STP during morning hours for a period of 1 year in white plastic containers that were prior cleaned with metal-free soap, rinsed repeatedly with distilled water, then soaked in 10% nitric acid for 24 h and finally rinsed with ultrapure water. All water samples were stored in insulated cooler containing ice and taken on the same day to laboratory and stored at 4 °C until processing and analysis (APHA 2005). pH and electrical conductivity (EC) were determined by pH meter (Bates 1978) and conductivity meter (Jasper 1988), respectively. Calcium (Ca) and magnesium (Mg) concentrations were determined by the versenate method (Kat and Navone 1964). Sodium (Na) and potassium (K) were analyzed using flame photometer (Thompson and Reynolds 1978). Biochemical oxygen demand (BOD_5) was determined using incubation method (Mancy and Jaffe 1966). Chemical oxygen demand (COD) was determined using reflux method (Pitwell 1983). Phosphate phosphorous (PO_4-P) was determined by molybdate method (Edwards et al. 1965), and nitrate nitrogen (NO_3-N) was determined by phenyldisulfonic acid method (Brown and Bellinger 1978), respectively, using spectrophotometer.

Results and discussion

Sequence batch reactor (SBR) process can remove carbonaceous constituents (BOD_5, COD and TSS) efficiently up to the level of 90% (Dohare and Kawale 2014; Obaja et al. 2005). Mahvi et al. (2004) reported COD removal efficiency above 94.90% in SBR-based treatment system as the treatment system has ability to remove organic carbon and a better resistance against variable loadings, which suggests that reactor is able to guarantee process stability. Fernandes et al. (2013) also reported removal efficiency of TSS and volatile suspended solids (VSS) by 70% and 80%, respectively.

The physiochemical characteristics of influent and effluent are given in Fig. 1, and the correlation matrix of different parameters is given in Table 1. pH is one of the important parameters in wastewater treatment (Salunke et al. 2014). pH of the wastewater was alkaline and exhibited a mean value of 8.24 ± 0.07 and 8.35 ± 0.05 for influent and effluent, with significant variation within ($F_{11} = 7.49$, $P < 0.05$) and among ($F_1 = 26$, $P < 0.05$) the wastewaters (influent and effluent). Gautam et al. (2013) also reported the alkaline nature of the municipal wastewater. Increase in alkaline nature of the wastewater after treatment has been reported by Sharma et al. (2013). Akan et al. (2008) reported higher pH values for effluents as compared to influent. The pH of effluent determines its usefulness for a variety of purposes as very high or low pH is toxic to aquatic life and also alters the solubility of essential elements and chemical pollutants (Morrison et al. 2001).

Conductivity is a general indicator of wastewater quality, especially a function of the amount of dissolved salt, and is used to monitor processes in the wastewater treatment that causes changes in total salt concentration which in turn changes the conductivity (Aguado et al. 2006). EC showed significant variation within ($F_{11} = 12.13$, $P < 0.05$) and among ($F_1 = 49.94$, $P < 0.05$) wastewaters, with a value of 626.5 ± 21.43 µS/cm for influent, and for effluent values were 573 ± 30.18 µS/cm with mean removal efficiency of 8.53%. The high EC value is attributed to the high salinity and high mineral content. It also corresponds to the highest concentrations of dominant ions which are the result of ion exchange and solubilization in the water Gautam et al. (2013). The results are consistent with the findings of Rizvi et al. (2015) and Jan and Rafiq (2012) that there is

Fig. 1 Box-and-whisker plots of physiochemical characteristics of influent and effluent (open circles and asterisk denote outliers with 1.59 interquartile range (IQR) and 3IQR, respectively)

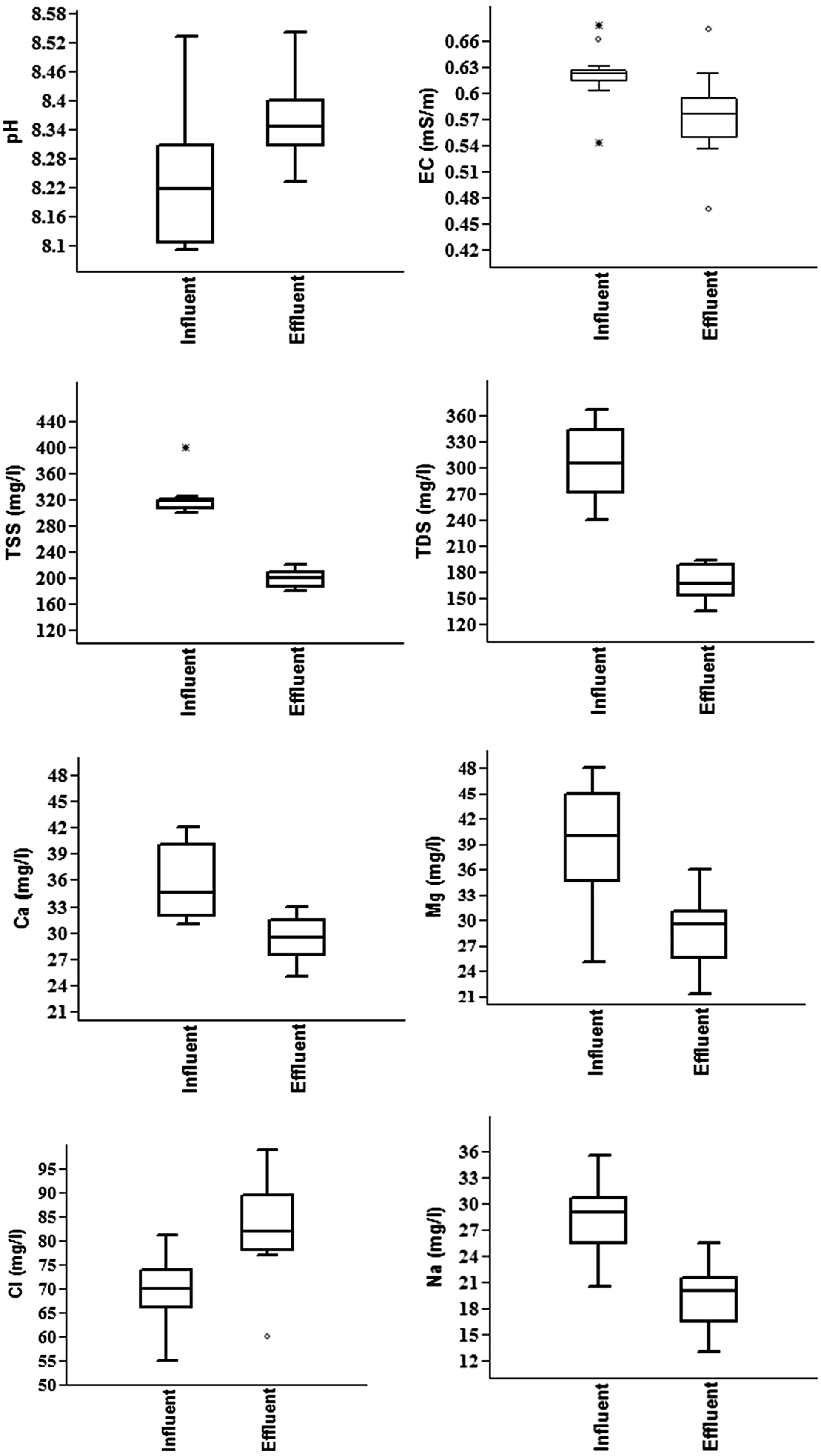
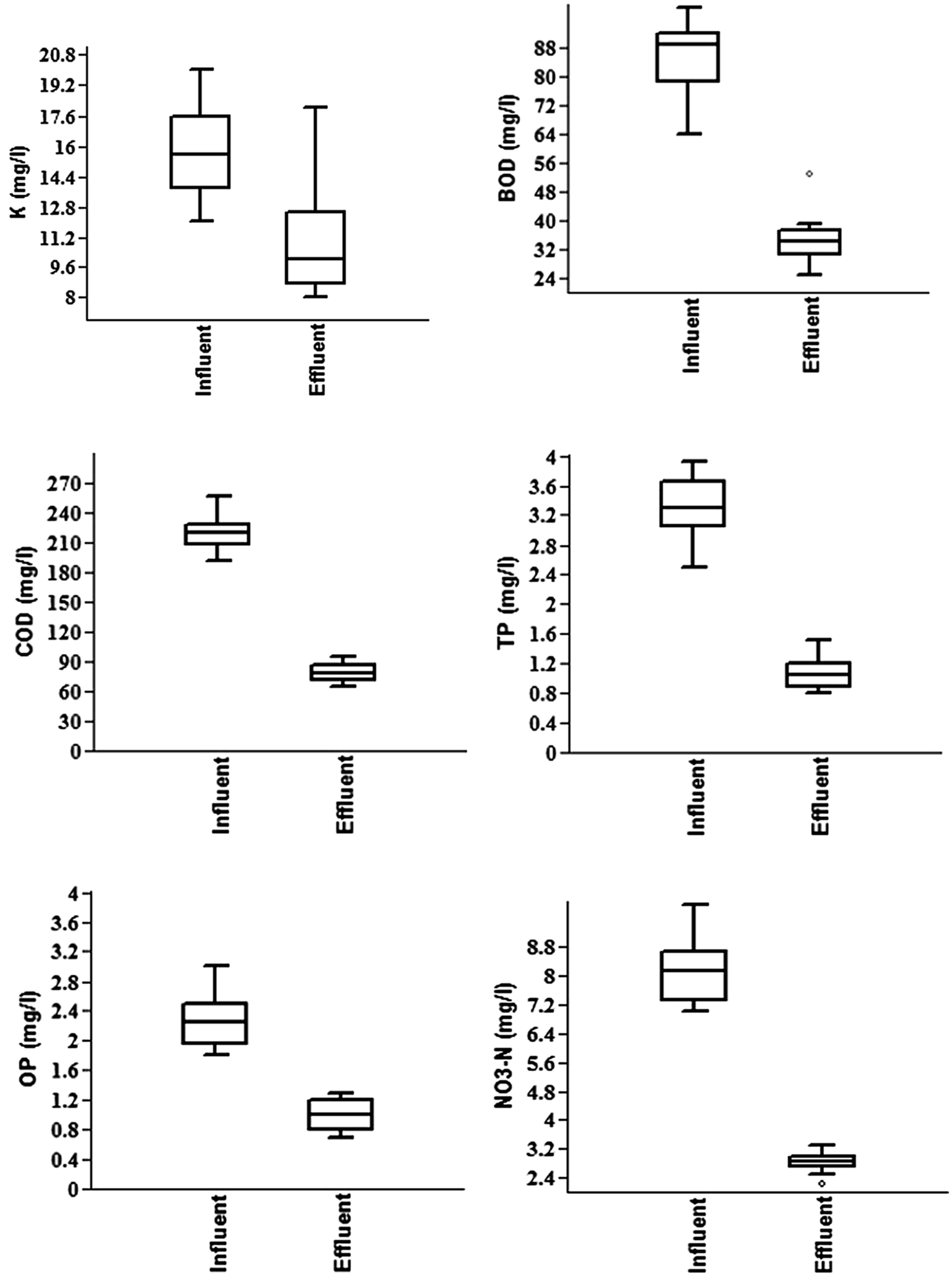


Fig. 1 (continued)



reduction in EC after treatment and is attributed to removal of salts–nitrates, ammonium, cations and associated chemicals (Lamichhane et al. 2011).

TSS is a measure of the floating particulate content of the wastewater and is an indicator of the clarity of the wastewater (Johal et al. 2014). Total suspended solids for influent were 321.11 ± 17.44 mg/l. The value was reduced for effluent to 199.06 ± 14.10 mg/l with mean removal efficiency of 38%. The variation in TSS was significant among ($F_1 = 165.21$, $P < 0.05$) wastewaters and non-significant within them ($F_{11} = 0.54$, $P < 0.05$). The decrease in total solids could be attributed to sedimentation process undergoing during the treatment. Decrease in TSS after treatment has also been reported by Khan et al. (2014). Mahvi et al. (2008) and Patel et al. (2013) conducted studies on reduction in TSS from wastewaters using SBR-based treatment and indicated removal efficiencies of 99% and 95.41%, respectively. TSS showed highly significant negative correlation with EC ($r = -0.796$; $P < 0.01$) as TSS had no contribution to salt concentration (EC) as compared to TDS. Negative correlation between TSS and EC has been reported by Bhandari and Nayal (2008), whereas positive correlation between TDS and EC by (Gautam et al. 2013).

Table 1 Correlation matrix of influent

	pH	EC	TSS	TDS	Ca	Mg	Cl	Na	K	BOD_5	COD	P	TP	NO_3-N
pH	1													
EC	– 0.049	1												
TSS	– 0.008	– **0.796****	1											
TDS	– 0.158	0.047	– 0.125	1										
Ca	– 0.161	– 0.257	0.295	– 0.135	1									
Mg	– 0.381	0.2	0.237	– 0.02	0.312	1								
Cl	– 0.079	0.066	– 0.408	0.35	– **0.646***	– 0.299	1							
Na	0.374	0.572	– 0.31	– 0.281	– 0.283	0.201	– 0.056	1						
K	0.217	0.43	– 0.164	0.574	– 0.218	0.211	0.162	0.326	1					
BOD_5	– 0.495	– 0.162	0.06	– 0.299	**0.579***	0.208	– 0.159	– 0.216	– 0.493	1				
COD	– 0.5	– 0.417	**0.728****	– 0.007	0.34	0.54	– 0.427	– 0.341	– 0.154	0.386	1			
OP	**0.791****	0.269	– 0.355	0.056	0.129	– 0.244	– 0.157	0.283	0.301	– 0.213	– 0.509	1		
TP	– 0.168	0.134	– 0.289	0.12	– 0.155	– 0.185	0.392	0.313	– 0.061	0.222	– 0.332	– 0.171	1	
NO_3-N	– 0.12	0.426	– 0.387	– 0.184	– 0.426	– 0.024	0.008	0.409	– 0.203	0.013	0.008	– 0.052	– 0.031	1

*Significance at 0.05 level and **significance at 0.01 level

The TDS value of the wastewater is mainly due to the ions/salts added during the use of water (Salunke et al. 2014). Significant variation ($F_1 = 150.40$, $P < 0.05$) was recorded among wastewaters (influent and effluent), whereas nonsignificant ($F_{11} = 1.96$, $P < 0.05$) within them. Value of total dissolved solids for influent was 306 ± 39.40 mg/l while as for effluent value was reduced to 168.83 ± 20.28 mg/l with mean removal efficiency of 44.82%. Ukpong (2013) also reported decrease in TSS after treatment. The decrease in TDS may be because of oxidative degradation of dissolved solid (Singh and Varshney 2013). Mahvi et al. (2008) conducted study on removal of TDS from wastewaters using SBR method and reported removal efficiencies of 61.25%.

The main sources of Ca and Mg in wastewater are calcite, dolomite, magnesite, anhydrite, gypsum feldspar, pyroxene and amphiboles present in catchment. Calcium hardness for influent was 35.67 ± 2.33 mg/l, and for effluent value was reduced to 29.33 ± 2.04 mg/l with mean removal efficiency of 17.77%. Magnesium exhibited a value of 38.82 ± 8.14 mg/l for influent and effluent with a concentration of 28.53 ± 3.52 mg/l with mean removal efficiency of 26.50%. The reduction in Ca has been reported by the findings of Kushwah et al. (2011) and Jan and Rafiq (2012). Calcium and magnesium exhibited significant variation within (Ca $F_{11} = 8.58$; Mg $F_{11} = 4.68$, $P < 0.05$) and among (Ca $F_1 = 91.66$; Mg $F_1 = 132.37$, $P < 0.05$) wastewaters. Decrease in concentration could be attributed to the grit separation, sedimentation process and active uptake of calcium and magnesium by microorganisms during treatment (Nathanson 2003).

Chloride for influent was 69.15 ± 5.07 mg/l while as for effluent the value increased to 82.83 ± 6.59 mg/l with an increase of 19.78%. Significant variation in chloride was recorded within ($F_{11} = 10.18$, $P < 0.05$) and among ($F_1 = 74.85$, $P < 0.05$) the influent and effluent. Higher concentration of chloride in sewage may result from the higher usage of washing agents like detergents, soaps and water filtering units, sodium chloride and also by discharging fecal matter (Von Sperling 1996). Chloride ion concentration is an important factor to be considered if the effluent is used for irrigation. Cl exhibited significant negative correlation with Ca ($r = -0.646$; $P < 0.05$) which indicates there are different sources as Ca is mainly attributed by catchment.

The natural source of Na in wastewater is weathering of plagioclase, pyroxene and hornblende from catchment (Najar and Khan 2012), in addition to household sources. Significant variation in sodium was observed within ($F_{11} = 11.31$, $P < 0.05$) and among ($F_1 = 192.64$, $P < 0.05$) the wastewaters with a value of 28.08 ± 1.97 mg/l for influent while as it was 19.41 ± 1.82 mg/l for effluent with removal efficiency of 30.87%. Higher concentration of sodium in wastewater may be as a result of excess usage of synthetic detergents by households and consumption of sodium chloride in addition to catchment source. Decrease in Na concentration in effluent could be due to exponential growth phase during biological treatment which resulted in the active uptake of potassium ion from sewage.

The natural sources of K are weathering of orthoclase, microcline, biotite and K-feldspar Gautam et al. (2013). Value of potassium for influent was 15.83 ± 1.23 mg/l and

11.17 ± 1.18 mg/l for effluent with a mean removal efficiency of 29.43%. Significant variation in K was recorded within ($F_{11} = 5.98$, $P < 0.05$) and among ($F_1 = 52.22$, $P < 0.05$) the influent and effluent. Wastewater exhibits higher concentration of potassium which may be attributed to the increase in the discharge of human excretory material as the urine fraction that contains 80% of the potassium (Claesson and Steineck 1996).

BOD_5 varied significantly ($F_1 = 307.89$, $P < 0.05$) between and insignificantly ($F_{11} = 0.91$, $P < 0.05$) among wastewaters with a mean value of 85.33 ± 4.75 mg/l and 34.66 ± 2.24 mg/l for influent and effluent, respectively. BOD removal is indicative of the efficiency of biological treatment processes and is the most widely used parameter to measure wastewater quality. BOD_5 value of effluent showed a significant decrease with removal efficiencies of 59.38%, and the reduction may be attributed to batch reactors which allow more oxidation of organic matter. Wakode and Sayyad (2016) also reported BOD reduction from 134.63 mg/l to 5.36 mg/l, with removal efficiency of 96% by using SBR process. Reduction in BOD has also been confirmed by the studies of Kushwah et al. (2011) and Ukpong (2013). Significant positive correlation of BOD with Ca ($r = 0.579$; $P < 0.05$) indicates some of the organic matter is attributed by catchment runoff in addition to water usage in households.

COD is the amount of oxygen consumed by the chemical breakdown of organic and inorganic matter and mainly serves to measure the ability of organic substances to consume oxygen in water (Akan et al. 2008). Significant variation in COD was recorded within ($F_{11} = 4.16$, $P < 0.05$) and between ($F_1 = 267.65$, $P < 0.05$) the influent and effluent with a mean value of 218.67 ± 8.92 mg/l and 79.16 ± 7.05 mg/l, respectively. The overall removal efficiency was 63.79%. Higher levels of COD in wastewater lead to drastic oxygen depletion once discharged into water body and adversely effect the biota. The decrease may be linked to the aeration and digestion processes, which has also been confirmed by Tian et al. (2011), Ghehi et al. (2014), Johal et al. (2014) and Ding et al. (2011) by 90% 94%, 98% and 99%, respectively. Highly significant positive correlation ($r = 0.728$; $P < 0.01$) of COD with TSS shows that increase in TSS increases the COD and TSS is composed of both organic and inorganic substances. Kokkinos et al. (2015) also reported positive correlation between COD and TSS.

The total phosphorous in municipal wastewater consists of 70–90% soluble orthophosphates and 30–10% organically bound phosphorous which is in soluble or particulate form, a small fraction of unbiodegradable phosphorous (Ekama and Marais 1984). Phosphate in sewage effluents arises from human wastes and domestic phosphate-based detergents and soaps (Ogunfowokan et al. 2005). Phosphorous is one of the important elements for the growth of algae, and its concentration in wastewater discharges has to be controlled/reduced in order to avoid noxious algal blooms. Total phosphorous showed insignificant ($F_{11} = 0.69$, $P < 0.05$) variation within, but significant ($F_1 = 336.85$ $P < 0.05$) among wastewaters. Mean values of total phosphorous showed reduction from 3.32 ± 0.66 mg/l to 1.05 ± 0.15 mg/l with mean removal efficiency of 68.37%. The decrease in total phosphorous may be attributed to various phenomena such as adsorption, precipitation and/or assimilation by microorganisms during the process of treatment (Rajeb et al. 2011). The result is consistent with the findings of Wakode and Sayyad (2016) and reported removal efficiency of 71.79%.

Ortho-phosphate or inorganic phosphate is often referred to as reactive phosphorous. It is the form most readily available to plants and thus may be the most useful indicator of excessive plant and algal growth (Wenzel and Ekama 1997). Variation was insignificant ($F_{11} = 2.31$, $P < 0.05$) within wastewaters, but significant ($F_1 = 624.54$, $P < 0.05$) among them. Ortho-phosphorus of influent was 2.27 ± 0.96 mg/l while as for effluent it was reduced to 1 ± 0.15 mg/l showing a mean removal efficiency of 55.94%. Highly significant positive correlation ($r = 0.791$; $P < 0.01$) exists between ortho-phosphate and pH. The results are in agreement with that of Mehdi and Rafiq (2012).

Nitrate nitrogen represents the end product of oxidation of nitrogenous matter, and its concentration depends on the nitrification and denitrification activities of microorganism (Mehdi and Rafiq 2013). Nitrates are inorganic sources of nitrogen that support the growth and development of fresh water weeds. However, increased levels of nitrate nitrogen result in nutrient enrichment (eutrophication) causing excessive plant growth, algal blooms, loss of diversity and overall ecosystem degradation (Emmanuel et al. 2010). Nitrate nitrogen showed decrease in mean values from 8.10 ± 1.48 µg/l to 2.82 ± 0.65 µg/l with mean removal efficiency of 65.18%. Nitrate nitrogen was insignificant ($F_{11} = 1.85$, $P < 0.05$) within, whereas significant ($F_1 = 68.10$, $P < 0.05$) among influent and effluent. The results were consistent with those of Singh and Varshney (2013) and Sharma et al. (2013) as they reported nitrate nitrogen removal efficiency of more than 80%.

Table 2 Factor loading values and explained variance of influent

Parameter	PC1	PC2	PC3	PC4	PC5	PC6
pH	**0.936**	−0.151	−0.186	−0.048	−0.098	0.141
EC	0.058	**0.856**	−0.056	0.183	0.028	0.403
TSS	−0.200	**−0.919**	0.083	−0.085	−0.278	0.105
TDS	−0.121	0.066	−0.111	**0.856**	0.058	−0.253
Ca	−0.009	−0.191	**0.946**	−0.044	−0.151	−0.027
Mg	−0.486	−0.028	0.323	0.208	−0.242	**0.634**
Cl	−0.094	0.169	**−0.534**	0.269	**0.552**	−0.325
Na	0.292	0.310	−0.205	−0.153	0.213	**0.826**
K	0.201	0.116	−0.155	**0.826**	−0.052	0.391
BOD_5	−0.420	0.066	**0.679**	−0.385	0.218	−0.12
COD	**−0.668**	−0.441	0.223	−0.045	−0.440	0.131
PO_4-P	**0.860**	0.280	0.211	0.137	−0.160	0.037
TP	−0.087	0.094	0.001	−0.033	**0.936**	0.113
NO_3-N	−0.221	**0.602**	−0.404	−0.448	−0.230	0.163
Eigenvalues	2.724	2.429	2.126	1.971	1.721	1.672
Total variance (%)	19.457	17.348	15.185	14.081	12.29	11.946
Cumulative variance (%)	19.457	36.805	51.99	66.071	78.361	90.307

Principal component analysis

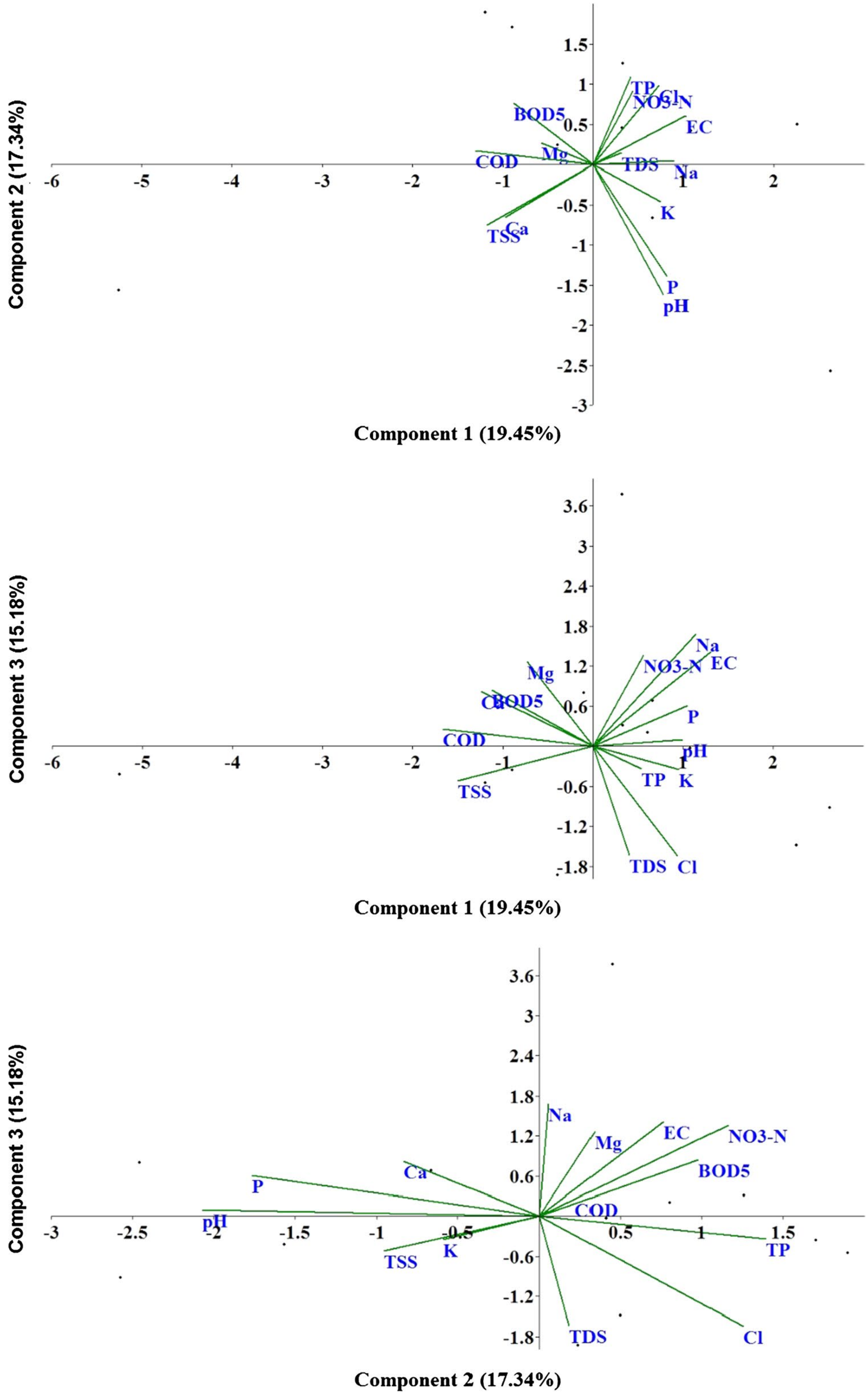
Principal component analysis was carried out on the data set of fourteen variables to identify the various parameters and their association. Six principal components (PCs) have been identified by factor analysis which explained 90.30% of total variance. PC1 explained 19.45%, PC2 17.34%, PC3 15.18%, PC4 14.08%, PC5 12.29% and PC6 11.94% of the total variance. The eigenvalues, variance, cumulative variance and component loadings are given in Table 2, and the biplot which is the graphical representation of factor loadings in different components is given in Fig. 2.

PC1 explaining 19.45% of total variance has strong loading on pH and PO_4-P and moderate negative loading of COD. The positive loading of pH is associated with alkaline nature of wastewater, with elevated levels of phosphates mainly from phosphate-based detergents and soaps; thus, PC1 represents alkaline factor. PC2 explaining 17.34% of variance has strong positive loading of EC, moderate positive loading of NO_3-N and strong negative loading of TSS; thus, PC2 represents salts/ions factor. PC3 explaining a variance of 15.18% has strong positive loading of Ca and moderate negative loading of Cl, whereas moderate positive loading of BOD_5. The negative loading of Cl indicates the source of Ca is other than catchment as Ca is mainly contributed by catchment geology, but its positive association with BOD_5 indicated it is added during the usage of water due the addition of organic matter; thus, PC3 represents household/water usage factor. PC4 with a total variance of 14.08% has strong positive loading of TDS and K as both of them are in dissolved state; thus, PC4 represents dissolved salts factor. PC5 explaining 12.29% of total variance has strong positive loading of TP and moderate positive loading of Cl. Phosphates and chlorides are mainly contributed by soaps and detergents, in addition to catchment, thus PC5 represents soap/detergent factor. PC6 with a total variance of 11.94% has strong positive loading of Na and moderate positive loading of Mg. Na is contributed by both catchment and household usage of water, but its association with Mg indicates its source as catchment since the Mg is mainly contributed by catchment; thus, PC6 also represents catchment factor. Thus, overall characteristics of the wastewater are attributed by the household usage along with catchment geology.

Conclusion

The study revealed that SBR-based treatment plant significantly removed the objectionable physiochemical properties of wastewater prior to its discharge into water body, but least reduction in ortho-phosphate, total suspended solids

Fig. 2 Biplots for principal component analysis 1 + 2, 1 + 3 and 2 + 3 component of wastewater



and total dissolved solids is issue of concerns. There is possibility of adverse effects of effluent discharge on receiving water body as it is already under the stress of pollution load, and thus, there should be a continuous monitoring program by the concerned authorities to ensure the best practices/measures with regard to treatment and discharge of wastewater into the receiving lake system.

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