

## **Seasonal variation in physico-chemical properties of effluent generated at a sewage treatment plant in Varanasi and its suitability for irrigation**

### **Abstract**

The current investigation was carried out to ascertain the suitability of the influent and effluent of Varanasi's Bhagwanpur sewage treatment plant for irrigation as well as variations in its physicochemical properties throughout the year 2018. The suitability of the water for irrigation was evaluated by taking water samples from the plant's inlet, aerator, and outlet tanks. Then, these samples were examined for heavy metals as well as parameters like pH, EC, TDS, BOD, COD, and dominant anions and cations. The plant's effluent is suitable for irrigating agricultural fields because parameters like pH, nitrate, phosphate, and other cations are below the permissible limit and will provide the necessary nutrients for crops. However, higher concentrations of some heavy metals were a notable concern that will need close attention and ongoing monitoring in the near future if effluent water is to be used for irrigation. The treatment process significantly lowers the effluent water's COD, sulphates, and other ions to levels that allow for surface water discharge, but it leaves the BOD, nitrate, and phosphate content just above levels which are recommended, making it unsuitable for discharge into the holy Ganges since it will cause eutrophication.

**Keywords: Influent, effluent, Sewage treatment, irrigation.**

### **Introduction**

Despite being replenished by nature, fresh water is a scarce resource. The amount of water per person which depends on the population of the nation, is steadily decreasing in India. In 2001 and 2011, the average annual water availability per person was estimated to be 1,816 cubic metres and 1,545 cubic metres, respectively which may further decline due to increase in population. (Annual report 2020-2021, GOI). The waste and waste waters from humans or household operations that are discharged to water bodies or otherwise enters a treatment works is known as domestic sewage. Before approaching its targeted destiny, this domestic sewage enriched with lots of extraneous materials through contacting the various industrial wastes, pharmacy waste, agricultural runoff and other sources of water pollution. According to the National Commission for Integrated Water Resources Development's (NCIWRD) research, 72.48% of the water consumed overall in 2025 under the high demand scenario will be used for irrigation.

Therefore, using sewage water as a source of irrigation is a commendable strategy to meet the increased demand for water for agricultural production. By offering a substitute for the direct discharge of sewage effluent into water bodies and by supplying a sizable amount of carbon, major nutrients, and micronutrients to the soil that are crucial for crop production, it has been proven to be an environmentally beneficial strategy. However, the continual use of sewage water to irrigate agricultural areas may also increase the heavy metal load in the soil, rendering it unsuitable for growing crops due to their bio-transfer pattern through the chain: sewage-soil-vegetation-animal-humans. The physicochemical characteristics of sewage water must therefore be continuously monitored, either before it is used for irrigation or before it is discharged into

water bodies. The quality of effluent may vary significantly in different seasons. Therefore, the present study was planned and executed to better understand the seasonal changes in the quality of sewage effluent at the Bhagwanpur sewage treatment plant in Varanasi, Uttar Pradesh, India.

## Material and Method

### Sample collection

At the Bhagwanpur Sewage Treatment Plant Varanasi, Uttar Pradesh, India, located at 25°16'21" N latitude and 83°00'16" E longitude, at an elevation of 74.518 m above mean sea level (figure 1 representing the location map), sewage water samples were taken from three different tanks: the infiltration tank, sedimentation tank, and outlet tank. Sampling was done in the month of February (autumn), May (pre monsoon), August (rainy) and November (post monsoon) during the year 2018 to assess the seasonal variation in physico-chemical properties of sewage effluent. Samples were collected in polythene water bottles which were thoroughly washed and then rinsed with the same effluent water samples prior to sampling.

### Laboratory analysis

Samples were preserved immediately after collection using a variety of parameter-wise standard preservation techniques (EPA 1983). The samples' various physico-chemical characteristics were examined. While EC and TSS were recorded using an EC meter, pH was measured using a pH meter. COD were estimated using the dichromate reflux method with a ferroine indicator and BOD was estimated using the azide modification of Winkler's method (APHA, 2005), TDS was estimated using the evaporation of the filtered water sample followed by oven drying (Tripathi and Govil, 2001). Complexometric titration using disodium solution of EDTA ( $C_6H_{16}O_8N_2$ ) i.e. versenate was used to determine the total hardness of the sewage water sample, nitrate nitrogen was estimated by Devarda's alloy reduction method and sulphate by turbidimetric method using spectrophotometer (Tandon, 2009). By titrating a known volume of water against standard  $H_2SO_4$  and using phenolphthalein and methyl orange as indicators, respectively, the concentrations of carbonate and bicarbonate were determined titrimetrically, phosphate was determined colorimetrically using a spectrophotometer, and potassium was determined using a flame photometer (Tandon, 2009). Using an atomic absorption spectrophotometer, the presence of the heavy metals Fe, Cu, Mn, Zn, Pb, Cd, Ni, and Cr was determined (APHA, 2005).

### Data Analysis

Mean values with the standard deviations from mean values for the collected data sets from laboratory analysis were calculated and compared for analyzing the seasonal variation in the composition of sewage effluent and difference due to treatment of sewage water at plant level. To establish the relationship between physicochemical parameters in the sample Pearson's correlation was used. The statistical analysis was done by using MS excel 2021.

## Result and Discussion

Samples of sewage water were taken from each tank at the sewage treatment facility at Bhagwanpur and were then examined for several chemical parameters. Table 1 displays the annual mean of the various physico-chemical characteristics of influent, effluent, and aerator tank water samples and table 2, 3 and 4 display the seasonal variations in the same. Indicating its

alkaline character, the pH of sewage water was neutral to slightly alkaline and seasonally varied from 7.2 to 7.8 before treatment and from 7.4 to 8.0 after treatment. It was discovered that the influent's annual average pH was 7.6, whereas the effluent's was 7.7. The slightly alkaline nature of the waste water may be due to the washing area. Water's electrical conductivity, which corresponds to the dominating ions that are the result of ion exchange and solubilization in the water, is a key factor in determining whether it is suitable for irrigation. The EC of influent fluctuates seasonally from 962 to 1054  $\mu\text{S cm}^{-1}$  with an average mean of 1002  $\mu\text{S cm}^{-1}$ , and the EC of effluent varies seasonally from 584 to 644  $\mu\text{S cm}^{-1}$  with an average mean of 610  $\mu\text{S cm}^{-1}$ . Both the influent and effluent's EC have a strong positive correlation with TDS, as well as with the cations Ca, Na, K, and Mg and the anions carbonate and bicarbonate, among others (Tables 5 and 6). Sewage influent had an annual average total alkalinity of 564  $\text{mg L}^{-1}$ , with seasonal variations ranging from 542 to 579  $\text{mg L}^{-1}$ , whereas effluent had an annual average total alkalinity of 342  $\text{mg L}^{-1}$ , with seasonal variations ranging from 321 to 374  $\text{mg L}^{-1}$ . The data showed that pH, EC and TDS were within the limits described in the revisions made to Environment (Protection) Rules, 1986 Schedule I in 2016 for its safe release into the in land surface water and on land irrigation.

Nitrate levels in influent and effluent samples vary seasonally from 20.96 to 25.36 and 11.52 to 15.88  $\text{mg L}^{-1}$ , respectively, with yearly averages of 22.87 and 13.73  $\text{mg L}^{-1}$ . The nitrate concentration in sewage effluent corresponds to the household stuffs, runoffs from agricultural fields, cattle yards etc. According to reports, sewage discharge is a significant source of phosphate from a variety of sources, which causes eutrophication of aquatic bodies. The phosphate content of the influent sample ranged from 12.23 to 16.36  $\text{mg L}^{-1}$  with an average yearly concentration of 13.60  $\text{mg L}^{-1}$ , while the phosphate content of the effluent ranged from 5.86 to 9.50  $\text{mg L}^{-1}$  with an average annual concentration of 7.29  $\text{mg L}^{-1}$ . One of the important contributing factors for concentration of potassium ion in the water sample is rain water (Davis and De Wiest 1967). While the potassium ion content in the influent sample varies from 9.77 to 10.13  $\text{mg L}^{-1}$  with an average annual value of 9.98  $\text{mg L}^{-1}$ , it is 6.97 to 7.97  $\text{mg L}^{-1}$  with an average annual value of 7.50  $\text{mg L}^{-1}$  in the effluent sample.

An increase in dissolved oxygen concentration in the effluent sample was observed during the investigation which is due to the addition of air by the aerator during the wastewater treatment process and the lower concentration of DO during the summer months may be caused by an increase in the rate of microbial breakdown of organic contaminants owing to higher temperatures (Ravindra et. Al. 2003). The biological oxygen demand (BOD) is typically employed as an index to quantify the level of organic contamination in waste water which can be decomposed by bacteria under anaerobic condition. Seasonal variation in BOD of influent at Bhagwanpur STP was from 173 to 213  $\text{mg L}^{-1}$  with an annual average of 190  $\text{mg L}^{-1}$  and of effluent was from 55 to 77  $\text{mg L}^{-1}$  with an average of 66  $\text{mg L}^{-1}$ . Whereas, COD of the influent varied seasonally from 415 to 534  $\text{mg L}^{-1}$  and that of effluent from 183 to 219  $\text{mg L}^{-1}$ . Year around average COD of the influent and effluent was 456 and 199  $\text{mg L}^{-1}$  respectively. Summertime saw the highest levels of BOD and COD in the sewage water, which is a result of increased chemical and biological activity brought on by summer's higher temperatures (Matta et al 2018).

Average content of calcium, magnesium and sodium in influent was 92.59  $\text{mg L}^{-1}$ , 23.70  $\text{mg L}^{-1}$  and 21.21  $\text{mg L}^{-1}$  respectively, whereas the same in effluent was 88.5  $\text{mg L}^{-1}$ , 20.41  $\text{mg L}^{-1}$

<sup>1</sup> and 11.52 mg L<sup>-1</sup> respectively. The total hardness of effluent water, which is influenced by the presence of calcium and magnesium, makes it unusable for irrigation as calcium in waste water clogs pipes and poses a serious problem for micro-irrigation techniques. Average RSC of the influent was 4.37 meq L<sup>-1</sup> (toxic as per BIS, 2019) and that of effluent was 1.00 meq L<sup>-1</sup> (good as per BIS, 2019). Whereas the SAR of the influent and effluent was 0.51 and 0.29 respectively which was good as per BIS, 2019.

Due to their toxicity and accumulative behaviour in the system, heavy metal load in sewage water has drawn a lot of attention in recent years. These pollutants undergo a worldwide ecological cycle and are non-biodegradable in comparison to other polluting substances (CPCB 2001). Due to their inability to biodegrade, these substances enter the food chain through a variety of channels, where they accumulate in the organs of people and animals over time as a result of prolonged exposure to contaminated environments (Jain et al 2010). Researchers found that the use of industrial water for irrigation resulted in soil discoloration, the presence of green and dark brown tinges as physical evidence of the presence of heavy metals in soil, and an increased incidence of dysentery and respiratory issues in the farmer community and consumers of the vegetables grown on heavy metal-polluted soil (Hameed et al 2021). Table 1 and 4 and figure 2 is showing the seasonal variation and annual average of heavy metal levels in influent and effluent at Bhagwanpur STP. Before utilising the effluent as an alternate source for irrigation, it is advised to continuously monitor it since the concentration of cadmium, chromium, manganese, copper and zinc in the effluent are above permissible limit (BIS, 2019). The iron, lead and nickel content were found within the desirable limits prescribed by BIS / FAO for irrigation water. Although iron concentration was within the permissible limit but it is not recommended for micro irrigation purpose as iron content of more than 0.3 mg L<sup>-1</sup> results in oxidized insoluble forms that could cause black or brown stains on foliage of plants if used with sprinkler irrigation (BIS, 2019). A considerable negative shift was observed in the heavy metal load of influent vs effluent samples which was due to chelation of metal cations with organic matter present in the raw sewage influent which was further transformed into sludge throughout the treatment process.

A statistical indicator of the interdependence of two or more random variables is the correlation coefficient (r). Correlation analysis measures the closeness and degree of linear association between independent and dependent variables. The correlation coefficient 'r' for water quality parameters of influent and effluent sample are presented in table 5 and 6 respectively. Although EC and TDS were shown to have a substantial positive link, EC also showed a positive correlation with cations like calcium, magnesium, and sodium as well as anions like carbonate and bicarbonate. Pearson correlation coefficient between BOD and COD exhibited a significant positive correlation. Nitrate also showed significant positive correlation with phosphates. The amount of dissolved oxygen and phosphates in the effluent water were inversely correlated. A significant positive correlation was observed between pH and alkalinity of the effluent sample.

## Conclusion

This study provides a collective information regarding sewage water quality at Bhagwanpur sewage treatment plant, Varanasi throughout the treatment process. The quality parameters of influent and effluent samples were compared with BIS standards and revealed that effluent qualities meet acceptable standard in physicochemical parameters, like pH, temperature and

electrical conductivity and it can be used for agricultural use with the continuous monitoring of heavy metals concentration of cadmium, chromium, manganese, copper and zinc which fell short of regularity limits for agricultural use.

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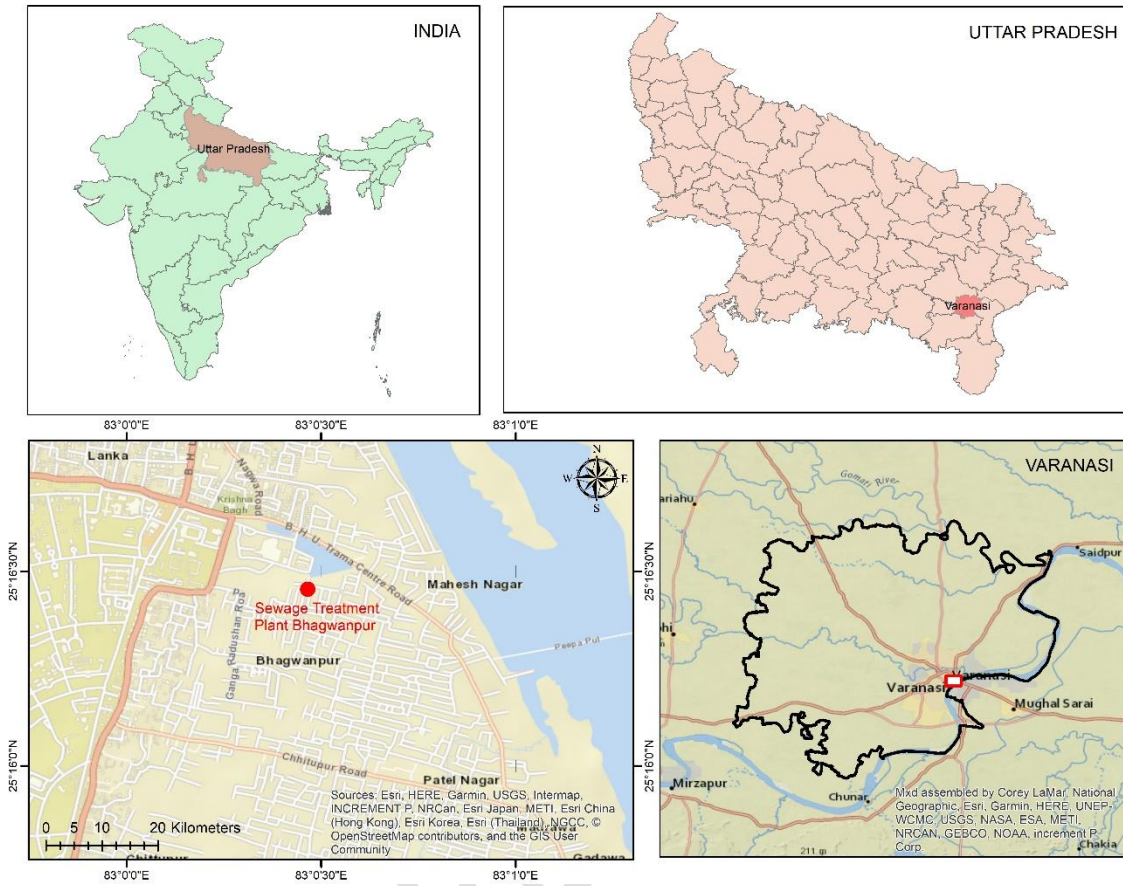
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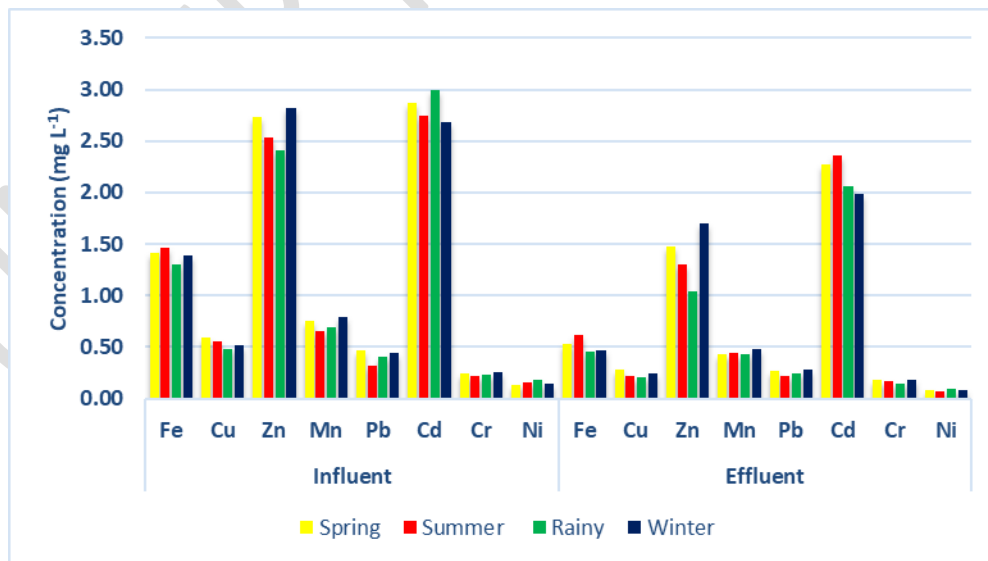
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**Tables and Figures:**



**Figure 1: Location map of sampling site**



**Figure 2: Seasonal variation in heavy metal concentration of sewage water**

**Table 1: Characteristics of influent, aerator tank water and effluent (Annual mean  $\pm$  standard deviation)**

| <b>Parameter</b> | <b>Influent</b>   | <b>Aerator Tank</b> | <b>Effluent</b>   |
|------------------|-------------------|---------------------|-------------------|
| Temperature      | 26.7 $\pm$ 0.05   | 26.7 $\pm$ 0.03     | 26.7 $\pm$ 0.04   |
| pH               | 7.64 $\pm$ 0.05   | 7.66 $\pm$ 0.00     | 7.69 $\pm$ 0.02   |
| EC               | 1002 $\pm$ 25     | 842 $\pm$ 3         | 610 $\pm$ 16      |
| TDS              | 594 $\pm$ 05      | 552 $\pm$ 3         | 413 $\pm$ 3       |
| DO               | 1.70 $\pm$ 0.02   | 2.14 $\pm$ 0.02     | 3.00 $\pm$ 0.02   |
| BOD              | 190 $\pm$ 4       | 185 $\pm$ 1         | 66 $\pm$ 02       |
| COD              | 465 $\pm$ 3       | 432 $\pm$ 01        | 199 $\pm$ 6       |
| Nitrate N        | 22.87 $\pm$ 0.28  | 21.88 $\pm$ 1.08    | 13.73 $\pm$ 0.66  |
| Phosphate        | 13.60 $\pm$ 0.79  | 13.14 $\pm$ 0.59    | 7.29 $\pm$ 0.50   |
| Potassium        | 9.98 $\pm$ 0.05   | 9.52 $\pm$ 0.12     | 7.5 $\pm$ 0.09    |
| Calcium          | 92.59 $\pm$ 0.88  | 89.5 $\pm$ 1.39     | 88.5 $\pm$ 1.32   |
| Magnesium        | 23.70 $\pm$ 0.44  | 22.97 $\pm$ 0.69    | 20.41 $\pm$ 0.61  |
| Sulphate         | 35.13 $\pm$ 0.36  | 33.73 $\pm$ 0.43    | 33.18 $\pm$ 1.10  |
| Sodium           | 21.21 $\pm$ 0.25  | 20.54 $\pm$ 0.59    | 11.52 $\pm$ 0.75  |
| Alkalinity       | 564 $\pm$ 03      | 504 $\pm$ 02        | 342 $\pm$ 08      |
| Iron             | 1.39 $\pm$ 0.01   | 1.16 $\pm$ 0.03     | 0.52 $\pm$ 0.01   |
| Copper           | 0.536 $\pm$ 0.01  | 0.488 $\pm$ 0.013   | 0.238 $\pm$ 0.02  |
| Zinc             | 2.623 $\pm$ 0.06  | 2.599 $\pm$ 0.05    | 1.376 $\pm$ 0.05  |
| Manganese        | 0.722 $\pm$ 0.02  | 0.651 $\pm$ 0.01    | 0.445 $\pm$ 0.02  |
| Lead             | 0.410 $\pm$ 0.01  | 0.374 $\pm$ 0.01    | 0.254 $\pm$ 0.003 |
| Cadmium          | 2.827 $\pm$ 0.06  | 2.743 $\pm$ 0.03    | 2.168 $\pm$ 0.06  |
| Chromium         | 0.237 $\pm$ 0.03  | 0.227 $\pm$ 0.03    | 0.169 $\pm$ 0.01  |
| Nickel           | 0.153 $\pm$ 0.005 | 0.129 $\pm$ 0.001   | 0.081 $\pm$ 0.01  |
| RSC              | 4.37 $\pm$ 0.06   | 3.51 $\pm$ 0.13     | 1.00 $\pm$ 0.18   |
| SAR              | 0.51 $\pm$ 0.01   | 0.50 $\pm$ 0.02     | 0.29 $\pm$ 0.02   |

*\* All the parameters are expressed in mg L<sup>-1</sup>, except Temperature (°C), pH and EC ( $\mu$ s cm<sup>-1</sup>), RSC (meq L<sup>-1</sup>) and SAR.*

**Table 2: Seasonal variation in physicochemical characteristics of sewage water from Bhagwanpur STP (mean  $\pm$  standard deviation)**

| Season / Parameter | Influent Characteristics           |                 |               |              |                 |              |              |                  |                  |                  |
|--------------------|------------------------------------|-----------------|---------------|--------------|-----------------|--------------|--------------|------------------|------------------|------------------|
|                    | Temperature                        | pH              | EC            | TDS          | DO              | BOD          | COD          | Nitrate N        | Phosphate        | Potassium        |
| Spring             | 23.1 $\pm$ 0.06                    | 7.78 $\pm$ 0.11 | 1013 $\pm$ 44 | 621 $\pm$ 11 | 1.88 $\pm$ 0.06 | 185 $\pm$ 08 | 445 $\pm$ 07 | 23.53 $\pm$ 1.06 | 13.47 $\pm$ 2.21 | 10.10 $\pm$ 0.36 |
| Summer             | 32.3 $\pm$ 0.10                    | 7.28 $\pm$ 0.04 | 980 $\pm$ 33  | 576 $\pm$ 9  | 0.98 $\pm$ 0.05 | 213 $\pm$ 05 | 534 $\pm$ 09 | 25.36 $\pm$ 0.70 | 16.36 $\pm$ 2.01 | 10.13 $\pm$ 0.50 |
| Rainy              | 28.7 $\pm$ 0.06                    | 7.65 $\pm$ 0.06 | 962 $\pm$ 50  | 544 $\pm$ 11 | 1.87 $\pm$ 0.05 | 173 $\pm$ 06 | 415 $\pm$ 12 | 21.63 $\pm$ 0.55 | 12.23 $\pm$ 1.57 | 9.77 $\pm$ 0.35  |
| Winter             | 22.7 $\pm$ 0.06                    | 7.85 $\pm$ 0.08 | 1054 $\pm$ 50 | 636 $\pm$ 12 | 2.04 $\pm$ 0.06 | 187 $\pm$ 05 | 466 $\pm$ 07 | 20.97 $\pm$ 0.84 | 12.35 $\pm$ 1.65 | 9.93 $\pm$ 0.42  |
|                    | Aerator tank water characteristics |                 |               |              |                 |              |              |                  |                  |                  |
|                    | Temperature                        | pH              | EC            | TDS          | DO              | BOD          | COD          | Nitrate N        | Phosphorus       | Potassium        |
| Spring             | 23.2 $\pm$ 0.10                    | 7.79 $\pm$ 0.04 | 852 $\pm$ 34  | 559 $\pm$ 9  | 2.20 $\pm$ 0.07 | 182 $\pm$ 05 | 412 $\pm$ 07 | 23.62 $\pm$ 1.81 | 12.90 $\pm$ 1.80 | 9.87 $\pm$ 0.31  |
| Summer             | 32.3 $\pm$ 0.10                    | 7.23 $\pm$ 0.03 | 820 $\pm$ 16  | 553 $\pm$ 6  | 1.90 $\pm$ 0.07 | 206 $\pm$ 04 | 503 $\pm$ 05 | 21.65 $\pm$ 0.73 | 15.39 $\pm$ 1.98 | 9.80 $\pm$ 0.40  |
| Rainy              | 28.6 $\pm$ 0.06                    | 7.64 $\pm$ 0.06 | 879 $\pm$ 30  | 515 $\pm$ 7  | 2.14 $\pm$ 0.04 | 174 $\pm$ 06 | 396 $\pm$ 08 | 21.47 $\pm$ 1.96 | 12.00 $\pm$ 1.45 | 9.63 $\pm$ 0.35  |
| Winter             | 22.6 $\pm$ 0.06                    | 7.96 $\pm$ 0.06 | 818 $\pm$ 24  | 580 $\pm$ 8  | 2.34 $\pm$ 0.05 | 179 $\pm$ 04 | 418 $\pm$ 09 | 20.78 $\pm$ 1.10 | 12.28 $\pm$ 1.62 | 8.77 $\pm$ 0.45  |
|                    | Effluent Characteristics           |                 |               |              |                 |              |              |                  |                  |                  |
|                    | Temperature                        | pH              | EC            | TDS          | DO              | BOD          | COD          | Nitrate N        | Phosphorus       | Potassium        |
| Spring             | 23.3 $\pm$ 0.06                    | 7.74 $\pm$ 0.06 | 599 $\pm$ 25  | 423 $\pm$ 6  | 2.97 $\pm$ 0.05 | 68 $\pm$ 07  | 196 $\pm$ 12 | 11.52 $\pm$ 0.92 | 7.43 $\pm$ 1.12  | 6.97 $\pm$ 0.25  |
| Summer             | 32.4 $\pm$ 0.06                    | 7.43 $\pm$ 0.05 | 644 $\pm$ 59  | 462 $\pm$ 6  | 2.73 $\pm$ 0.05 | 77 $\pm$ 03  | 219 $\pm$ 07 | 15.88 $\pm$ 1.49 | 9.50 $\pm$ 1.80  | 7.57 $\pm$ 0.21  |
| Rainy              | 28.8 $\pm$ 0.10                    | 7.57 $\pm$ 0.05 | 584 $\pm$ 34  | 358 $\pm$ 6  | 3.14 $\pm$ 0.06 | 55 $\pm$ 04  | 183 $\pm$ 06 | 13.95 $\pm$ 1.57 | 6.35 $\pm$ 1.13  | 7.50 $\pm$ 0.36  |
| Winter             | 22.5 $\pm$ 0.06                    | 8.04 $\pm$ 0.07 | 611 $\pm$ 17  | 409 $\pm$ 7  | 3.16 $\pm$ 0.06 | 64 $\pm$ 05  | 199 $\pm$ 10 | 13.57 $\pm$ 0.99 | 5.86 $\pm$ 0.71  | 7.97 $\pm$ 0.40  |

\* All the parameters are expressed in mg L<sup>-1</sup>, except Temperature (°C), pH and EC ( $\mu$ s cm<sup>-1</sup>).

**Table 3: Seasonal variation in physicochemical characteristics of sewage water from Bhagwanpur STP (mean  $\pm$  standard deviation)**

| Season / Parameter | Influent Characteristics           |                  |                  |                  |                  |                 |                  |
|--------------------|------------------------------------|------------------|------------------|------------------|------------------|-----------------|------------------|
|                    | Calcium                            | Magnesium        | Sodium           | Sulphate         | Total alkalinity | RSC             | SAR              |
| Spring             | 94.00 $\pm$ 2.00                   | 24.54 $\pm$ 0.62 | 20.52 $\pm$ 2.10 | 28.86 $\pm$ 0.29 | 576 $\pm$ 10     | 4.46 $\pm$ 0.25 | 0.49 $\pm$ 0.056 |
| Summer             | 92.00 $\pm$ 2.00                   | 21.61 $\pm$ 1.34 | 20.85 $\pm$ 0.96 | 41.18 $\pm$ 0.30 | 542 $\pm$ 04     | 4.11 $\pm$ 0.14 | 0.51 $\pm$ 0.03  |
| Rainy              | 88.67 $\pm$ 3.06                   | 22.86 $\pm$ 1.10 | 21.08 $\pm$ 1.37 | 39.51 $\pm$ 0.52 | 561 $\pm$ 05     | 4.55 $\pm$ 0.15 | 0.52 $\pm$ 0.03  |
| Winter             | 95.67 $\pm$ 2.08                   | 25.78 $\pm$ 0.91 | 22.38 $\pm$ 1.92 | 30.95 $\pm$ 1.45 | 579 $\pm$ 01     | 4.37 $\pm$ 0.20 | 0.52 $\pm$ 0.04  |
|                    | Aerator tank water characteristics |                  |                  |                  |                  |                 |                  |
|                    | Calcium                            | Magnesium        | Sodium           | Sulphate         | Total alkalinity | RSC             | SAR              |
| Spring             | 92.67 $\pm$ 2.52                   | 22.81 $\pm$ 0.66 | 20.23 $\pm$ 1.18 | 28.09 $\pm$ 0.47 | 533 $\pm$ 02     | 3.88 $\pm$ 0.11 | 0.49 $\pm$ 0.03  |
| Summer             | 91.33 $\pm$ 3.06                   | 23.72 $\pm$ 1.13 | 19.51 $\pm$ 1.08 | 40.14 $\pm$ 0.99 | 486 $\pm$ 08     | 3.02 $\pm$ 0.03 | 0.47 $\pm$ 0.03  |
| Rainy              | 86.67 $\pm$ 3.06                   | 20.64 $\pm$ 0.72 | 21.33 $\pm$ 1.67 | 39.30 $\pm$ 1.08 | 488 $\pm$ 11     | 3.46 $\pm$ 0.17 | 0.53 $\pm$ 0.04  |
| Winter             | 87.33 $\pm$ 3.06                   | 24.71 $\pm$ 1.32 | 21.08 $\pm$ 1.84 | 27.40 $\pm$ 1.13 | 510 $\pm$ 06     | 3.66 $\pm$ 0.25 | 0.51 $\pm$ 0.04  |
|                    | Effluent Characteristics           |                  |                  |                  |                  |                 |                  |
|                    | Calcium                            | Magnesium        | Sodium           | Sulphate         | Total alkalinity | RSC             | SAR              |
| Spring             | 91.33 $\pm$ 4.16                   | 21.52 $\pm$ 0.60 | 12.35 $\pm$ 1.10 | 26.73 $\pm$ 1.46 | 374 $\pm$ 09     | 1.29 $\pm$ 0.05 | 0.30 $\pm$ 0.03  |
| Summer             | 86.67 $\pm$ 2.31                   | 17.65 $\pm$ 0.73 | 10.14 $\pm$ 1.20 | 40.13 $\pm$ 1.56 | 321 $\pm$ 08     | 0.93 $\pm$ 0.32 | 0.26 $\pm$ 0.03  |
| Rainy              | 85.33 $\pm$ 3.06                   | 19.55 $\pm$ 1.30 | 12.03 $\pm$ 1.37 | 38.43 $\pm$ 1.84 | 327 $\pm$ 11     | 0.97 $\pm$ 0.16 | 0.31 $\pm$ 0.04  |
| Winter             | 90.67 $\pm$ 3.06                   | 22.90 $\pm$ 1.50 | 11.54 $\pm$ 1.33 | 27.44 $\pm$ 1.10 | 347 $\pm$ 06     | 0.80 $\pm$ 0.32 | 0.28 $\pm$ 0.04  |

\* All the parameters are expressed in  $\text{mg L}^{-1}$ , except RSC and SAR.

**Table 4: Seasonal variation in heavy metal concentration of sewage water from Bhagwanpur STP (mean  $\pm$  standard deviation)**

| Season / Parameter | Influent Characteristics           |                  |                  |                  |                  |                  |                  |                  |
|--------------------|------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                    | Iron                               | Copper           | Manganese        | Zinc             | Lead             | Cadmium          | Chromium         | Nickle           |
| Spring             | 1.41 $\pm$ 0.05                    | 0.592 $\pm$ 0.02 | 0.757 $\pm$ 0.03 | 2.729 $\pm$ 0.12 | 0.462 $\pm$ 0.02 | 2.875 $\pm$ 0.10 | 0.249 $\pm$ 0.04 | 0.134 $\pm$ 0.02 |
| Summer             | 1.47 $\pm$ 0.04                    | 0.561 $\pm$ 0.03 | 0.653 $\pm$ 0.04 | 2.535 $\pm$ 0.12 | 0.320 $\pm$ 0.03 | 2.751 $\pm$ 0.08 | 0.223 $\pm$ 0.05 | 0.153 $\pm$ 0.03 |
| Rainy              | 1.31 $\pm$ 0.06                    | 0.476 $\pm$ 0.02 | 0.688 $\pm$ 0.03 | 2.408 $\pm$ 0.15 | 0.411 $\pm$ 0.01 | 2.994 $\pm$ 0.15 | 0.227 $\pm$ 0.07 | 0.185 $\pm$ 0.06 |
| Winter             | 1.39 $\pm$ 0.10                    | 0.513 $\pm$ 0.02 | 0.789 $\pm$ 0.01 | 2.822 $\pm$ 0.17 | 0.448 $\pm$ 0.06 | 2.687 $\pm$ 0.22 | 0.251 $\pm$ 0.06 | 0.139 $\pm$ 0.03 |
|                    | Aerator tank water characteristics |                  |                  |                  |                  |                  |                  |                  |
|                    | Iron                               | Copper           | Manganese        | Zinc             | Lead             | Cadmium          | Chromium         | Nickle           |
| Spring             | 1.16 $\pm$ 0.04                    | 0.527 $\pm$ 0.04 | 0.684 $\pm$ 0.02 | 2.712 $\pm$ 0.25 | 0.422 $\pm$ 0.04 | 2.718 $\pm$ 0.10 | 0.231 $\pm$ 0.04 | 0.111 $\pm$ 0.01 |
| Summer             | 1.22 $\pm$ 0.02                    | 0.499 $\pm$ 0.02 | 0.619 $\pm$ 0.02 | 2.491 $\pm$ 0.12 | 0.296 $\pm$ 0.02 | 2.741 $\pm$ 0.08 | 0.216 $\pm$ 0.04 | 0.129 $\pm$ 0.04 |
| Rainy              | 1.08 $\pm$ 0.05                    | 0.464 $\pm$ 0.01 | 0.610 $\pm$ 0.02 | 2.396 $\pm$ 0.10 | 0.363 $\pm$ 0.01 | 2.831 $\pm$ 0.14 | 0.214 $\pm$ 0.07 | 0.154 $\pm$ 0.04 |
| Winter             | 1.17 $\pm$ 0.09                    | 0.463 $\pm$ 0.02 | 0.690 $\pm$ 0.05 | 2.797 $\pm$ 0.20 | 0.413 $\pm$ 0.05 | 2.683 $\pm$ 0.07 | 0.248 $\pm$ 0.04 | 0.123 $\pm$ 0.04 |
|                    | Effluent Characteristics           |                  |                  |                  |                  |                  |                  |                  |
|                    | Iron                               | Copper           | Manganese        | Zinc             | Lead             | Cadmium          | Chromium         | Nickle           |
| Spring             | 0.53 $\pm$ 0.04                    | 0.281 $\pm$ 0.03 | 0.429 $\pm$ 0.02 | 1.474 $\pm$ 0.21 | 0.268 $\pm$ 0.01 | 2.276 $\pm$ 0.12 | 0.185 $\pm$ 0.04 | 0.076 $\pm$ 0.01 |
| Summer             | 0.62 $\pm$ 0.06                    | 0.221 $\pm$ 0.03 | 0.439 $\pm$ 0.05 | 1.297 $\pm$ 0.22 | 0.223 $\pm$ 0.02 | 2.355 $\pm$ 0.19 | 0.164 $\pm$ 0.03 | 0.067 $\pm$ 0.02 |
| Rainy              | 0.46 $\pm$ 0.03                    | 0.206 $\pm$ 0.04 | 0.424 $\pm$ 0.03 | 1.037 $\pm$ 0.17 | 0.249 $\pm$ 0.01 | 2.059 $\pm$ 0.09 | 0.147 $\pm$ 0.02 | 0.096 $\pm$ 0.01 |
| Winter             | 0.46 $\pm$ 0.06                    | 0.243 $\pm$ 0.05 | 0.486 $\pm$ 0.01 | 1.695 $\pm$ 0.16 | 0.275 $\pm$ 0.02 | 1.981 $\pm$ 0.13 | 0.181 $\pm$ 0.02 | 0.084 $\pm$ 0.01 |

\* All the parameters are expressed in mg L<sup>-1</sup>.

**Table 5: Correlation matrix of raw sewage of Bhagwanpur STP showing Pearson's correlation coefficient between parameters**

|                               | Temp.   | pH     | EC     | TDS    | DO      | BOD     | COD    | NO <sub>3</sub> <sup>-</sup> | PO <sub>4</sub> <sup>-3</sup> | K <sup>+</sup> | Ca <sup>++</sup> | Mg <sup>++</sup> | SO <sub>4</sub> <sup>-2</sup> | Na <sup>+</sup> | CO <sub>3</sub> <sup>-2</sup> | HCO <sub>3</sub> <sup>-</sup> |
|-------------------------------|---------|--------|--------|--------|---------|---------|--------|------------------------------|-------------------------------|----------------|------------------|------------------|-------------------------------|-----------------|-------------------------------|-------------------------------|
| Temp.                         | 1       |        |        |        |         |         |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| pH                            | -0.948  | 1      |        |        |         |         |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| EC                            | -0.805  | 0.648  | 1      |        |         |         |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| TDS                           | -0.797  | 0.579  | 0.956* | 1      |         |         |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| DO                            | -0.851  | 0.974* | 0.486  | 0.384  | 1       |         |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| BOD                           | 0.517   | -0.750 | 0.002  | 0.102  | -0.873  | 1       |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| COD                           | 0.500   | -0.722 | 0.058  | 0.124  | -0.841  | 0.992** | 1      |                              |                               |                |                  |                  |                               |                 |                               |                               |
| NO <sub>3</sub> <sup>-</sup>  | 0.607   | -0.804 | -0.395 | -0.175 | -0.884  | 0.803   | 0.726  | 1                            |                               |                |                  |                  |                               |                 |                               |                               |
| PO <sub>4</sub> <sup>-3</sup> | 0.681   | -0.879 | -0.305 | -0.150 | -0.962* | 0.936   | 0.892  | 0.951*                       | 1                             |                |                  |                  |                               |                 |                               |                               |
| K <sup>+</sup>                | 0.079   | -0.388 | 0.207  | 0.435  | -0.578  | 0.791   | 0.733  | 0.811                        | 0.779                         | 1              |                  |                  |                               |                 |                               |                               |
| Ca <sup>++</sup>              | -0.686  | 0.447  | 0.948  | 0.984* | 0.243   | 0.256   | 0.286  | -0.085                       | -0.018                        | 0.506          | 1                |                  |                               |                 |                               |                               |
| Mg <sup>++</sup>              | -0.972* | 0.931  | 0.881  | 0.815  | 0.838   | -0.466  | -0.420 | -0.694                       | -0.694                        | -0.149         | 0.730            | 1                |                               |                 |                               |                               |
| SO <sub>4</sub> <sup>-2</sup> | 0.963*  | -0.835 | -0.801 | -0.868 | -0.697  | 0.337   | 0.344  | 0.369                        | 0.475                         | -0.182         | -0.767           | -0.898           | 1                             |                 |                               |                               |
| Na <sup>+</sup>               | -0.399  | 0.447  | 0.664  | 0.419  | 0.433   | -0.143  | -0.024 | -0.704                       | -0.466                        | -0.400         | 0.454            | 0.604            | -0.219                        | 1               |                               |                               |
| CO <sub>3</sub> <sup>-2</sup> | -0.965* | 0.963* | 0.822  | 0.738  | 0.897   | -0.567  | -0.520 | -0.769                       | -0.777                        | -0.263         | 0.641            | 0.992**          | -0.866                        | 0.607           | 1                             |                               |
| HCO <sub>3</sub> <sup>-</sup> | -0.984* | 0.977* | 0.689  | 0.679  | 0.914   | -0.654  | -0.644 | -0.661                       | -0.769                        | -0.197         | 0.546            | 0.934            | -0.927                        | 0.325           | 0.948                         | 1                             |

\*Correlation is significant at  $\alpha_{0.05}$  (2- tailed) and \*\* Correlation is significant at  $\alpha_{0.01}$  (2- tailed)

**Table 6: Correlation matrix of effluent from Bhagwanpur STP showing Pearson's correlation coefficient between parameters**

|                               | Temp.   | pH     | EC     | TDS     | DO       | BOD    | COD    | NO <sub>3</sub> <sup>-</sup> | PO <sub>4</sub> <sup>-3</sup> | K <sup>+</sup> | Ca <sup>++</sup> | Mg <sup>++</sup> | SO <sub>4</sub> <sup>-2</sup> | Na <sup>+</sup> | CO <sub>3</sub> <sup>-2</sup> | HCO <sub>3</sub> <sup>-</sup> |
|-------------------------------|---------|--------|--------|---------|----------|--------|--------|------------------------------|-------------------------------|----------------|------------------|------------------|-------------------------------|-----------------|-------------------------------|-------------------------------|
| Temp.                         | 1       |        |        |         |          |        |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| pH                            | -0.914  | 1      |        |         |          |        |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| EC                            | 0.486   | -0.296 | 1      |         |          |        |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| TDS                           | 0.240   | -0.203 | 0.901  | 1       |          |        |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| DO                            | -0.654  | 0.693  | -0.802 | -0.845  | 1        |        |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| BOD                           | 0.338   | -0.310 | 0.911  | 0.994** | -0.898   | 1      |        |                              |                               |                |                  |                  |                               |                 |                               |                               |
| COD                           | 0.426   | -0.289 | 0.988* | 0.956*  | -0.846   | 0.962* | 1      |                              |                               |                |                  |                  |                               |                 |                               |                               |
| NO <sub>3</sub> <sup>-</sup>  | 0.834   | -0.541 | 0.677  | 0.311   | -0.483   | 0.367  | 0.570  | 1                            |                               |                |                  |                  |                               |                 |                               |                               |
| PO <sub>4</sub> <sup>-3</sup> | 0.707   | -0.745 | 0.781  | 0.803   | -0.997** | 0.864  | 0.818  | 0.517                        | 1                             |                |                  |                  |                               |                 |                               |                               |
| K <sup>+</sup>                | 0.046   | 0.359  | 0.280  | -0.077  | 0.298    | -0.111 | 0.150  | 0.565                        | -0.298                        | 1              |                  |                  |                               |                 |                               |                               |
| Ca <sup>++</sup>              | -0.864  | 0.763  | -0.049 | 0.273   | 0.191    | 0.177  | 0.049  | -0.711                       | -0.264                        | -0.171         | 1                |                  |                               |                 |                               |                               |
| Mg <sup>++</sup>              | -0.982* | 0.969* | -0.468 | -0.295  | 0.733    | -0.397 | -0.435 | -0.730                       | -0.783                        | 0.137          | 0.803            | 1                |                               |                 |                               |                               |
| SO <sub>4</sub> <sup>-2</sup> | 0.971*  | -0.861 | 0.312  | 0.011   | -0.453   | 0.110  | 0.228  | 0.824                        | 0.517                         | 0.140          | -0.959*          | -0.926           | 1                             |                 |                               |                               |
| Na <sup>+</sup>               | -0.705  | 0.451  | -0.933 | -0.696  | 0.724    | -0.730 | -0.874 | -0.897                       | -0.728                        | -0.437         | 0.380            | 0.645            | -0.595                        | 1               |                               |                               |
| CO <sub>3</sub> <sup>-2</sup> | -0.945  | 0.983* | -0.464 | -0.353  | 0.790    | -0.454 | -0.453 | -0.640                       | -0.835                        | 0.268          | 0.726            | 0.989*           | -0.865                        | 0.599           | 1                             |                               |
| HCO <sub>3</sub> <sup>-</sup> | -0.800  | 0.518  | -0.351 | 0.068   | 0.191    | 0.003  | -0.219 | -0.927                       | -0.244                        | -0.596         | 0.870            | 0.674            | -0.878                        | 0.664           | 0.559                         | 1                             |

\*Correlation is significant at  $\alpha_{0.05}$  (2- tailed) and \*\* Correlation is significant at  $\alpha_{0.01}$  (2- tailed)