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ASSESSMENT OF VARIOUS PHYSICO–CHEMICAL PARAMETERS OF TREATED AND UNTREATED WASTE WATER FROM DISTRICT FATEHGARH SAHIB, PUNJAB, INDIA

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ABSTRACT

Direct release of improper and untreated wastes in various water bodies deteriorates its quality, which makes it unsuitable for drinking and other economic activities. Study of various physico-chemical parameters of water will create primary data which is essential for effective and specific treatment methods to recuperate our water resources. In the present study, various physico-chemical parameters like total dissolved solids, total suspended solids, total alkalinity, Cl^-, SO_4^{-2}, Na/K ions, total hardness, different forms of nitrogen (nitrites, nitrates, ammonical nitrogen) and phosphorous (total phosphate, total ortho phosphate, acid hydrolysable phosphate), carbonate/ bicarbonate, BOD and COD of treated and untreated waste water was studied. As per Bureau of Indian standards, values of certain physico-chemical parameters were found to be substantially higher than the permissible limits in untreated waste water in comparison to treated one. BOD, COD, TDS, TH, chloride and ammonical nitrogen values showed strong positive correlation with each others.

KEY WORDS : Waste water, BOD, COD, TDS, Nitrogen, Phosphorous

INTRODUCTION

Water is one of the valuable natural resources of this planet, which is essential for the survival, existence and maintenance of metabolic process of all living organisms. From total water on this earth, only 0.036% is accessible to human beings through lakes and rivers (Reddy and Lee, 2012; Dwivedi, 2017). Owing to exponential growing population, urbanization, industrialization, agriculture activities and improved living standards, the stress on water resources is increasing, especially in urban and suburban areas. From the last few decades, water pollution is one of the major ecological challenges faced by every country, especially in developing countries like India. As per National Rural Drinking Water Programme data, 163 million people of India are living without access to clean water (Annual report 2014-15, Ministry of drinking water and sanitation, Govt. of India).

In India, the rate of sewage production was estimated to be 60 L/day per person in cities and 120 L/day in metropolitan cities (Subashini *et al.*, 2017). It was estimated that, ejection of unprocessed sewage is single most important cause for surface and ground water pollution in India. Even where waste-water treatment plants exist, they were inadequately designed, constructed and maintained (Kushwaha, 2011). Raw sewage has polluted water ecology by two main reasons; First, due to presence of nutrients in raw sewage like nitrogen and phosphorous, it stimulates the growth of microorganisms and aquatic plants which deteriorate water quality by increasing biological and chemical oxygen demands. Secondly, presence of pathogenic microorganisms likes bacteria, fungus and viruses cause serious illness in human beings, that make it unfit for human consumption (Bhargava, 2016). So, disposal of such polluted water in water bodies have severe effect on environment and water ecology.

Waste-water is a combination of water, surface runoff water; water-carried wastes from various industries and sewage waste (Bhatti *et al.,* 2016). Before the treatment of wastewater, it is absolutely imperative to study the quality and quantity of various pollutants it possess. This will create primary data about the type of pollution, which is essential for effective and economical waste management programmes and choice of treatment methods in a planned and controlled manner. The aim of this study is to analyze the physico-chemical contamination of inflowing and out flowing water from a residential waste-water treatment plant and the junction where the treated water amalgamated with municipality waste and surface runoff water from the nearby village Chunni Kalan, Fatehgarh sahib, Punjab.

MATERIALS AND METHODS

Sample collection

Water samples were aseptically collected from 3 different sites; Site 1 (untreated sewage waste water), Site 2 (treated sewage water) and Site 3 (where treated sewage water from residential treatment plant blended with outside waste water) as shown in Figure 1. To study the seasonal variations in physico-chemical properties of water samples, samples were collected from same site during winter (January, 2018) and summer season (June, 2018) in the morning hours (7 A.M to 8 A.M). Water samples were collected from 30-40 cm below the surface and stored in polytetrafluoroethylene bottles at 4^0C for analysis.

Chemicals

All chemicals and reagents used in present study were of analytical grade (AR) and purchased from Merck (India) and Sigma-Aldrich (India). Autoclaved double distilled water was used for all experiments.

Physico-chemical analysis

Total dissolved solids (TDS), total suspended solids (TSS), total alkalinity (TA), ammonical nitrogen (NH_4-N), nitrates (NO_3^-), nitrites (NO_2^-), sodium (Na^+), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), chlorides (Cl^-), sulphates (SO_4^{-2}), phosphates (PO_4^{-2}) were analyzed by standard methods as described by American Public Health Association (APHA, 2005). Biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were analyzed by modified Winkler's method (McCormick, 1972). A negative control was always used to confirm the sterility of media. All experiments were performed in triplicates and readings were taken as mean ($\pm$standard deviation).

RESULTS AND DISCUSSION

Total dissolved solids (TDS) and Total suspended solids (TSS)

Water with high TDS is unpleasant and not suitable for drinking. TDS is composed of all inorganic and organic substances which directly contribute towards conductance. High TDS increase the eutrophication which directly increases water pollution (Bheemappa *et al.,* 2015; Appavu *et al.,* 2016). At site 1 during winter TDS was found to be higher than summer (209.17$\pm$22.75 mg/L vs

Fig. 1. View of different sites described in present study from where samples were collected for physico-chemical analysis.

182.2±8.28 mg/L). At site 2 and 3 TDS was observed to be higher in summer (37.66±5.65 and 189.23±8.00, respectively) than winter (30.44±2.59 and 172.39±10.98, respectively) as shown in Table 1. These values are higher than permissible limit at site 1 and 3. TSS is that portion of total solid that is retained on water filter paper (micron), which do not dissolved in water and have capable to settle down. In the present study, TSS were found to be higher in summer than winter at all three sites as shown in Table 1.

Sulphates and chlorides

In water, concentration of dissolved sulphates (SO_4^{2-}) increases due to oxidation of reduced sulphur, pyrites, sulphides and also due to presence of fertilizers. Discharge from domestic sewage and industrial effluents also increase the concentration of sulphates (Appavu *et al.*, 2016; Dwivedi, 2017). The average concentration of sulphates in the present study ranged from 27.68±2.8 in summer to 29.46±6.67 mg/L in winter at site 1 as shown in Table 1. Similarly, at site 2 and 3, concentration of sulphates were found to be 19.62±3.99 mg/L and 79.96±6.52 mg/L, respectively in summer as compared to 13.85±2.92 mg/L and 89.26±7.28 mg/L, respectively in winter, which was higher than the permissible limits. Chlorides are naturally present in water, but its concentration remains low. Increase in concentration of chlorides related to pollution of water. Sewage water and industrial effluents increases the concentration of chlorides in water. In present study, at site 1 and 2, concentration of chlorides in water was found to be slightly higher in winter season than summer. But, at site 3, concentration of chlorides was observed to be

Table 1. Estimation of various physico-chemical parameters of waste water at different sites.

Parameters (mg/L)	Sample Site	January	June
TDS	Site 1	209.17±22.75	182.2±8.28
	Site 2	30.44±2.59	37.66±5.65
	Site 3	172.39±10.98	189.23±8.00
TS	Site 1	251.01±12.52	311.47±11.95
	Site 2	50.80±5.65	74.03±4.23
	Site 3	295.92±6.88	336.09±3.92
TSS	Site 1	15.95±1.71	31.92±4.49
	Site 2	8.15±1.73	14.62±1.66
	Site 3	63.2±4.84	93.03±4.83
Sulphates	Site 1	29.46±6.67	27.68±2.88
	Site 2	13.85±2.92	19.62±3.99
	Site 3	89.26±7.28	79.96±6.52
Chlorides	Site 1	87.79±10.66	85.11±5.97
	Site 2	96.23±7.89	90.43±6.32
	Site 3	150.18±15.58	169.19±18.91
Sodium Ion	Site 1	23.55±4.35	14.39±3.09
	Site 2	8.11±1.82	7.95±1.20
	Site 3	14.55±1.89	22.46±3.25
Potassium Ion	Site 1	6.06±1.71	4.76±1.26
	Site 2	3.26±0.67	4.20±1.61
	Site 3	8.37±2.56	10.67±2.03
B.O.D	Site 1	84.05±9.25	75.10±4.76
	Site 2	10.95±1.84	14.53±3.02
	Site 3	90.58±3.83	78.61±5.79
C.O.D	Site 1	123.17±10.85	145.36±6.50
	Site 2	38.09±3.10	46.52±3.72
	Site 3	265.37±17.76	215.41±5.37
Total hardness	Site 1	636.41±14.32	592.90±12.92
(Calcium+Magnesium)	Site 2	617.93±6.24	570.36±2.26
	Site 3	637.48±16.06	596.63±7.31
Calcium	Site 1	75.45±3.54	55.86±2.67
	Site 2	63.66±2.59	48.90±8.68
	Site 3	84.31±4.04	69.38±1.40

higher in summer as compared to winter season (169.19±18.91 mg/L vs. 150.18±15.58 mg/L).

Sodium and potassium ions

Sodium and potassium ions are mostly present in water without undergoing any precipitation. Both of these ions are increases due to disposal of sewage wastes and agricultural activities. High concentration of sodium in water is not suitable for drinking purposes as it causes toxemia in pregnant woman and cardiovascular diseases in human (Appavu *et al.*, 2016). It is also proposed that those people who are on restricted sodium diet should avoid water with sodium concentration above 200 mg/L. The standard of 100 mg/L concentration of sodium is proposed for drinking purposes (Appavu *et al.*, 2016; Dwivedi, 2017). In our study, at sites 1 and 2, sodium ions were present in higher concentration in winter as comparison to summer as shown in table 1. Whereas, at site 3, concentration of sodium ions were higher in summer as compared to winter (22.46±3.25 mg/L vs 14.55±1.89 mg/L). Potassium ions were also found to be higher in summer as compared to winter season at sites 2 and 3 (table 1). But, concentration of potassium ions were found to be slightly higher in winter season as compared to summer season at site 1 (6.06±1.71 vs 4.76±1.26).

Biochemical oxygen demand (B.O.D) and chemical oxygen demand (C.O.D)

BOD is a measure of dissolved oxygen in the water that is required by aerobic organisms. It only measures biodegradable fraction of the total potential dissolved oxygen consumption of a water sample. Increase in BOD value is reflection of oxygen demands by aerobic microorganisms which leads to depletion of dissolved oxygen which may cause hypoxia conditions with consequent adverse effects on aquatic biota (Bheemappa *et al.*, 2015; Appavu *et al.*, 2016). Domestic sewage, industrial effluents increase BOD demand in water bodies. It is one of the most common measures of organic pollutant in water (Appavu *et al.*, 2016). In our study, as shown in table 1, BOD was found to be higher in winter season at site 1 and 3 (84.05±9.25 mg/L and 90.58±3.83 mg/L, respectively) as compared to summer season (75.10±4.76 mg/L and 78.61±5.79 mg/L, respectively), which is above the permissible limit. BOD values were found to be higher in summer season as compared to winter season (14.53±3.02 mg/L vs 10.95±1.84 mg/L) at site 2.

Beside BOD, COD is another parameter to characterize the organic strength of domestic wastewater. This test does not differentiate between biologically oxidisable and biologically inert material in water bodies. COD is a measure of oxygen equivalent of that portion of organic matter in a water sample that is susceptible to oxidation by strong chemical oxidant (Bheemappa *et al.*, 2015; Appavu *et al.*, 2016). Due to depletion of oxygen, there is growth of anaerobic microorganisms whose end products of various biochemical reactions result in aesthetically displeasing tastes, odors and colors in water bodies. In the present study, COD was found to be higher in summer season at site 1 and 2 (145.36±6.50 mg/L and 46.52±3.72 mg/L, respectively) as compared to winter season (123.17±10.85 mg/L and 38.09±3.10 mg/L, respectively). But, COD was found to be higher in winter as compared to summer season at site 3 (265.37±17.76 mg/L vs. 215.41±5.37 mg/L).

Total Hardness

Total hardness is sum of calcium (Ca^{+2}) and Magnesium (Mg^{+2}) ions concentration in water bodies and is one of the parameter to study water quality. Total hardness above 250 mg/L causes encrustation and has adverse health effect, hence unsuitable for drinking purposes (Murhekar, 2011). Total hardness was found to be higher in winter in comparison to summer (636.41±14.32 mg/L vs 592.90±12.92 mg/L) at site 1. Similarly, at site 2 and 3, total hardness was found to be higher in winter season (617.93±6.24 mg/L and 637.48±16.06 mg/L, respectively) than in summer season (570.36±2.26 mg/L and 596.63±7.31 mg/L, respectively). Calcium hardness was also studied at different sites. Calcium hardness also showed the same trend i.e. it was found to be higher in winter season as compared to summer season at all the three sites as shown in Table 1.

Alkalinity/carbonate and bicarbonate

Alkalinity can be defined as the capacity to neutralize acids. In natural water, alkalinity is derived mainly from salts of weak acids. Carbonate, bicarbonate and hydroxide ions are dominant source of natural alkalinity (Ramesh *et al.*, 2016). Reaction of CO_2 with magnesium and calcium carbonates contributes in the amount of bicarbonates in water. Beside this, humic acid, an organic acid, also forms salts that increase alkalinity

(Dohare *et al.,* 2014; Ramesh *et al.,* 2016). In the present study, alkalinity was studied by two methods, phenolphthalein alkalinity and methyl-orange alkalinity. In case of phenolphthalein alkalinity, the average alkalinity was found to be higher in summer as compared to winter seasons at all the three sites, as shown in Table 2. It was recorded minimum at site 2 in winter (28.88±2.04 mg/L) and maximum at site 1 in summer (74.04±4.24 mg/L). Methyl-orange alkalinity was found to be higher in winter season at sites 1 and 3 (396.96±13.93 mg/L and 318.80±14.81 mg/L, respectively) as compared to summer season (376.54±13.00 mg/L and 269.05±12.14 mg/L, respectively). Whereas, it was found to be slightly higher in summer season as compared to winter season (165.84±4.23 mg/L vs. 162.65±10.23 mg/L) at site 2. Carbonate and bicarbonate contributes in alkalinity of water. Average carbonate concentration was found to be higher in winter season at site 2 and 3 (20.00±1.06 mg/L and 38.54±1.88 mg/L, respectively) as compared to summer season (17.84±1.50 mg/L and 27.05±3.09 mg/L, respectively). But, at site 1, average carbonate concentration was found to be little higher in summer as compared to winter (29.14±3.70 mg/L vs. 25.05±2.75 mg/L). Average bicarbonate concentration was found to be higher in winter as compared to summer season at all sites (Table 2). Minimum bicarbonate concentration was observed at site 2 in summer (114.80±8.13 mg/L) and maximum was observed at site 3 in winter (445.69±28.99 mg/L). High alkaline water is unpalatable and unsuitable for drinking as it may cause gastrointestinal discomfort. Discharge of industrial effluents and domestic wastes increases both alkalinity and total hardness in water bodies (Dohare *et al.,* 2014; Ramesh *et al.,* 2016).

Phosphate and Nitrogen

Phosphate concentration increases in water due to agriculture activities like use of pesticides and

Table 2. Estimation of Various Physico-chemical parameters of waste water at different sites.

Parameters (mg/L)	Sample Site	January	June
Phenolphthalein Alkalinity	Site 1	57.12±4.94	74.04±4.24
	Site 2	28.88±2.04	47.32±2.13
	Site 3	53.41±11.76	65.86±4.81
Methyl Orange Alkalinity	Site 1	396.96±13.93	376.54±13.00
	Site 2	162.65±10.23	165.84±4.23
	Site 3	318.80±14.81	269.05±12.14
Carbonate	Site 1	25.05±2.75	29.14±3.70
	Site 2	20.00±1.06	17.84±1.50
	Site 3	38.54±1.88	27.05±3.09
Bicarbonate	Site 1	227.45±16.61	175.02±17.13
	Site 2	214.52±6.67	114.80±8.13
	Site 3	445.69±28.99	285.3±11.16
Total Ortho phosphate	Site 1	1.44±0.19	1.20±0.10
	Site 2	0.54±0.10	0.39±0.007
	Site 3	3.36±0.80	2.90±0.22
Acid hydrolysable Phosphate	Site 1	4.63±0.081	3.89±0.39
	Site 2	2.96±0.04	2.45±0.32
	Site 3	6.87±0.96	5.46±0.82
Total Phosphate	Site 1	20.57±2.49	22.85±0.30
	Site 2	14.40±1.44	11.18±0.63
	Site 3	22.66±0.95	20.93±2.06
Ammonical Nitrogen	Site 1	3.90±0.18	3.44±0.57
	Site 2	0.74±0.21	0.79±0.11
	Site 3	12.78±0.68	15.14±1.41
Nitrite – Nitrogen	Site 1	0.186±0.04	0.189±0.01
	Site 2	0.133±0.01	0.170±0.01
	Site 3	0.263±0.03	0.224±0.02
Nitrate – Nitrogen	Site 1	20.62±0.78	19.93±2.10
	Site 2	8.49±0.55	11.59±1.29
	Site 3	40.34±3.50	48.75±3.26

fertilizers, whereas natural contaminating source includes phosphate containing rocks, liquid and solid wastes and detergents (surfactants). Orthophosphate concentration increases mainly due to presence of domestic waste and sewage effluents. Phosphates contribute significantly in eutrophication process (Sarkinnoma *et al.*, 2013; Appavu *et al.,* 2016). Linear regression analysis of standard graphs were used to find out the unknown concentration of different forms of nitrogen and phosphorous in various water samples (Figure 2). As shown in Table 2, total phosphate did not show any significant difference with respect to seasons. Average total phosphate was found to be minimum in summer season at site 2 (11.18±0.63 mg/L) and maximum at site 1 in summer season (22.85±0.30 mg/L). Acid hydrolysable phosphate was found to be little higher in winter season as compared to summer season at all sites as shown in Table 2. It was found to be lowest at site 2 in summer (2.45±0.32 mg/L) and highest at site 3 in winter (6.87±0.96 mg/L). Similarly, total orthophosphate did not showed any significant variation with respect to the effect of season. It was found to be minimum in summer season at site 2 (0.39±0.007 mg/L) and maximum at site 3 in winter (3.36±0.80 mg/L).

In water bodies, ammonia exists in two forms: ammonium ions and free ammonia. Ammonification of organic matter is an important source of ammonia. At higher pH, ammonia is toxic to aquatic flora and fauna. In the present study, ammonical nitrogen was found to be higher in summer season at site 3 (15.14±1.41 mg/L), whereas it was found to be minimum at site 2 in winter season (0.74±0.21 mg/L) (Table 2). Sewage wastes tend to increase the amount of ammonia due to presence of large quantity of nitrogenous matter. Concentration of ammonia (NH^{4+}) is generally higher in winter because nitrification process is more affected at higher temperature (Sarkinnoma *et al.,* 2013). In the present study, BOD, COD, TDS, TH, chloride and ammonical nitrogen values showed strong positive correlation with each others.

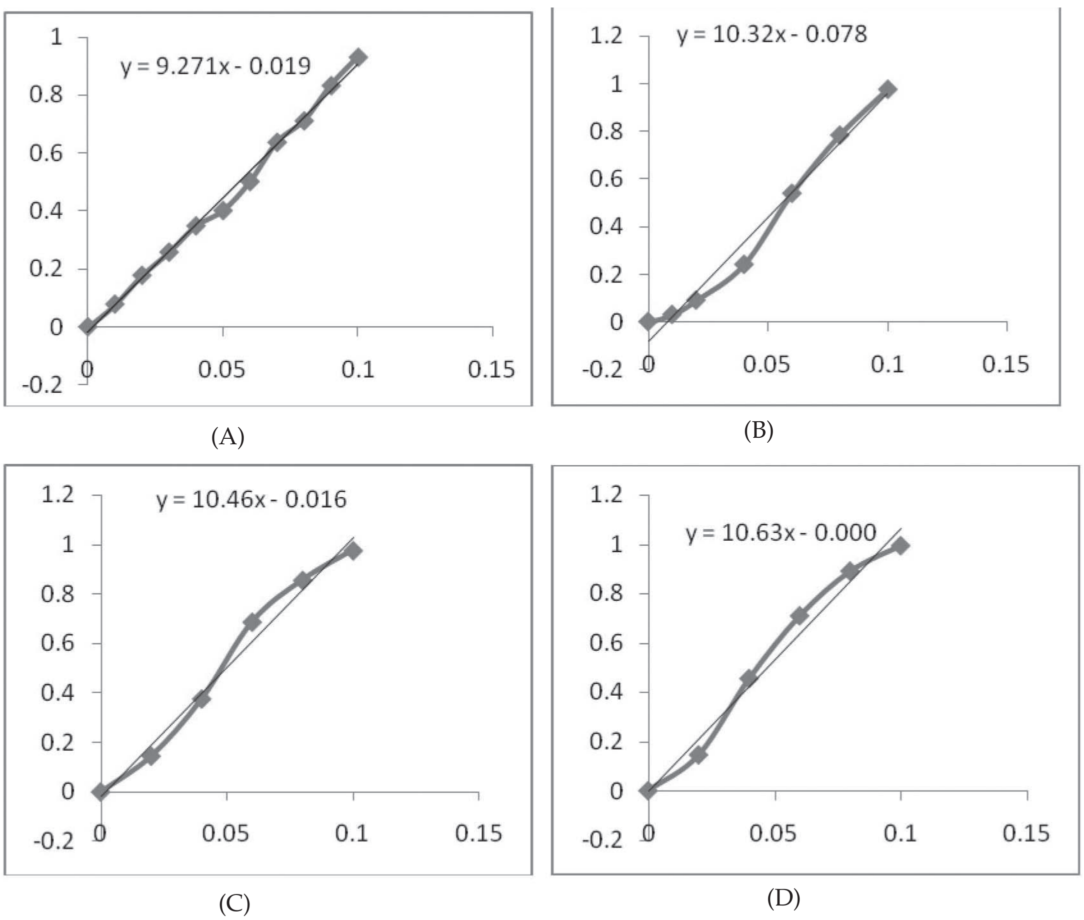

Fig. 2. Standard graph for the estimation of [A] Phosphate [B] Ammonical-nitrogen [C] Nitrite-nitrogen [D] Nitrate-nitrogen.

Nitrate is the highest oxidized and stable form of nitrogen and an important parameter to calculate the organic pollution. It occurs naturally in water bodies as a result of decaying plants and other organic matters, run off chemical fertilizers, domestic wastes and sewage and industrial effluents. Nitrates contamination leads to eutrophication and hence increase in population of pathogenic microorganisms (Sarkinnoma *et al.*, 2013). High concentration of nitrates (>90 mg/L) have very toxic effect on aquatic biota. In our studies, nitrate was found to be slightly higher in summer season at site 2 and 3 (11.59 ± 1.29 mg/L and 48.75 ± 3.26 mg/L, respectively) as compared to winter season (8.49 ± 0.55 mg/L and 40.34 ± 3.50 mg/L, respectively). At site 1, there was slight increase in the concentration of nitrate in winter season as compared to summer seasons (20.62±0.78 mg/L vs. 19.93±2.10 mg/L). Nitrite-nitrogen showed minimum concentration at site 2 in winter (0.133±0.01 mg/L) and maximum at site 3 in winter (0.263±0.03 mg/L) as shown in Table 2.

CONCLUSION

Water is essential for the existence of all life forms, but this cherished resource is now in a threatened stage due to unstoppable population growth and unchecked economic activities. Improper and untreated municipality waste water along with unplanned industrialization has deteriorated the quality of water by disturbing its normal physico-chemical parameters. There is a need to plan strategies for development of wastewater treatment facilities, its recycling, recharging, and storage. The future of potable water in any country will depends upon the how much efficient is their wastewater treatment policies. This project is completed with the objectives to get the primary information on various physico-chemical parameters of treated and untreated waste water from a residential area, which is necessary for every government and non-government organizations to make various strategies and plans to protect the water resources and for maintenance of water inviolability.

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REFERENCES

APHA, 2005. *Standard Methods For Examination of Water and Wastewater*, 20th Edition, American Public Health Association, Washington D. C.

Appavu, A., Thangavelu, S. Muthukanan, S.K., Jesudoss, J.S. and Pandi, B. 2016. Study of water quality parameters of Cauvery river water in Erode region. *J. Glob. Biosci.* 5 (9): 4556-4567.

Bhargawa, A. 2016. Physico-chemical waste water treatment technologies: An overview. *Int. J. Scientific Res. Ed.* 4 (5) : 5308-5319.

Bhatti, S.S., Kumar, V., Singh, N., Sambyal, V., Singh, J., Katnoria, J.K. and Nagpal, A.K. 2016. Physico-chemical Properties and Heavy Metal Contents of Soils and Kharif Crops of Punjab, India. *Procedia Environ. Sci.* 35 : 801-808.

Bheemappa, K., Nandini, N., Vijaykumar, M. and Raghavendra, M. 2015. Temporal variation in water quality parameters of Bandematta Hosakere lake-peri urban area of Bengaluru, Karnataka, India. *Int. J. Adv. Res.* 3(7) : 1283-1291.

Bureau of Indian Standards (BIS) 10500. 2012. Specification for drinking water. *Indian Standards Institution*, New Delhi, pp. 1-5.

Dohare, D., Deshpande, S. and Kotiya, A. 2014. Analysis of ground water quality parameters: A review. *Res. J. Engineering Sci.* 3(5): 26-31.

Dwivedi, A.K. 2017. Researches in water pollution: A review. *Int. Res. J. Nat. Appl. Sci.* 4(1) : 118-142.

Kushwaha, J.P., Srivastava, V.C., Mall, I.D. 2011. An overview of various technologies for the treatment of dairy wastewaters. *Critical reviews in Food Science and Nutrition*. 51 (05) : 442-452.

McCormick, P.G. 1972. The determination of dissolved oxygen by the winkler method: A student laboratory experiment. *J. Chem. Educ.* 49(12):839.

Ministry of Drinking Water and Sanitation, Govt. of India. *Annual report 2014-15. http://www.india.gov.in/ministry-drinking-water-and-sanitation-annual-reports.*

Murhekar, G.H. 2011. Determination of Physico-chemical parameters of surface water sasmples in and around Akot city. *Intern. J. Res. Chem. Enviorn.* 1(2): 183-187.

Ramesh, P., Abraham, K., Suresh, B. and Damodharam, T. 2016. Analysis of Physico-chemical characteristics of industrial effluents in Tirupati, Andhra Pradesh. *J. Res. Enviorn. Earth Sci.* 2(9): 01-06.

Reddy, K.D.H., Lee, S.M. 2012. Water pollution and treatment technologies. *J Environ Anal Toxicol*. 2:e103.

Sarkinnoma, A., Yarkasuwa, C.I. and Modu, K.A. 2013. Analysis of Physicochemical parameters of sewage water used for irrigation in bauchi meteropolis-Nigeria. *J. Environ. Earth Sci.* 3 (10) : 37-41.

Subashini, M.L., Ramesh A., Pradeep. 2017. Waste water characterization of dairy industry. *International Journal of Pure and Applied Mathematics*. 116(13): 465-471.