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Monitoring of Physico-chemical and Microbiological Characteristics of Municipal Wastewater at Treatment Plant, Haridwar City (Uttarakhand) India

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ABSTRACT

The present investigation was conducted to monitor the physico-chemical and microbiological characteristics of Municipal Wastewater (MWW) at treatment plant, Haridwar, installed under Ganga Action Plan (GAP)/National River Action Plan (NRAP) to control the pollution of river Ganga. The results revealed that the untreated MWW has high inorganic and organic pollution load. The treatment plant received the MWW from various Sewage Pumping Stations (SPSs) being treated through different stages viz. primary (physical), secondary (chemical) and tertiary (disinfection) treatments. In the present study, a significant ($p<0.001$) decrease was observed in the physico-chemical and microbiological parameters viz. turbidity, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chlorides (Cl^-), alkalinity, hardness, free carbon dioxide (CO_2), Total Kjeldahl Nitrogen (TKN), phosphate (PO_4^{3-}), sulphate (SO_4^{2-}), iron (Fe^{2+}), Most Probable Number (MPN) and Standard Plate Count (SPC) after treatment. The Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), Zinc (Zn), Cadmium (Cd), Copper (Cu), Nickel (Ni) and Chromium (Cr) were also recorded to be significantly ($p<0.01$) decreased in treated MWW. The maximum removal of turbidity (66.92%), TSS (88.37%), EC (89.43%), pH (14.18%), BOD (91.31%), COD (91.84%), Cl^- (86.76%), alkalinity (90.42%), hardness (39.06%), free CO_2 (79.23%), TKN (71.40%), PO_4^{3-} (90.16%), SO_4^{2-} (85.90%), Fe^{2+} (95.86%), Zn (95.06%), Cd (87.50%), Cu (92.30%), Ni (91.30%), Cr (85.71%) and MPN (99.99%) and SPC (99.99%) of MWW were recorded after final treatment. The maximum increase in DO (135.28%) was recorded in finally treated (outlet) wastewater. Thus the treatment plant had a significant role in the control of pollution loads of wastewater installed under GAP/ NRAP at Haridwar city.

Key words: Municipal wastewater, treatment plant, physico-chemical, characteristics, microbiological characteristics

INTRODUCTION

India is rich in water resources, having a network of as many as 113 rivers and vast alluvial basins to hold plenty of groundwater (CWC, 2000). India is also blessed with snow-capped peaks in the Himalayan range which can meet a variety of water requirements of the country. However, with the rapid increase in the population of the country and the need to meet the increasing demands of irrigation, domestic and industrial consumption, the available water resources in many parts of the country are getting depleted and the water quality has deteriorated. In India, water pollution comes from three main sources: Domestic sewage, industrial effluents and run-off from agriculture (Mielke *et al.*, 1999; Brar *et al.*, 2000).

Urban environmental management is one of the most pressing issues as the urbanization trend continues globally. Among the challenges faced by urban planners is the need to ensure ongoing basic human services such as the provision of water and sanitation. The under-management of municipal wastewater in many southern urban areas presents a major challenge (Mulkerrins *et al.*, 2004; Jamrah *et al.*, 2008a). Management of waste water in metropolitan cities is a difficult task. The unsafe disposal of waste water generates pollution of water as well as terrestrial. It causes various health problems, epidemics due to serving the contaminated water (Som *et al.*, 1994; Yadav *et al.*, 2002). By adding it eutrophicates the water bodies, causing the mortality of aquatic biological resources. Thus, the role of treatment plants is in the sustainable use of wastewater as they make the water usable for various purposes (Dixon *et al.*, 1999; Casanova *et al.*, 2001; Steinmetz *et al.*, 2002; Jamrah *et al.*, 2006, 2008a).

The effective management of any wastewater requires a reasonably accurate knowledge of its characteristics. Detailed characterization data regarding these characteristics are necessary not only to facilitate the effective design of wastewater treatment and disposal systems but also to enable the development and application of water conservation and waste load reduction strategies. However, for many existing developments and for almost any new development, wastewater characteristics must be predicted (Bennett and Daniel, 1975; Al-Jayyousi, 2003).

India supports more than 16% of the world's population with only 4% of the world's fresh water resources (Singh, 2003). In India, total wastewater generated per annum from 200 cities is about 2600 Mm^3 (CWC, 2000) and also the use of sewage effluents for irrigating agricultural lands is on the rise especially in the peri-urban area. These wastewaters carry appreciable amounts of nutrients and trace toxic metals (Feign *et al.*, 1991; Pescod, 1992; Som *et al.*, 1994; Brar *et al.*, 2000; Yadav *et al.*, 2002) and concentrations of trace metals in sewage effluents vary from city to city (Rattan *et al.*, 2002). Although the concentration of heavy metals in sewage effluents are low, long-term use of these waste waters on agricultural lands often results in the build-up of the elevated levels of these metals in soils (Gupta *et al.*, 1998; Rattan *et al.*, 2002). Extent of build-up of metals in waste water-irrigated soils depends on the period of its application (Bansal *et al.*, 1992). Crops raised on the metal-contaminated soils accumulate metals in quantities excessive enough to cause clinical problems both to animals and human beings consuming these metal rich plants (Tiller, 1986).

The accumulation of human waste is constant and unmanaged wastewater directly contributes to the contamination of locally available freshwater supplies. Additionally, the cumulative results of unmanaged wastewater can have broad degenerative effects on both public and ecosystem health. It is estimated that 22,900 Million Liters per Day (MLD) of municipal wastewater is generated from urban centres against 13,500 ML D of industrial wastewater. The river Ganga basin spreads over an area of 8,61,404 Km^2 covering the States of Uttarakhand, Uttar Pardesh, Haryana, Delhi, Madhya Pradesh, Rajasthan, Bihar, Jharkhand and West Bengal. There are 223 cities/towns (Municipalities/ Corporations) generating significant amount of sewage in the Ganga basin. These cities/towns generate about 8,250 MLD (million liter per day) of wastewater, out of which about 2,460 MLD is directly discharged into the river Ganga, about 4,570 MLD is discharged into its tributaries or sub- tributaries and about 1220 MLD is disposed on land or on low- lying areas. Out of 8,250 MLD wastewater generated in the Ganga basin, the treatment facilities available for 3,500 MLD of wastewater. Out of 3,500 MLD treatment capacities, 882 MLD is created under the GAP or NRAP Phase-2. The treatment facilities at 48 additional towns along the Ganga River and 23 towns on its tributaries/sub- tributaries are being created under GAP Phase-2 (CWC, 2000).

Haridwar is a holy city and municipal board in the Haridwar District of Uttarakhand State, India. In Hindi, Haridwar stands for Dwar (Gate) of Hari (God) or Gateway to God and is regarded as one of the seven holiest places to Hindus (Forbes-Lindsay, 1903). Haridwar is one of the first towns where Ganga emerges from the Gangotri glacier in Himalayan Mountains to touch the plains. The water in the river Ganga is mostly clear and generally cold, except in the rainy season, during which soil from the upper regions flows down into it. Being a place of intense religious significance, Haridwar also hosts several religious festivals throughout the year. People of different religions and communities of national as well as foreign gathered here and take parts in celebration of festivals and other religious activates in Haridwar. They generate lots of waste during their stay which is the main cause of pollution of river Ganga at Haridwar city (CWC, 2000). Thus, the present investigation was conducted to monitor the physico-chemical and microbiological characteristics of municipal wastewater before and after treatment at treatment plant installed under GAP/ NRAP at Haridwar city (Uttarakhand) India.

MATERIALS AND METHODS

Municipal wastewater collection and analysis: The Municipal Wastewater (MWW) samples were collected from municipal treatment plant installed under GAP at Haridwar (29°55'10.81" N and 78°07'08.12" E). The total installed capacity of the treatment plant was 18 MLD. The MWW was collected from different residential as well as industrial vicinity of Haridwar city by various Sewage Pumping Stations (SPSs). The MWW samples were collected from inlet, Primary Settling Tank (PST), Secondary Settling Tank (SST) and outlet of the treatment plant installed to reduce the BOD and solids using plastic container. The samples brought to the laboratory was analyzed for various physico-chemical, microbiological and heavy metals viz. turbidity, total suspended solids (TSS), pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chlorides (Cl^-), alkalinity, hardness, free CO_2 total Kjeldahl Nitrogen (TKN), Phosphate (PO_4^{3-}) and sulphate (SO_4^{2-}) and iron (Fe), Zinc (Zn), Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), Standard Plate Count (SPC) and Most Probable Number (MPN) following standard methods (APHA, 1999).

Heavy metals analysis: For heavy metal analysis, 5-10 mL sample of MWW was taken in digestion tube and add 3 mL conc. HNO_3 digest on electrically heated block for 1 h at 145°C. Then add 4 mL of $HClO_4$ and heated to 240°C for an additional hour. Cool and filter through Whatman No. 42 filter paper and makeup volume 50 mL and used for analysis following standard methods (APHA, 1999).

Efficiency of the effluent treatment plants: Wastewater treatment plants usually include a series of physical, chemical and biological processes. The overall objectives of a wastewater treatment plant are to separate the wastes from the water for disposal elsewhere and to produce an effluent which can be discharged to a receiving water body without causing pollution.

The inlet and outlet streams of all the four industrial units were compared to have an idea about the efficiency of their effluent treatment plants (ETPs). The percentage removal efficiency was calculated following the standard method (Hurst, 1997):

$$\text{Removal Efficiecy (\%)} = \frac{\text{Ci - Ce}}{\text{Ci}} \times 100$$

Where:

Ci = Concentration of waste material in influent

Ce = Concentration of waste material in effluent

Statistical analysis: Data were analyzed for one way Analysis of Variance (ANOVA) for determining the difference between MWW sample characteristics before and after treatment collected from inlet, PST, SST and Outlet of the treatment plant. The mean and standard deviation were also calculated with the help of MS Excel, SPSS12.0 and Sigma plot, 2000.

RESULTS AND DISCUSSION

Municipal wastewater characteristic: The Mean±SD values of physico-chemical and microbiological parameters viz. turbidity, TSS, EC, pH, DO, BOD, COD, Cl^-, alkalinity, hardness, free CO_2, TKN, PO_4^{3-}, SO_4^{2-}, Fe^{2+}, Zn, Cd, Cu, Ni, Cr and MPN and SPC of MWW are presented in Table 1.

In the recent studies, Sirianuntapiboon *et al.* (2006) reported BOD (118.00 mg L^{-1}), COD (173.00 mg L^{-1}) and pH (7.1±0.3), TKN (38.40 mg L^{-1}) and TP (12.00 mg L^{-1}) in municipal wastewater in Bangkok, Thailand. The 92.00% removal of BOD, 91.00% COD, 90.00% TKN and 95.00% phosphorus were observed by using constructed wetlands for domestic water.

Turbidity and TSS: All natural waters contain some dissolved solids due to the dissolution and weathering of rock and soil. Suspended solids are determined by filtering a known volume of water and weighing the residue. Some but not the entire suspended solids act as conductors and contribute to turbidity. Waters with high TSS are unpalatable and potentially unhealthy.

In the present study, the turbidity and TSS of the treated MWW (outlet) was decreased 6.90±4.29 NTU, 212.00±9.16 mg L^{-1} from its 20.86±6.82 NTU, 1824.42±8.46 mg L^{-1} initial (Inlet) level. It was found with 17.94±6.35 NTU, 1216.42±4.13 mg L^{-1} in PST and 13.66±4.43 NTU, 696.46±5.18 mg L^{-1} in SST. It was found to be significantly ($p<0.001$) different from inlet, PST and SST.

Jamrah *et al.* (2008b) reported 84 and 100% removal efficiency of TSS in a settling tank installed in a treatment plant. Removal levels of TSS were found to be associated with the anoxic good settling characteristics of sludge were obtained throughout the treatment and the problem of sludge bulking or foaming was absent. Katayon *et al.* (2008) also reported 50-88% removal of TSS in domestic wastewater using subsurface constructed wetlands in Malaysia.

EC and pH: Conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions. Conductivity itself is not a human or aquatic health concern but because it is easily measured, it can serve as an indicator of other water quality problems. If the conductivity of a stream suddenly increases, it

Table 1: Physico-chemical and microbiological characteristics of municipal sewage water before and after treatment at treatment plant, Haridwar city

		Treatment stages				
Parameter	Inlet	PST	SST	Outlet.	CD	F-calculated
Turbidity (NTU)	20.86±6.82	17.94 ± 6.35^{abc} (-13.99%)	$13.66^{abc} \pm 4.43$ (-34.51%)	$6.90^{abc} \pm 4.29$ (-66.92%)	4.00^{***}	4.43
TSS (mg L^{-1})	1824.42±8.46	$1216.42^{abc} \pm 4.13$ (-33.32%)	$696.46^{abc} \pm 5.18$ (-61.82%)	$212.00^{abc} \pm 9.16$ (-88.37%)	36.49^{***}	0.18
EC (dS m^{-1})	2.84±0.21	$1.52^{abc} \pm 0.52$ (-46.47%)	$1.08^{abc} \pm 0.44$ (-61.97%)	$0.30^{abc} \pm 0.19$ (-89.43%)	2.19^{**}	0.3
pH	8.39±0.19	$7.91^{abc} \pm 0.20$ (-5.72%)	$7.74^{abc} \pm 0.23$ (-7.74%)	$7.20^{abc} \pm 0.20$ (-14.18%)	319.35^{**}	0.55
DO (mg L^{-1})	2.42±1.14	$4.54^{abc} \pm 1.18$ (+87.60%)	$5.36^{abc} \pm 1.15$ (+121.48%)	$6.42^{abc} \pm 1.12$ (+165.28%)	274.52^{**}	5.75
BOD (mg L^{-1})	620.27±6.82	$317.98^{abc} \pm 6.35$ (-48.73%)	$133.26^{abc} \pm 7.43$ (-78.51%)	$53.90^{a} \pm 4.29$ (-91.31%)	6.00^{***}	6.46
COD (mg L^{-1})	1420.54±8.16	$927.50^{abc} \pm 5.88$ (-34.70%)	$480.25^{abc} \pm 4.65$ (-66.19%)	$115.88^{a} \pm 5.48$ (-91.84%)	154.51^{***}	6.62
Cl^- (mg L^{-1})	346.58±2.68	$225.82^{abc} \pm 5.66$ (-34.84%)	$105.99^{abc} \pm 4.76$ (-69.41%)	$45.88^{abc} \pm 2.68$ (-86.76%)	710.98^{***}	5.85
Hardness (mg L^{-1})	382.26±7.23	$327.23^{abc} \pm 5.74$ (-14.39%)	$279.44^{abc} \pm 4.33$ (-26.89%)	$232.94^{abc} \pm 3.84$ (-39.06%)	40.97^{***}	3.39
Free CO_2 (mg L^{-1})	122.99±2.90	$81.29^{abc} \pm 3.82$ (-33.90%)	$63.06^{abc} \pm 2.84$ (-48.72%)	$25.54^{abc} \pm 2.28$ (-79.23%)	1344.16^{***} 7.95	
Alkalinity (mg L^{-1})	254.33±8.85	$141.54^{abc} \pm 4.60$ (-44.34%)	$71.96^{abc} \pm 4.81$ (-71.70%)	$24.34^{a} \pm 3.39$ (-90.42%)	151.39^{***}	6.22
TKN (mg L^{-1})	84.99±10.92	$62.85^{abc} \pm 7.61$ (-26.05%)	$41.27^{abc} \pm 2.98$ (-51.44%)	$24.30^{abc} \pm 6.06$ (-71.40%)	26.36^{***}	6.86
PO_4^{3-} (mg L^{-1})	124.42±5.52	$82.94^{abc} \pm 3.38$ (-33.33%)	$39.48^{abc} \pm 3.65$ (-68.26%)	$12.24^{abc} \pm 1.22$ (-90.16%)	42.22^{***}	8.96
SO_4^{2-} (mg L^{-1})	336.49±6.09	$196.91^{abc} \pm 7.97$ (-41.48%)	$89.97^{abc} \pm 5.88$ (-73.26%)	$47.42^{abc} \pm 3.12$ (-85.90%)	30.00^{***}	7.01
Fe^{2+} (mg L^{-1})	7.74±0.74	$3.79^{abc} \pm 0.30$ (-51.03%)	$1.68^{abc} \pm 0.18$ (-78.29%)	$0.32^{abc} \pm 0.02$ (-95.86%)	30.59^{***}	0.62
Zn (mg L^{-1})	3.24±0.44	$1.56^{abc} \pm 0.17$ (-51.85%)	$0.64^{abc} \pm 0.06$ (-80.24%)	$0.16^{abc} \pm 0.03$ (-95.06%)	233.43^{**}	0.14
Cd (mg L^{-1})	0.64±0.06	$0.40^{abc} \pm 0.12$ (-37.50%)	$0.21^{abc} \pm 0.03$ (-67.18%)	$0.08^{abc} \pm 0.00$ (-87.50%)	134.53^{**}	0.02
Cu (mg L^{-1})	0.78±0.08	$0.39^{abc} \pm 0.03$ (-30.42%)	$0.24^{abc} \pm 0.08$ (-69.23%)	$0.06^{abc} \pm 0.02$ (-92.30%)	104.14^{**}	0.49
Ni (mg L^{-1})	0.46±0.04	$0.24^{abc} \pm 0.11$ (-47.82%)	$0.19^{abc} \pm 0.01$ (-58.69%)	$0.04^{abc} \pm 0.02$ (-91.30%)	52.7^{**}	0.26
Cr (mg L^{-1})	0.21±0.02	$0.12^{abc} \pm 0.01$ (-42.85%)	$0.08^{abc} \pm 0.01$ (-61.90%)	$0.03^{abc} \pm 0.01$ (-85.71%)	199.97^{**}	0.06
MPN (MPN100 mL^{-1})	$28.36 \times 10^{8} \pm 86$	$16.75 \times 10^{6abc} \pm 66$ (-40.93%)	$12.86 \times 10^{4abc} \pm 64$ (-99.54%)	$8.56 \times 10^{2abc} \pm 89$ (-99.99%)	211.98^{***}	12.23
SPC (SPC mL^{-1})	$17.42 \times 10^{6} \pm 45$	$15.26 \times 10^{4abc} \pm 56$ (-99.12%)	$13.84 \times 10^{2abc} \pm 72$ (-99.99%)	$363^{abc} \pm 16$ (-99.99%)	225.23^{***}	16.58

Mean±SD of three values; Significant F -***p-0.01%, **p-0.1% level;% decrease in comparison to inlet given in parenthesis; a, b, c: Significantly different to the inlet, PST and SST values indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. The pH is a measure of the amount of free hydrogen ions in water. Specifically, pH is the negative logarithm of the molar concentration of hydrogen ions. A pH of 7 is considered to be neutral. Acidity increases as pH values decrease and alkalinity increases as pH values increase. Most natural waters are buffered by a carbon-dioxide-bicarbonate system, since the carbon dioxide in the atmosphere serves as a source of carbonic acid. The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. As acidity increases, most metals become more water soluble and more toxic. The toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity).

In the present study, the EC and pH of the treated MWW (outlet) was decreased 0.30±0.19, 7.20±0.20 from their 2.84±0.21, 8.39±0.19 initial (Inlet) level. It was found 1.52±0.52, 7.91±0.20 with PST and 1.08±0.44, 7.74±0.23 with SST. The change in EC and pH (outlet) were found to be significantly ($P<0.01$) different from inlet, PST and SST.

Dissolved oxygen BOD and COD: Dissolved Oxygen (DO) is the most important pollution assessment parameter of the receiving water bodies. Stabilization of organic matter, when discharged untreated or partially treated in receiving waters, leads to depletion of their DO. Nutrients (nitrogen and phosphorus) addition due to discharge of untreated or treated sewage may lead to algal growth in streams as a result depletion of DO in waters. Thus, it is observed that all the polluting constituents of sewage have their direct or indirect effect on DO of receiving waters. The impact of an effluent or wastewater discharge on the receiving water is predicted by its oxygen demand. This is because the removal of oxygen from the natural water reduces its ability to sustain aquatic life.

Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. The main focus of wastewater treatment plants is to reduce the BOD in the effluent discharged to natural waters. Wastewater treatment plants are designed to function as bacteria farms, where bacteria are fed oxygen and organic waste. The excess bacteria grown in the system are removed as sludge. If effluent with high BOD levels is discharged into a stream or river, it will accelerate bacterial growth in the river and consume the oxygen levels in the river. The oxygen may diminish to levels that are lethal for most fishes and many aquatic insects.

Chemical Oxygen Demand (COD) is a vital test for assessing the quality of effluents and wastewaters prior to discharge. The COD test predicts the oxygen requirement of the effluent and is used for monitoring and control of discharges and for assessing treatment plant performance. Thus, COD is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water.

In the present study, DO was increased 6.42±1.12 mg L^{-1} from it initial level 2.42±1.14 mg L^{-1} followed by 4.54±1.18 mg L^{-1} with PST and 5.36±1.15 mg L^{-1} with SST. The BOD and COD of the untreated MWW were recorded 620.27±6.82 mg L^{-1} and 1420.54±8.16 mg L^{-1}. The BOD and COD were decreased 53.90±4.29 mg L^{-1}, 115.88±5.48 mg L^{-1} in finally treated MWW followed by 317.98±6.35, 133.26±7.43 mg L^{-1} in PST and 927.50±5.88, 480.25±4.65 mg L^{-1} in SST of the treatment plant, respectively. The dissolved oxygen was increased significantly ($p<0.01$) in finally treated (outlet) MWW in comparison to inlet, PST and SST. The BOD and COD were decreased significantly ($p<0.001$) in treated MWW in inlet, PST and SST.

Jamrah *et al.* (2008b) reported that the optimum grey water treatment conditions for the removal of COD can be achieved when the fill and react time is 5 h. The highest COD removal efficiencies are obtained when the duration of the fill phase is 2 h and the duration of the react phase is 3 h. Overall, the COD removal efficiency ranged between 66 and 94% in a settling tank installed in a treatment plant. Tiku *et al.* (2007) reported that the ETP (effluent treatment plant) significantly decreased the different parameters like pH, color, COD, BOD, percent Na, SAR, TDS and total hardness in paper mill effluent. Grover *et al.* (1999) reported the maximum COD reduction of about 60% with anaerobic baffled reactor. Ali and Sreekrishnan (2001) reported reduction of COD of black liquor and bleach plant effluent from an agro residue based pulp and paper mill by anaerobic treatment. Katayon *et al.* (2008) reported 56-77% removal of COD in domestic wastewater using subsurface constructed wetlands in Malaysia.

Chlorides and free carbon dioxide: The chlorides and free carbon dioxide in MWW of inlet were recorded 346.58±2.68 and 122.99±2.90 mg L^{-1}. After treatment the values of chlorides and free carbon dioxide were found 45.88±2.68 and 25.54±2.28 mg L^{-1} in outlet followed by 225.82±5.66, 81.29±3.82 mg L^{-1} in PST and 105.99±4.76, 63.06±2.84 mg L^{-1} in SST. The chlorides and free carbon dioxide were decreased to be significantly ($p<0.001$) in finally treated (outlet) MWW in comparison to inlet, PST and SST. Sundaravadivel and Vigneswaran (2001) also reported significant removal in chlorides and free carbon dioxide in municipal wastewater treated by constructed wetlands.

Alkalinity and hardness: Alkalinity is the capacity to neutralize acids and the alkalinity of natural water is resulting mainly from the salts of weak acids. The carbonates, bicarbonates and hydroxide are the dominant source of natural alkalinity. Reactions of carbon dioxide with calcium or magnesium carbonate create considerable amounts of bicarbonates. Organic acids such as humic acid also form salts that increase alkalinity. Alkaline waters are unpalatable and can cause gastrointestinal discomfort.

The alkalinity and hardness of MWW were decreased 24.34±3.39 and 232.94±3.84 mg L^{-1} from their initial level 254.33±8.85 and 382.26±7.23 mg L^{-1}. In PST the value of alkalinity and hardness were found 141.54±4.60 and 327.23±5.74 mg L^{-1} and in SST these were 71.96±4.81 and 279.44±4.33 mg L^{-1}. The reduction in alkalinity and hardness were found to be significantly ($p<0.001$) different in outlet samples of MWW in comparison to inlet, PST, SST. A significant removal in alkalinity and hardness of wastewater was reported by Steer *et al.* (2002).

Total kjeldhal nitrogen, phosphate and sulphate: Nutrients such as phosphorous and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these photosynthesizers which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, can overstimulate aquatic plant and algae growth.

The total nitrogen, phosphate and sulphate were recorded in untreated MWW 84.99±10.92, 124.42±5.52 and 336.49±6.09 mg L^{-1}. After final treatment they were decreased 24.30±6.06 12.24±1.22 and 47.42±3.12 mg L^{-1} followed by 62.85±7.61, 82.94±3.38, 196.91±7.97 mg L^{-1} in PST and 41.27±2.98, 39.48±3.65, 89.97±5.88 mg L^{-1} in SST, respectively. The total nitrogen, phosphate and sulphate were decreased to be significantly ($p<0.001$) in finally treated (outlet) MWW in comparison to inlet, PST, SST. Katayon *et al.* (2008) reported 20-88% removal of TP and 27-96% of NH_4^+ in domestic wastewater in domestic wastewater using subsurface constructed wetlands in

Malaysia. It was due to that hydraulic retention times caused significant effect on removal rate of COD, TP and NH_4^+ but not to TSS and total coliforms removal. The total number of coliforms was positively correlated with concentration of COD, TP and NH_4^+ in effluents. Planted wetland cells were superior in both NH_4^+ and total phosphorus removal to unplanted wetland cells.

Heavy metals: The heavy metals are at very low concentrations in the natural environment and they are typically introduced to surface waters as waste from human activities. Some of the metals of concern for human and aquatic health are cadmium, lead, copper, mercury, selenium and chromium etc.

The content of Fe, Zn, Cd, Cu, Ni and Cr were recorded 7.74±0.74, 3.24±0.44, 0.64±0.06, 0.78±0.08, 0.46±0.04 and 0.21±0.02 mg L^{-1} in inlet wastewater. After final treatment these were decreased 0.32±0.02, 0.16±0.03, 0.08±0.00, 0.06±0.02, 0.04±0.02 and 0.03±0.01 mg L^{-1} in outlet effluent followed by 3.79±0.30, 1.56±0.17, 0.40±0.12, 0.39±0.03, 0.24±0.11, 0.12±0.01 mg L^{-1} in PST and 1.68±0.18, 0.64±0.06, 0.21±0.03, 0.24±0.08, 0.19±0.01, 0.08±0.01 mg L^{-1} in SST, respectively. The content of various heavy metals viz. Zn, Cd, Cu, Ni and Cr were decreased to be significantly ($p<0.01$) in finally treated (outlet) MWW in comparison to inlet, PST, SST. The content of Fe was also recorded to be significantly ($p<0.001$) different in finally treated (outlet) MWW in comparison to inlet, PST, SST. Vargova *et al.* (2005) reported the content of various heavy metals viz. Cd (0.29), Pb (0.66), Cu (1.22) and Zn (7.15) in untreated wastewater. The removal in the content of Cd (97.3%), Pb (80.30%), Cu (94.5%) and Zn (96.2%) were recorded after the biological treatment.

MPN and SPC: Bacterial parameters, such as Fecal Coliform (FC) which serve as indicators of fecal pollution are also very important when human health is the prime concern. The specific identification of pathogenic bacteria is extremely difficult; the coliform group of organisms is used as an indicator of the presence in wastewater of pathogenic organisms. Coliform bacteria are found in intestinal tract of human beings. Coliform group of bacteria include genera Escherichia and Aerobacter.

The MPN and SPC in untreated wastewater were found 28.36×10^8±86 MPN100 mL^{-1} and 17.42×10^6±45 SPC mL^{-1}. They were decreased in outlet 8.56×10^2±89 MPN100 mL^{-1}; 363±16 SPC mL^{-1} followed by 16.75×10^6±66 MPN100 mL^{-1}, 15.26×10^4±56 SPC mL^{-1} in PST and 12.86×10^4±64 MPN100 mL^{-1}, 13.84×10^2±72 SPC mL^{-1} in SST, respectively. The MPN and SPC were decreased significantly ($p<0.001$) in outlet in comparison to inlet, PST, SST wastewater. The 99% removal of total coliforms numbers in domestic wastewater using subsurface constructed wetlands in Malaysia was reported by Katayon *et al.* (2008). The findings were supported by Mashauri *et al.* (2000), Neralla *et al.* (2000) and Steer *et al.* (2002).

CONCLUSION

The present study, was concluded that the treatment plant installed under Ganga Action Plan (GAP)/National River Action Plan (NRAP) is working extensively. The significant ($p<0.001$) reduction was observed in the physico-chemical and microbiological characteristics viz. turbidity, TSS, EC, pH, BOD, COD, Cl^-, alkalinity, hardness, free CO_2, TKN, PO_4^{3-}, SO_4^{2-}, Fe^{2+}, Zn, Cd, Cu, Ni, Cr and MPN and SPC of treated MWW. The various steps (PST, SST) of the treatment, significantly ($p<0.001$) increased the dissolved oxygen in finally treated MWW in comparison to untreated MWW. The maximum removal of turbidity (66.92), TSS (88.37%), EC (89.43%), pH

(14.18%), BOD (91.31%), COD (91.84%), Cl^- (86.76%), alkalinity (90.42%), hardness (39.06%), free CO_2 (79.23%), TKN (71.40%), PO_4^{3-} (90.16%), SO_4^{2-} (85.90%), Fe $^{2+}$(95.86%), Zn (95.06%), Cd (87.50%), Cu (92.30%), Ni (91.30%), Cr (85.71%) and MPN (99.99%) and SPC (99.99%) of MWW were recorded after final treatment. Thus it is helpful in the control of the pollution of river Ganga and there is also need for another treatment plant due to generation of more MWW in Haridwar city as it has tourist as well as religious importance.

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