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Full Length Research Paper

Water Quality Management Plan for Patalganga River for Drinking Purpose and Human Health Safety

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Abstract. Deteriorating water quality of rivers is of major concern in India; this is especially true for rivers being used as drinking water sources. One such river considered in this study is the Patalganga, which is located about 60 km from Mumbai and is a significant source of water supply for Panvel, Alibaug and Rasayani. This paper aims to determine the polluting sources responsible for the poor water quality of the Patalganga River and to suggest a scientifically sound water quality management plan to improve the same. A total of 14 water samples from different point sources of pollution were collected and tested for physico-chemical parameters (pH, temperature, DO, BOD, COD, TSS, TDS, EC, PO_4^{3-}, NO_3-N and NH_3-N), metals (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) and microbiological parameter using World Health Organization (WHO) and the Bureau of Indian Standards (BIS) standards. Based on, the water quality at most of the sampling stations was found to be unsuitable for drinking. Hierarchical cluster analysis (HCA) classified the 14 sampling stations into three clusters. The HCA identified a uniform source of parameters (physico-chemical and nutrients) for all the sampling stations, excluding two sampling stations (7 and 12) that exhibited anomalous concentrations. Furthermore, as per the WQI, the water quality status of Patalganga River fell under good category, except at the sampling station 7 and 12 where the water quality index were bad (49) and medium (51) category, respectively, and were totally unfit for drinking purpose. Water quality management plan specific to the individual sites has been delineated in the paper.

Keywords: Classification, Cluster, Metals, Nutrients, Patalganga River, Water quality, Water quality index

1. INTRODUCTION

Universally, requirement for freshwater will continue to rise significantly over the coming decades to meet the needs of increasing populations, growing economies, changing lifestyles and evolving consumption patterns. This will greatly amplify the pressure on limited natural resources and ecosystems. Unsafe water and sanitation account for almost one tenth of the global burden of disease (Fewtrell et al., 2007). Total 768 million and 2.5 billion people in the world are living without access to clean water and proper sanitation, respectively (WHO, 2002; WHO and UNICEF, 2013a). According to the World Commission on water for the 21st century, more than half of the world's major rivers are depleted and contaminated to the extent that they threaten human health and poison the surrounding ecosystems (Interpress, 1999). Contaminated drinking water can cause various diseases such as typhoid fever, dysentery, cholera and other intestinal diseases (Udoh, 1987; Adeyemi, 2004; Dixit and Shanker, 2009).

In developing countries, about 1.8 million people, mostly children, die every year as a result of water related diseases (Payen, 2011; Onda et al., 2012; Wolf et al., 2013; WHO, 2006; WHO, 2011; WHO/UNICEF, 2013a). Anthropogenic activities have resulted in a significant decrease in surface water quality of aquatic systems in watersheds (Anhar et al., 1998; Mohd Kamil et al., 1997a; 1997b; May et al., 2006). In India, rivers are an important source of water, as many Indian cities are situated on the banks of the rivers. Untreated discharge of pollutants into a river from domestic sewers, storm water discharges, industrial wastewaters, agricultural runoff and other sources can have short-term as well as long-term effects on the water quality of a river system (Singh, 2007; Varghese et al., 2011; Rai et al., 2012; Giri and Singh, 2014). Total 80% of the water in India has become polluted due to the discharge of untreated domestic sewage and partially-treated industrial effluents into the natural water source (Ensink et al., 2009; CPCB 2007a). High levels of pollutant input in river water systems cause an increase in biological oxygen demand (BOD), chemical oxygen demand

(COD), total dissolved solids (TDS), total suspended solids (TSS), metals such as Cd, Cr, Ni and Pb, and fecal coliforms (Mohd Kamil,1991; Sangodoyin, 1991; Chatterjee et al., 2000; Adekunle and Eniola, 2008).

The correlation coefficients (r) between the water quality parameters were calculated in order to indicate the nature and the sources of the polluting substances (Bajpayee et al., 2012). Hierarchical cluster analysis (HCA) was used to reduce the number of variables into a small number of indices while preserving the relationship present in the original data. The application of HCA helps identify the vital components or factors which account for most of the variances of a system (Ouyang et al., 2006; Shrestha and Kazama, 2007). Various techniques have been used for quality assessment of surface waters, amongst which use of water quality indices is one of most acceptable methods (Nikoo et al., 2011). A water quality index based on some very important parameters can provide a single indicator of water quality. The general WQI was developed by Brown et al., (1970) and improved by Deininger for the Scottish Development Department (1975). It is one of the most effective ways to communicate water quality (Ott, 1978; Pesce and Wunderlin, 2000; Prakirake et al., 2009; Taner et al., 2011).

The Patalganga River is located between the Western Ghats and the Arabian Sea. It is an important source of drinking water and industrial raw water for the nearby villages and industries, respectively. The sewage from the towns and villages along the river is directly disposed into the river without any treatment. Mainly textile, pharmaceuticals and dye intermediate manufacturing industries are located in the catchment of the Patalganga River. It is, therefore, of vital importance to monitor the water quality parameters of the Patalganga River to ascertain whether the water quality is still suitable for various purposes. So, far no systematic study has been undertaken to assess the water quality of Patalganga River. The increased anthropogenic activities in the catchment area will normally influence water quality downstream and this will impact on water treatment steps required to ensure safe water. Therefore, this study envisaged (i) to quantitative determination of some of the physico-chemical parameters, microbial status and metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn) content of the Patalganga River water along its 17 km stretch and to compare the values with the drinking water standards recommended by the World Health Organization (WHO) and the national agency, Bureau of Indian Standards (BIS) (ii) to evaluation of river water quality using correlation coefficient (r) and water quality index (WQI) (iii) to apply a hierarchical cluster analysis for better interpretation of river water quality data (iv) to provide a water quality management plan for Patalganga River for drinking purpose to minimize the health risks.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling

The Patalganga valley is surrounded by the Karnala ridge, the Matheran ridge and the Sahyadri ranges. The Patalganga River originates from the hilly range of Sahyadri and formed by the tailrace water released from the Tata Hydro Power Station near Khopoli; it then flows to the west through Khopoli city, Khalapur region, and ultimately joins the Arabian Sea at the Dharamtar creek. It is located across 18°48'0" N and 73°4'0" E and at an elevation of 7 m above sea level. The catchment area of Patalganga River is 338 km^2. The river serves as the southern boundary of the Mumbai Metropolitan Region and is also the boundary between Panvel and Khalapur regions. The stretch from Khopoli (from Tata Hydropower) up to the Chawane weir is the fresh water zone, whereas in the stretch beyond the Chawane weir, tidal influence is observed. Many industries have been established in the vicinity of the said river. The sampling stations of the study area have been described in Table 1 and depicted in Figure 1. The river water samples were collected in pre-cleaned, acid washed jerry cans from the river Patalganga at fourteen sampling stations located at the river and inlets (sampling stations 5, 7 and 12) during the winter season of 2013 and was later stored in a refrigerator below 4 °C until used. For orthophosphate determination, the samples were collected in glass bottles in order to avoid adsorption on the walls of polyethylene containers. The glass bottles were previously soaked in diluted HNO_3 and then rinsed with deionized water. The mean value of each sampling station was considered for river water quality assessment.

2.2. Analytical Methods

On site measurement and laboratory analyses were carried out as per standard methods. On site measurement included fixation of dissolved oxygen (DO), electrical conductivity (EC) and temperature. Dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), total solid (TS), ammoniacal - nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), orthophosphate (PO_4^{3-}), oil and grease and *E. Coli* were analyzed as per APHA Standard Methods (APHA, AWWA, WEF, 1995). For metal analysis the samples were preserved with the addition of 2 ml/l HNO_3 to avoid precipitation of the metals. For the analysis of metals samples were digested with 5 ml of di-acid mixture (10 ml HNO_3 + 5 ml $HClO_4$) on a hot plate and filtered by Whatman No. 42 filter paper and made up the volume to 50 ml by double distilled water for analysis of metals using Inductively Coupled Plasma Optical Emission Spectrophotometer (Optima 4100 DV ICP-OES) (APHA, 1995).

Table 1: Description of the Sampling Stations

Sampling stations	Description
1.	Gagangiri (upstream): Origin of Patalganga River, background river water quality. This water comes from Tata Hydro power station with no apparent human habitation in the stretch from the Tata Hydro power station and Gagangiri Ashram.
2.	Gagangiri (downstream): Washing and bathing activities at the Ashram were observed. The Ashram is equipped with 37 toilets catering to the needs of 5000 regular visitors. During the peak period the number of visitors increases to 100,000. The untreated sewage directly flows into the Patalganga River.
3.	Chemical manufacturing industry upstream.
4.	Chemical manufacturing industry downstream.
5.	Burning Ghat : River water near the cremation ground mixes with the untreated municipal waste water from west Khopoli. Khopoli does not have an operational sewage treatment plant. The mean flow rate 70~75 mld.
6.	Hanuman Temple (backside water) : The river water was oily as seen from the steps side, further on in its vicinity sewage water from the public toilets mixes with the river water and flows below the bridge between the Hanuman temple and the Masjid.
7.	Drain : After the Hanuman Temple. Domestic and public toilet wastewater is discharged untreated directly into the river. The mean flow rate 30~35 mld.
8.	Near Masjid : Beyond the drain.
9.	Esamba Phata : The river receives water from industries on either side.
10.	Savroli Phata: Impact of washing, bathing and tankers washing activities.
11.	Kharsundi Bandhara : Reservoir
12.	Kharsundi industrial area: The wastewater comes from various industries. The mean flow rate 40~45 mld.
13.	Vayal (Raw water): The Vayal weir is made for arresting the river water. Intake point for drinking water supply to Navi Mumbai and JNPT. The river water is taken in through a small channel into the pumping station via the screens, pumping 120 MLD of raw river water to the Bhokarpada water treatment pant.
14.	Vayal (treated water): Used for drinking purpose.

2.3. Statistical Analysis

Pearson Correlation Coefficient was used to determine the relationships between observed water quality characteristics. A Microsoft Excel add-in module XLSTAT 4.3 was used to carry out the hierarchical cluster analysis (HCA). The calculation of WQI was made as per National Sanitation Foundation.

3. RESULTS AND DISCUSSIONS

3.1. Physico-chemical Parameters

Degradation of water quality negatively affects the accessibility of water for humans and increasing financial costs for human beings, and diminishing species diversity and abundance of resident communities. These changes in environmental quality can be associated with changes in water quality parameters (UN GEMS/Water Programme, 2006). Therefore, assessment of the water samples for pollution has been made by comparing assessed values of all the physico-chemical parameters with the corresponding standards prescribed for drinking water by various organizations such as World Health Organization (WHO) and the Bureau of Indian Standards (BIS), as detailed in Table 2. Water temperature is one of the most important physical characteristics of aquatic systems. As water temperature rises, the rate of photosynthesis increases, thereby providing adequate amounts of nutrients (FOEN 2011). The water temperature values were found to be within the permissible limit of the WHO.

pH is important to quantify the health of a river since the water is used by the public for drinking purpose (Sharma and Kansal, 2011). The river water exhibited a near neutral pH (7.0 to 7.5) and was well within the acceptable range given by WHO and BIS for drinking water. The conductivity apparently increased at sampling stations 7 (1683 µS/cm) and 12 (1082 µS/cm) due to domestic and industrial wastewaters inflow, respectively. However, this, too, was well within the acceptable range given by BIS and WHO for drinking water. The TDS content of water samples collected at the selected stations ranged between 22-1128 mg/L, which is well below the limit value of 500 mg/L (WHO 1984) acceptable for potable use, except at stations 7 (1128 mg/L) and 12 (725 mg/L). In the absence of a suitable potable water source, the permissible limits for TDS as per WHO and BIS are 2000 mg/L and 2100 mg/L, respectively. The steady increase in TDS and conductance indicates that water is contaminated due to discharge of domestic and industrial wastewaters.

Dissolved Oxygen (DO) measures the amount of gaseous oxygen dissolved in an aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration and photosynthesis. As a DO levels drop below 5.0 mg/L, aquatic life is put under stress (Liu et al., 2009; Li and Bishop, 2004). DO was much above the desired value (5 mg/L) as per WHO and BIS guidelines for drinking water quality at all the sampling stations due to significant turbulence in the river waters. The highest and lowest DO values were found from the sample stations 1 and 12, respectively. The Biological oxygen demand (BOD) is a measure of organic carbon loading in the water system that exerts a high level of biological oxygen demand to the system (Sullivan et al., 2010). Generally, unpolluted waters typically have BOD values of 2 mg/L or less, and those receiving wastewaters may have values up to 10 mg/L or more, while COD in unpolluted surface waters range from 20 mg/L or less to greater than 200 mg/L in waters receiving effluents (Agbaire et al., 2009; Garg et al., 2010; Utang and Akpan, 2012). If effluents with high BOD levels are discharged into a river, it will accelerate bacterial growth and consume the dissolved oxygen in the river (Kulshrestha and Sharma, 2006; Kumar and Chopra, 2012). Total eleven sampling stations showed high BOD concentrations above the permissible limit for drinking water (WHO 1998) with the peaks at sampling stations 7 (65 mg/L) and 12 (50 mg/L). These are the areas where direct anthropogenic influence and the discharge of untreated municipal wastewater have been noticed. Unusually low DO and high BOD values were observed at sampling stations 7 and 12. The COD concentrations were found to be more than WHO permissible limit (10 mg/L) at all the sampling stations with peaks being observed at sampling stations 7 (122 mg/L) and 12 (76 mg/L) (Figure 2). Direct discharge of untreated domestic and industrial wastewater into the river was responsible for the high organic pollution, and led to very high BOD and COD values in the downstream sampling stations.

The NO_3-N concentration in surface water is generally low, but can reach high levels from agricultural runoff, or from contamination by human or animal wastes (WHO 1998). NO_3-N concentrations were within the permissible limits at all the sampling stations. However, NH_4-N values were astronomical when compared with the WHO standard at all the sampling stations, except at sampling station 1 (0.08 mg/L). Generally, the high concentration of NH_4-N causes a problem with taste and odour of water apart from toxicity to aquatic lives. Unusually high NH_4-N concentration was reported at sampling station 7 (5.41 mg/L) due to domestic and public toilet wastewater is discharged untreated directly into the river water. The high NH_4-N concentration at sampling station 14 (drinking water) reflects deterioration of water quality, which requires additional wastewater treatment technology (Metcalf and Eddy 2003). Moreover, drinking water containing more than 0.2 mg/L of ammonia drastically decreases the disinfection efficiency. Symptoms of NH_4-N poisoning are restlessness, dullness, weakness, muscle tremors profuse salivation, vocalization, lung edema, tonic-clonic convulsion, and finally death by heart failure (Markesbery et al., 1984; Camargo and Alonso, 2006; Majumder et al., 2006; Ojosipe, 2007). The high NO_3-N with low amount of NH_4-N enhanced the self-purification activities of surface water, by increasing the rate of nitrification-denitrification transformation process in river water (Li and Bishop, 2004). The PO_4^{3-} values reported were well within the tolerable limits. PO_4^{3-} is rarely found in high concentrations in waters as it is actively taken up by macrophytes and algae. However, high concentrations of PO_4^{3-} can show the presence of contamination and are largely responsible for eutrophic conditions (WHO, 1998).

Oil and grease in the aquatic environment may be damaging in a variety of ways. Even at low concentrations, oil and grease may be toxic to aquatic life, reduce dissolved oxygen, and alter the usability and aesthetics of a water body (Khan et al., 2006). Additionally, oil and grease may interfere with aerobic and anaerobic biological processes and lead to decreased wastewater treatment efficiency. Recent monitoring indicates that oil and grease concentrations ranged from nil to 19.6 mg/L. Especially, sampling stations 6 (19.6 mg/L) showed high oil and grease concentrations compared with BIS standard due to inflow of temple wastewaters.

E. coli is the traditional bio-indicator of sewage pollution in aquatic ecosystems and determination revels vital information regarding water quality (Wright et al., 2004; Ram et al., 2008). Samples from sample stations 2 to 13 showed presence of *E. coli*. Hence, the data show that the river water is completely unfit for drinking purposes unless given proper treatment.

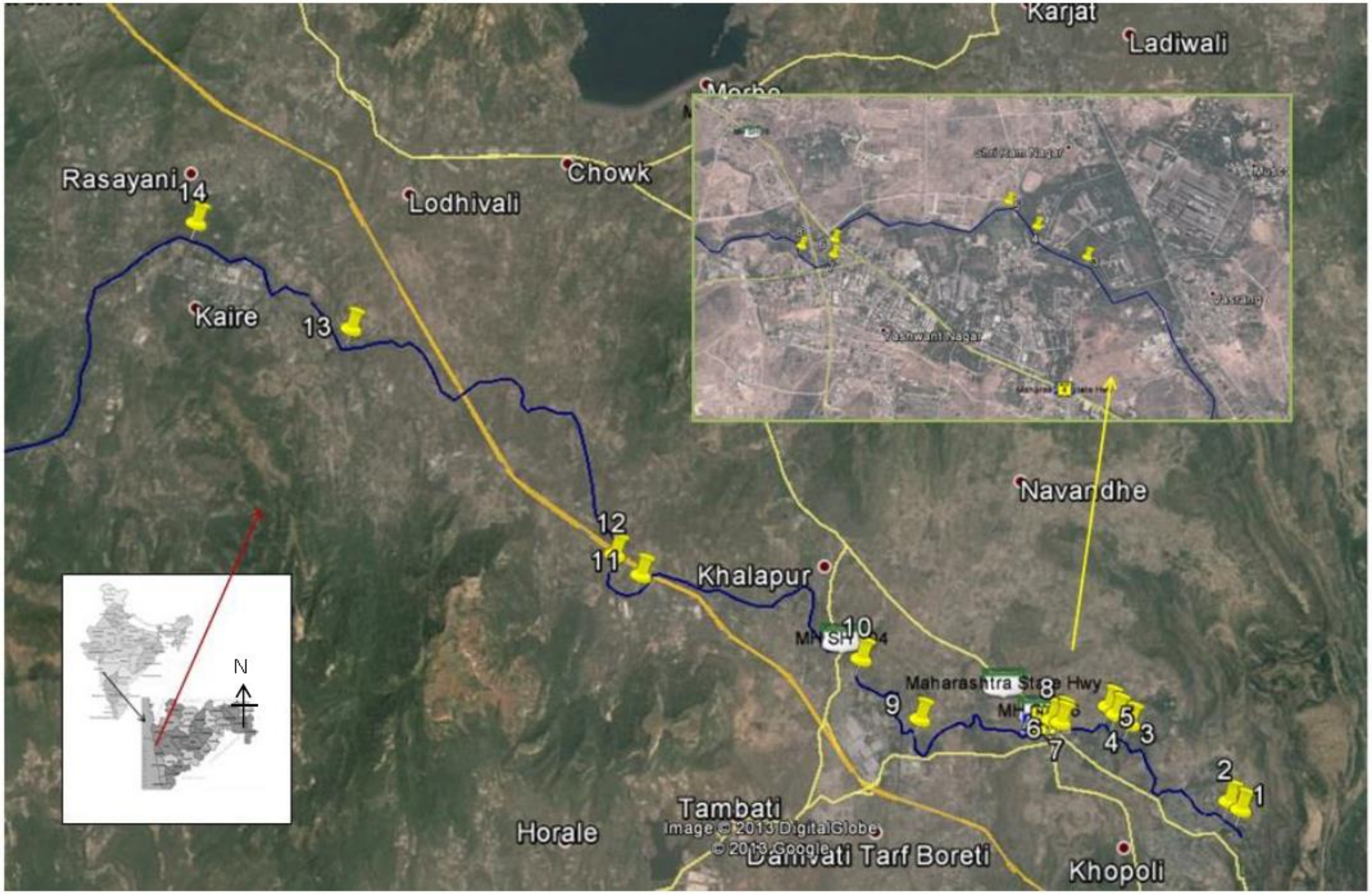

Fig. 1 : Sampling Locations at Patalganga River Stretch

Table 2: Physico-chemical and Microbial Characteristics of Patalganga River (all the values in mg/L except pH, temperature, conductivity and E. Coli)

	Air Temp (°C)	Water Tem (°C)	pH	Conductivity (µS/cm)	TDS	SS	DO	BOD	COD	NO_3-N	NH_4-N	PO_4^{3-}	Oil and Grease	E coli
WHO	-	30-35	6.5-8.5	1800	500	-	5.0	6.0	10.0	45	0.10	-	-	*
BIS	-	-	6.5-8.5	-	500	-	5.0	2.0	-	45	-	-	10.0	
1	31.5	22.5	7.2	33	22	2.0	10.2	5.0	20	0.24	0.08	0.016	1.2	-
2	31.5	23.5	7.2	41	28	3.0	10.0	11.0	33	0.30	0.15	0.014	0.8	+
3	31.5	23.0	7.5	45	30	4.0	9.6	6.0	23	0.36	0.41	0.106	1.8	+
4	34.5	24.0	7.5	88	59	5.0	9.4	8.0	34	0.64	0.45	0.016	3.0	+
5	34.0	24.0	7.2	43	29	6.0	9.8	6.9	46	1.25	0.26	0.040	1.2	+
6	32.0	24.0	7.5	51	34	6.0	8.4	13.0	39	0.57	0.48	0.059	19.6	+
7	32.0	24.5	7.5	1683	1128	65.5	6.5	64.8	122	35.1	5.41	0.356	7.6	+
8	32.0	24.2	7.2	46	31	4.0	10.0	11.5	35	0.87	0.13	0.031	1.2	+
9	34.5	27.0	7.2	167	112	15.0	7.3	15.2	42	1.51	0.16	0.099	0.8	+
10	32.5	25.5	7.0	92	62	11.0	7.6	23.8	59	0.69	0.13	0.086	6.4	+
11	29.5	25.5	7.0	132	88	3.0	8.3	22.6	47	1.27	0.18	0.181	0.4	+
12	31.0	29.0	7.5	1082	725	9.0	5.2	49.6	76	17.3	0.68	0.254	2.4	+
13	31.5	27.3	7.0	107	72	3.0	9.8	19.5	57	2.62	0.42	0.018	0.5	+
14	29.0	25.5	7.0	95	64	1.0	8.9	3.4	10	0.32	0.16	0.016	0.0	-

+ : present; - : absent ; * : Must not be detectable in any 100 ml sample

Table 3: Metals Content in Patalganga River Water (all the values in mg/L)

	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BIS	0.05	0.01	-	0.050	0.050	0.30	0.10	0.020	0.050	5.00
WHO	0.01	0.003	0.04	0.200	2.000	0.30	0.10	0.020	0.015	3.00
1.	ND	ND	ND	0.003	0.015	0.17	0.09	0.002	0.001	0.03
2.	1.24	ND	ND	0.020	0.015	0.40	0.11	0.003	0.004	0.07
3.	ND	ND	ND	0.008	0.010	0.10	0.05	0.003	0.001	0.06
4.	ND	ND	ND	0.050	0.020	0.26	0.03	0.003	0.001	0.04
5.	ND	ND	ND	0.004	0.010	0.23	0.003	0.002	0.001	0.03
6.	1.00	ND	ND	0.008	0.020	0.44	0.18	0.004	0.005	0.08
7.	ND	ND	ND	0.010	0.008	1.18	0.03	0.002	0.0005	0.07
8.	1.46	ND	ND	0.005	0.006	0.17	0.03	0.003	0.005	0.06
9.	ND	ND	ND	0.007	0.011	0.25	0.17	0.002	0.0002	0.04
10.	ND	ND	ND	0.003	0.020	0.30	0.02	0.003	0.003	0.06
11.	ND	ND	ND	0.0005	0.010	0.26	0.19	0.020	0.001	0.14
12.	3.57	ND	ND	0.001	0.020	0.22	0.03	0.003	0.007	0.09
13.	ND	ND	ND	0.008	0.020	0.16	0.03	0.002	ND	0.06
14.	ND	ND	ND	0.003	0.010	0.20	0.02	0.001	ND	0.02

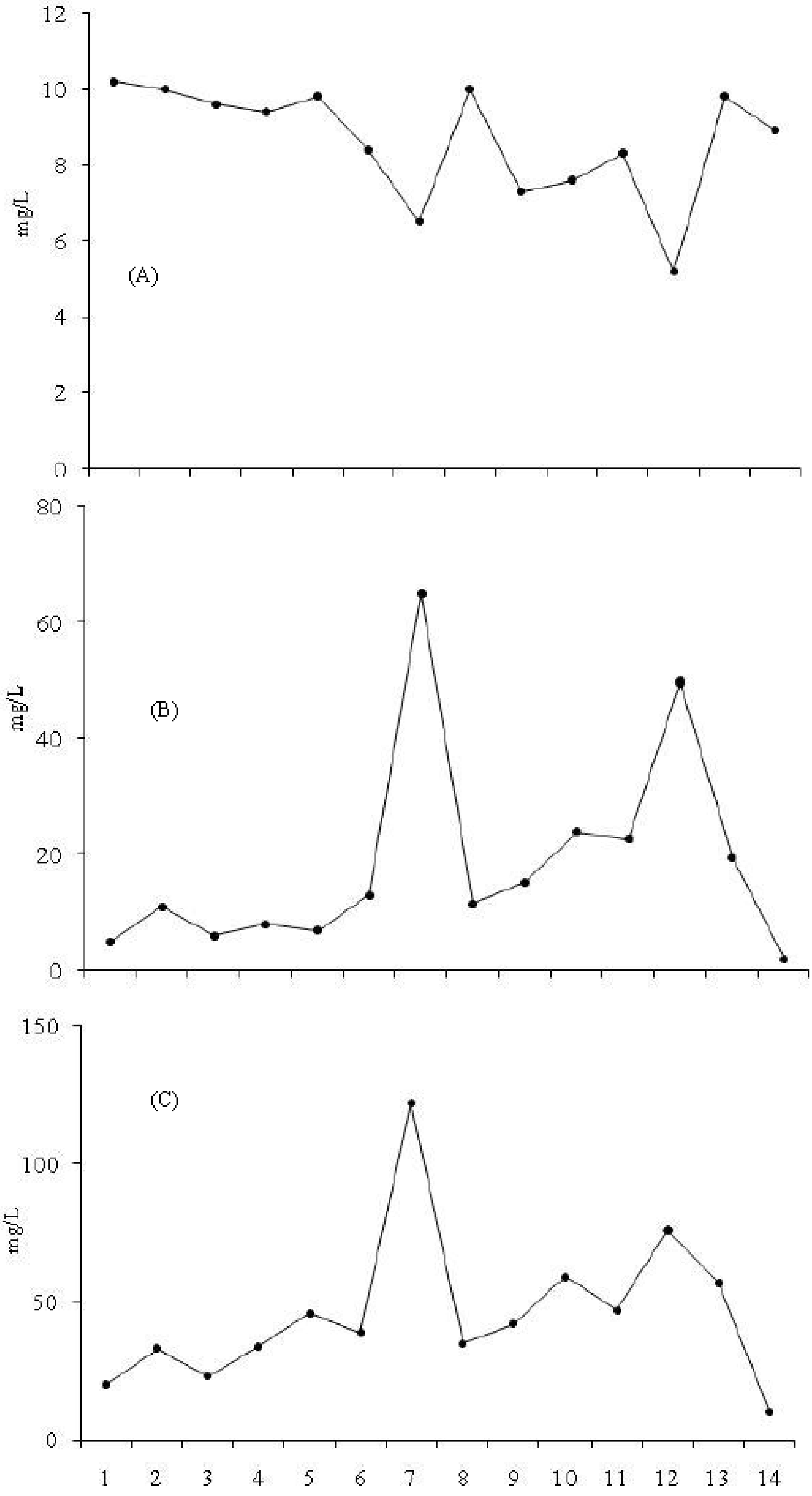

Fig. 2: Concentrations of (A) Dissolved Oxygen; (B) Biological Oxygen Demand; (C) Chemical Oxygen Demand at 14 Different Sampling Stations

3.2. Metals Analysis

Metals enter the river from a variety of sources, which can be either natural or anthropogenic (Bem et al., 2003; Wong et al., 2003; Adaikpoh et al., 2005; Akoto et al., 2008). Usually, in unaffected environments, the concentrations of most of the metals are very low and are mostly derived from the mineralogy and weathering of rocks (Karbassi et al., 2008). Rivers in urban areas have also been associated with water quality problems due to the practice of discharge of untreated domestic and industrial waste into the water bodies, which lead to an increase in the level of metal concentrations in the river water (Rim-Rekeh et al., 2006; Iqbal et al., 2006; Khadse et al., 2008; Juang et al., 2009; Jumbe et al., 2009; Venugopal et al., 2009; Sekabira et al., 2010). Metals are non-degradable and can accumulate in the human body, causing damage to the nervous system and internal organs (Lee et al., 2007; Lohani et al., 2008).

The concentration trend of different metals in the river water and the maximum values for metals in water have been prescribed by the WHO and BIS, and shown in Table 3. The As concentrations were observed high compared with WHO and BIS standards at sampling stations 2, 6, 8 and 12 due to inflow of domestic and industrial wastewaters, respectively. The adverse effects of chronic exposure to drinking arsenic water on human body are cardiovascular disease, neurological effects, chronic lung disease, reproductive disease, adverse renal affects, developmental abnormalities, hematological disorders, diabetes mellitus and cancers of skin, lung, liver, kidney and bladder. In dose-response manner; the children who use the drinking water with high arsenic concentration (> 0.05 mg/L) execute lower performance than those children, using drinking water with low arsenic (<0.005 mg/L) (Wasserman et al., 2004; WHO, 2006; Rakib and Bhuiyan 2014). The Cd and Co concentrations were reported nil at all the sampling station. The concentrations of Cr, Cu, Ni, Pb and Zn in the river water were quite low and found within the WHO and BIS permissible limits. The concentrations of Fe and Mn were found highest at sampling station 7 (1.18 mg/L) and 11 (0.19 mg/L), respectively. The high Fe concentrations could be attributed to anthropogenic activities and land runoff. The high level (> 200 mg/L) of Fe can cause hemochromatosis with symptoms such as chronic fatigue, arthritis, heart disease, cirrhosis, thyroid disease. The Fe concentration in water causes conjunctivitis, choroiditis, and retinitis if it contacts and remains in the tissues (Huang, 2003; Kayode et al., 2006). The presence of high concentration of Fe may also increase the hazard of pathogenic organisms; since most of them need Fe for their growth (Tiwana et al., 2005; Anonymous, 2008). Industrial activities were predominantly responsible for the high concentrations of Mn in river waters. Mn concentration over 0.1 mg/L lead to adverse impact on water coloration, metallic taste, odor problem, turbidity, biofouling and corrosion, and staining of laundry and plumbing fixture. The elevated amounts of Mn may cause apathy, irritability, headache, insomnia as well as gastrointestinal irritation and respiratory disease (Apostoli et al., 2000; Roccaro et al., 2007; Rygel, 2006; Menezes-Filho et al., 2011). In the worst form, it may lead to a permanent neurological disorder. However, exposure to Mn from drinking water is normally substantially lower than intake from food (USEPA, 2004). Although, in general, the relative high metals concentrations were observed at mid-stream as compared to upstream and downstream, it can be attributed to inflow of industrial and household wastewater in river stream.

The region has many small-scale as well as large industrial units located close to the Patalganga River that use toxic metals for various products and discharge their effluents directly or indirectly into the river. Apart from it, its tributaries also pass through some of the most industrialised belts and carry effluents that ultimately drain into the Patalganga River, increasing the load of toxic metals. The samples from various industrial units contained few metals above permissible limits of WHO and BIS for drinking water while some metals such as Cd and Co were totally absent. The Pb was found above the permissible limit only in one industrial effluent (a perfume manufacturing industry). Drinking water picks up Pb pollution from several sources such as household paint, vehicle exhausts and industrial wastes. Pb builds up in the human body over many years and can damage the brain, red blood cells and kidneys. It is an accumulative metabolic poison that affects behavior, as well as the hematopoietic, vascular, nervous, renal, and reproductive systems of the human body (USEPA, 2005; Moore and Ramamoorthy, 1984; Nadeem-ul-Haq et al., 2009; Singare et al., 2012).

4. DATA ANALYSES

4.1. Correlation Coefficient

In the present study, correlation coefficient was used to identify the highly correlated water quality parameters. This can help in selecting the treatments to minimize pollutants in river water (Joarder et al., 2008). Simple correlation coefficient (r) computed between physicochemical properties in Patalganga River is presented in Table 3. There was no significant correlation between water temperature and the other physical parameters except DO ($r = -0.67$; $p < 0.01$). Water temperature correlated negatively with the DO and positively with TDS and SS, with the latter showing a positive correlation with BOD. The EC, TDS, SS and TS displayed positive strong correlation with all the parameters except DO and Oil and grease. Strong positive correlation of EC with BOD ($r = 0.94$; $p < 0.01$) and COD ($r = 0.88$; $p < 0.01$) supported the presence of wastewater coming from industries as the chief causative factor for aquatic pollution (Dike et al. 2013). It is clear from the results that the DO was negatively correlated with all the variables and was not positively correlated with any of the studied parameters. The DO exhibited negative correlation with BOD ($r = -0.81$; $p < 0.01$), COD ($r = -0.68$; $p < 0.05$) and oil and grease ($r = -0.27$) – decrease in DO concentration is linked with oxidation of re-suspended organic matter (Kriest and Oschlies, 2013). Negative correlation between DO and NO_3-N ($r = -0.67$; $p < 0.01$) was observed due to high discharge, which increases concentration of DO in the interstitial water because of increased turbulence that reduces the anoxic environment required for denitrification (Lansdown et al., 2012). The NO_3-N showed significant positive correlation with BOD ($r = 0.93$; $p < 0.01$) suggests the addition of these nutrient to Patalganga River from organic waste and sewage discharge. Strong positive correlation between TDS and NO_3-N ($r = 0.99$; $p < 0.01$) might indicate that the pre-dominant fraction of the nitrogen species are present in dissolved form instead of particulate nitrogen (Charkhabi and Sakizadeh, 2006). The PO_4^{3-} showed strong negative correlation with DO ($r = -0.81$) with significant differences $p < 0.01$, while positive correlation with BOD ($r = 0.92$, $p < 0.01$) and COD ($r = 0.84$; $p < 0.05$). NO_3-N shows strong correlation with NH_4-N ($r = 0.93$; $p > 0.01$), such high correlation indicating contamination of the river water from point sources, i.e., industrial, sewage and animal wastes (Maitera et al., 2010).

The SS showed significant positive and negative correlation with NH_4-N ($r = 0.97$; $p > 0.01$), BOD ($r = 0.79$; $p > 0.01$) and DO ($r = -0.54$; $p > 0.05$), respectively. It was due to that SS can adsorb many organic matters and microorganisms (Ling et al., 2002). The Oil and grease showed positive correlation with all parameters except water temperature ($r = -0.16$) and DO ($r = -0.27$) (see table 4). The high concentration of oil and grease reduce dissolved oxygen in the river water and alter the usability and aesthetic values of the water (Khan et al., 2006).

Table 4: Correlation Coefficient of Various Parameters in Patalganga River Water

	W Tem	**pH**	**EC**	**TDS**	**SS**	**DO**	**BOD**	**COD**	**NO_3-N**	**NH_4-N**	**PO_4^{3-}**	**O&G**
W Tem	1											
pH	-0.18	1										
EC	0.34	0.46	1									
TDS	0.34	0.46	1	1								
SS	0.04	0.36	0.85**	0.85**	1							
DO	-0.67**	-0.30	-0.75**	-0.75**	-0.54*	1						
BOD	0.47	0.33	0.94**	0.94**	0.79**	-0.81**	1					
COD	0.37	0.28	0.88**	0.88**	0.84**	-0.68*	0.95**	1				
NO_3-N	0.26	0.45	0.99**	0.99**	0.90**	-0.67**	0.93**	0.89**	1			
NH_4-N	-0.02	0.42	0.87**	0.88**	0.97**	-0.46	0.78**	0.82**	0.93**	1		
PO_4^{3-}	0.35	0.40	0.90**	0.90**	0.78**	-0.81**	0.92**	0.84*	0.88**	0.76**	1	
O&G	-0.16	0.47	0.16	0.17	0.27	-0.27	0.21	0.25	0.18	0.28	0.18	1

** *p* = 0.01 level; * *p* = 0.05 level

4.2. Cluster Analysis

Hierarchical cluster analysis (HCA) was used to analyze the water quality data for spatial and temporal differences. The HCA was applied to a subgroup of the dataset to evaluate their usefulness to classify the river water samples, and to identify suitability for drinking water purpose. Guler et al. (2002) described hierarchical cluster analysis as “an efficient means to recognize groups of samples that have similar chemical and physical characteristics”. The distance cluster represents the degree of association between elements. The lower the value on the distance cluster, the more significant is the association. HCA is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set, and is generally illustrated by a dendrogram (McKenna, 2003). To classify the water quality in sampling stations and to determine the source of pollution, HCA with Ward method, Euclidean distance based on the standardized mean of the physico-chemical parameters were used. According to the thirteen parameters, HCA categorized fourteen sampling stations into three distinctive clusters described based on pollution magnitude as clean, slightly polluted, and polluted. Examination of Figure 3 shows the identification of three major branches in the dendrogram, labeled A, B and C. These were identified as major cluster groups because the linkage distance at which they combine with each other is relatively large, indicating that there are relatively large Euclidean distances between the samples. Group A consists of 12 sampling stations while groups B and C are represented by sampling stations 7 and 12, respectively. The group A was further divided into two subgroups A’ and A’’. The subgroup A' mainly represented upstream area and low nutrient concentrations compared to A" while A" represented mainly industrial wastewaters. The upstream area of rivers is less influenced by human activities. Therefore, the condition of river water was slightly clean and optimized. The group B (sampling station 7) was influenced by the inflow of domestic and public toilets wastewaters. Finally, the group C (sampling station 12) could be influenced by the extensive inflow of industrial wastewaters. Eventually, the result denotes that HCA is an effective technique to assess and classify river water in the Patalganga River case study. At the same time, it is significant to a large extent to authorities and decision makers to know the latest information on the river which guide them in the optimal strategy establishment in which sampling stations can be reduced.

Table 5: Classification of Water Quality Index

Range	Quality
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very bad

4.3. Water Quality Index

Based on the WQI an assessment was made whether the river water was acceptable for domestic use and drinking purpose. For this reason, this analysis is extremely necessary. Also, people living in these areas can determine from which part of the river they can draw the best quality water (Adak et al., 2001). Water quality has been assessed using Water Quality Index (WQI) developed by the U.S. National Sanitation Foundation Water Quality Index (NSF WQI) in 1970. This index has been widely tested on field and applied to data from a number of different geographical areas all over the world in order to calculate Water Quality Index (WQI) of various water bodies. Critical pollution parameters were considered (Sharifinia et al., 2013) for computing WQI. Expression for NSF WQI is given by

$$\text{NSF WQI} = \sum_{i=1}^{p} W_i I_i$$

Where Ii is the sub-index for i_{th} water quality parameters; W_i is the weight (in terms of importance) associated with i_{th} water quality parameter; p is the number of water quality parameters.

The water quality index uses a scale from 0 to 100 to rate the quality of the water, with 100 being the highest possible score. The classification criteria standards based on NSF WQI are given in Table 5. The computed overall WQI was 100 and can, therefore, be categorized into five types “excellent” to “very bad”. The results obtained from this study revealed that WQI of the Patalganga River waters falls under the range of 43 to 78 (Figure 4). The study area WQI assessment showed that water quality of river waters falls under “Good” category with the majority of the sampling stations having water quality with WQI in the range of 70 to 83 and need to be treated before its use. Sampling stations 7 and 12 showed “Bad” and “Medium” category, respectively, and were totally unfit for drinking purpose.

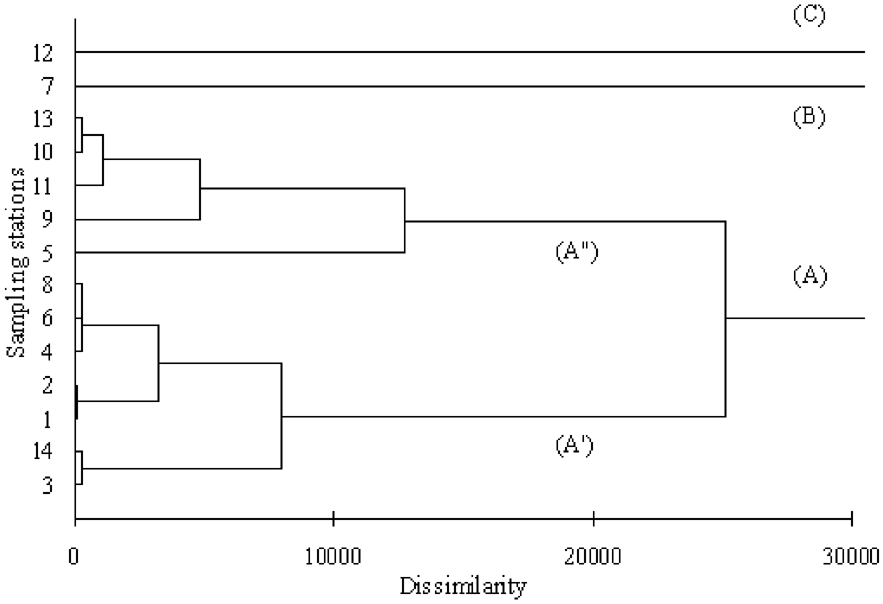

Fig. 3: Dendrogram from Hierarchical Cluster Analysis of Sampling Stations of Patalganga River

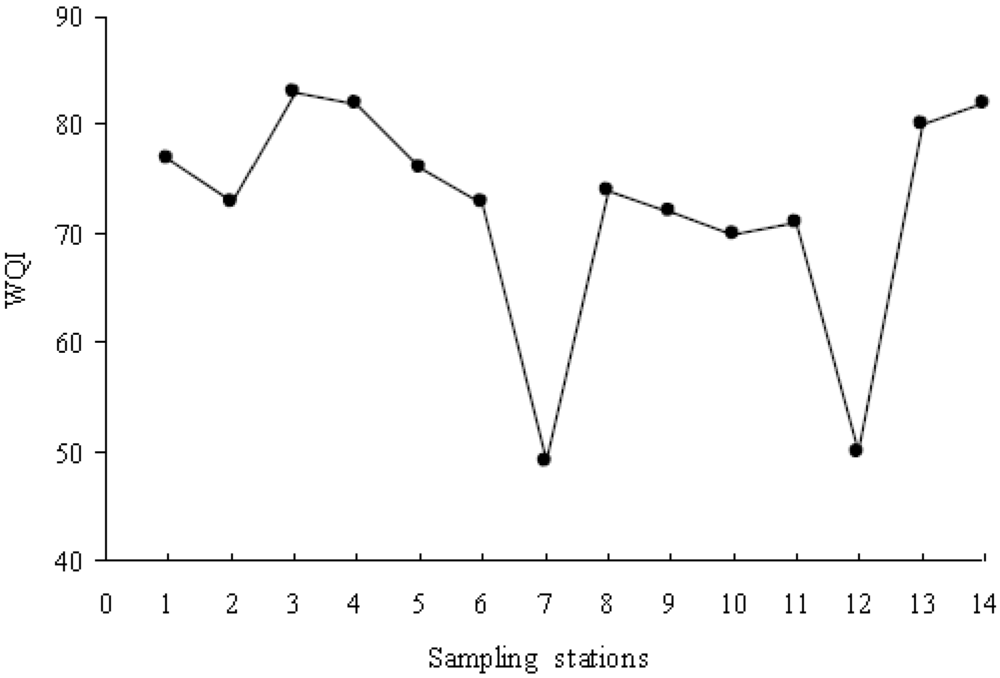

Fig. 4: WQI Range and Degree of Pollution at Sampling Stations

5. MANAGEMENT PLAN FOR WATER QUALITY IMPROVEMENT

Socio economic development is clearly linked to access to safe drinking-water. Environmental, economic and social policies associated with waste management are mostly inadequate and insufficient, resulting in increasing deterioration of the environment (Mara, 2003; Goldar and Banerjee, 2004; Hutton et al., 2007). The poor management of river water has resulted in a major shift in the quantity and quality of water and altered ecosystems, limiting the benefits available for human that depend on them. Improving the water quality in the Patalganga River is possible, but requires interventions in both domestic-municipal and industrial sectors. River pollution can be controlled by considering multiple options such as:

(a) Installation of STPs and using the treated wastewater for irrigation and ground water recharge - as the flow rate of the river is high *ex-situ* water purification by anchored PhytoRid will be useful (Kumar et al., 2010). The high NH_4-N concentration in drinking water requires additional wastewater treatment technology such as biological nitrification or physicochemical processes (such as ion exchange, membrane filtration, air stripping and ozonation).

(b) Waste segregation at source, localized recycling, localized/community level vermicomposting - in case of temple wastewater management awareness creation, and employment of small temporary plastic nets for solid waste removal are important steps.

(c) Regular monitoring for checking and improving the management practice.

(d) Public awareness and participation through media and organizing public programs for spreading the message effectively is essential.

(e) Low cost sanitation complexes to prevent open defecation.

(f) A separate truck washing terminal and treatment of wastewater produced. Use of oil spill control methods.

(g) Water quality laws and regulations need to be enforced effectively. Creation of no development zone about 500 m on the either side of the river.

6. CONCLUSION

Based on the cluster analysis, and on comparing the water quality parameters with national and international standards of parameters from 14 sampling stations, the sampling stations were divided into three major groups to reduce the number of sampling sites to ease future monitoring exercises. Three groups and one subgroup were generated from HCA method. Subgroup A' reflects the low physico-chemical, microbial and metals concentration. Subgroup A'' is mainly affected by industrial wastewaters. Group B is mainly influenced by domestic and public wastewaters. Group C reflects the characteristic of industrial wastewater. Based on WQI, it could be inferred that water quality at these above mentioned sampling stations are “Good”, “Medium” and “Bad” category and can only be used for drinking after conventional treatment and disinfection. The results suggest that anthropogenic activities have had significant effects on water quality in the river.

From this classification, it is possible to plan for optimum sampling strategies that can reduce the number of sampling points during assessment and the affiliated recurring cost during environmental monitoring. It was observed that the main causes of deterioration in water quality were high interference of anthropogenic activities, lack of proper sanitation, and industrial and domestic wastewater inflow. This work may assist the decision makers in the pollution control of the Patalganga River where the WQI and clustering process gives an effective overview about the locations where intensified monitoring activity and control measures are required. A specific management plan involving all stakeholders will help improve and maintain the river water quality.

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