Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 9(2), 2021: 148-167
http://dx.doi.org/10.7770/safer-V0N0-art2356

Investigation of water quality of Damanganga estuary using water quality index, south Gujarat, India.

Investigación de la calidad del agua del estuario Damanganga usando el índice de calidad del agua, Gujarat del sur, India.

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ABSTRACT

The seasonal investigation of water quality of Damanganga estuary from two riverine points (downstream and upstream) was carried out from January to December 2019 during three consecutive seasons: winter, summer, and monsoon. During this monitoring period, in total 29 parameters (24 physico-chemical parameters and 5 parameters for metals monitoring) were analyzed. Multivariate analyses exhibited inter-dependency among the studied parameters. Based on the major fluctuated and affected parameters, the Water Quality Index (WQI) is computed. The WQI for all three seasons ranged from 122.84 to 173.82, which suggested poor water quality of the water body. WQI suggests that the estuarine water quality is deteriorated due to high value of presence of heavy metals (Aluminum, Iron, Manganese, Boron and Zinc), along with accentuated contents of Chloride (900.11 ± 103.90 to 1840.91 ± 570.30), Ammonium (5.99 ± 0.056 to 8.63 ± 0.29)and Sulfate (151.51 ± 45.64 to 357.11 ± 25.50) in riverine water. The downstream is having more pollutants compared to the upstream. Temporally, the dominant susceptibility was found during the winter season followed by summer and monsoon. This study exhibited poor quality of water; the reason behind this might be the expanding industrial zone and uncontrolled anthropogenic activities. The Bray-Curtis cluster analysis shows percentage similarity level among the water quality parameters.

Keywords:Damanganga estuary, Seasonal assessment, water quality index, Normal Distribution, Cluster analysis.

RESUMEN

La investigación estacional de la calidad del agua del estuario de Damanganga desde dos puntos ribereños (río abajo y río arriba) se llevó a cabo de enero a diciembre de 2019 durante tres temporadas consecutivas: invierno, verano y monzón. Durante este período de seguimiento, se analizaron en total 29 parámetros (24 parámetros físico-químicos y 5 parámetros para el seguimiento de metales). Los análisis multivariados mostraron interdependencia entre los parámetros estudiados. Con base en los principales parámetros afectados y fluctuantes, se calcula el Índice de Calidad del Agua (WQI). El WQI para las tres temporadas osciló entre 122,84 y 173,82, lo que sugiere una mala calidad del agua del cuerpo de agua. WQI sugiere que la calidad del agua estuarina se deteriora debido al alto valor de presencia de metales pesados (Aluminio, Hierro, Manganeso, Boro y Zinc), junto con contenidos acentuados de Cloruro (900.11 ± 103.90 a 1840.91 ± 570.30), Amonio (5.99 ± 0.056 a 8.63 ± 0.29) y Sulfato (151.51 ± 45.64 a 357.11 ± 25.50) en aguas fluviales. El río abajo tiene más contaminantes en comparación con el río arriba. Temporalmente, la susceptibilidad dominante se encuentra durante la temporada de invierno seguida por el verano y el monzón. Este estudio mostró agua de mala calidad; la razón detrás de esto podría ser la zona industrial en expansión y las actividades antropogénicas incontroladas. El análisis de conglomerados de Bray-Curtis muestra un nivel de similitud porcentual entre los parámetros de calidad del agua.

Palabras clave: estuario de Damanganga, evaluación estacional, índice de calidad del agua, distribución normal, análisis de conglomerados

INTRODUCTION:

An ecosystem of estuary is very dynamic and tremendously productive [1], and their operational activities occurred in different systematic manner consisting of temporal and spatial cycles as well as diurnal and semidiurnal kind of tidal cycle [2]. The various life phases of marine organisms containing feeding, breeding and conservation from predators attained through the estuarine environment, and they provide shelter to several species; in addition to inhabitant species which pass across the life cycle in this habitat, more or less they contribute to social and economic values [3]. Alternations in the terra and aqua zone sensitively affected the estuarine ecosystem due to its fragile and sensitive nature. Water-quality declines could endanger aquatic life in estuarine areas [4]. Aquatic perspective of this studied estuary is very abstruse because of its dynamic nature influenced through the besieged industrial and urban estates within the vicinity of the field. The human interventions, particularly increasing population, industrialization, and tourism in the coastal areas are the major threats to the coastal marine environment. The estuary is known as preclusive zone between the terrain and the ocean. Most of the world’s aqua has degraded water quality, though India has more severe status. In sight of water for the economic as well as population growth, a serious question in India is scarcity of natural resources. “Thought of a person depends on the type of food and water to which he is fed” conceded the Indian philosophers. This contention is scientifically credible, reason is that the normal physiology is disturbed through the ingestion of contaminated water and food. For the constitution of water quality status baseline, monitoring is a significant prior step, which also enlightens the effects of man-made activities on aquatic ecosystem. Hydrochemical investigation for water monitoring consist of the analysis of several dissolved or suspended elements and molecules in the water. Monitoring and assessment of the environment can help in realizing the cause of the deteriorating condition in the estuarine ecosystems and in clarifying the changes in spatiotemporal patterns, thus recommending sustainable management plans for ecosystem restoration [5].

The conjunct impacts of various water quality factors reflect in a rating scale called Water Quality Index. The several hydro-chemical parameters consociate into a number through the normalizing data to subjective scaling curve and generate a dimensionless number known as WQI. For the respective policy makers and citizen, WQI is one of the significant tools to convey the information about water quality [6]. The massive data transfigure is the rationale of WQI, that can be simply explicated [17].

The aim of the current study is to document a baseline record of the status of physicochemical factors, nutrients and trace elements in the water of the Damanganga estuary, South Gujarat, India. The objective of the study was to describe and discuss the inter-annual and seasonal changes of water quality, based on indicators monitored in Damanganga River estuary, as well as identifying the main drivers of such changes.

MATERIALS AND METHODS

Study Area: The Sahyadri hills is the origination point of the Damanganga river located in Nasik district, Maharashtra and its ending point is located at Daman into the Arabian Sea, it is streaming through the mountainous tracts of Maharashtra and Gujarat states and Dadra-Nagar Haveli and Daman Union Territoriesin company with its tributaries [7]. Figures 1 and 2 shows the Basin of Damanganga River. The coordinates are 20.38897 to 20.41697 N and 72.833917 to 72.86387 E with an average elevation of 7 m. Damanganga travels a distance of 131.30 km. There is 2318 sqkm^{-1} area which is occupied by the Damanganga river basin, of these 495 sqkm^{-1} (21.36 %) and 415 sqkm^{-1}(17.90%) is occupied by Valsad district and the union territory respectively. The industrial zones of Vapi, Silvassa and Dadra occupied the northern bank of the river and the estuarine field of this river has the town of Daman on both banks [8]. There are about 5105 numbers of small scale and medium scale industries running in the surrounding of Damanganga basin [7]. The estuary of Damanganga river has shallow depth due to the heavy sedimentation [9]. Damanganga River is very important for the socio-economic life of the people from Daman and the surrounding areas for which it is known as Ganga of Daman (Damanganga).

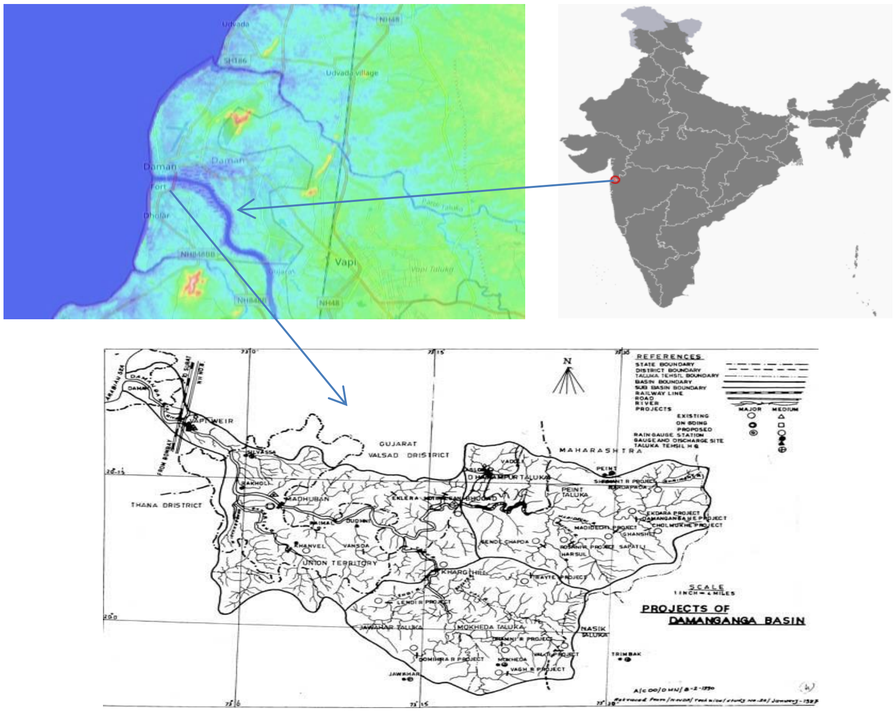

Figure 1: Geographical Map of India; Topological Map of Daman and Damanganga River Basin
Source: 1. Narmada, Water resources, Water supply and Kalpsar Department 2.https://www.mapsofindia.com

Figure 2. Map showing the field stations of South Gujarat.

Table 2.1: Sampling stations and their geographical locations

Stations	Downstream	Upstream
Latitude (N)	20°41'	20°37'
Longitude (E)	72°83'	72°87'

Samplings: For the seasonal monitoring of water quality, water samples were collected from January to December 2019 for a period of a year covering three consecutive seasons: winter, summer and monsoon on bimonthly intervals. There were four sites (two sites each from the downstream and the upstream) selected for sampling along the Damanganga estuary. The Downstream was near jetty garden, jerom fort, Daman (20°41" N; 72°83" E) and Upstream was near Zari village (20°37" N; 72°87" E). The sites were selected based on the preliminary screening process as well as sampling and on-site experimental avalilability. Three water samples were collected from each sampling site to make composite samples. For the experimental study, in total 24 water samples were analyzed for investigating physico-chemical parameters (Colour, Alkalinity, Total solids, TDS, TSS, Temperature, pH, Free CO_2, Salinity, Total hardness, Calcium hardness, Turbidity, Electrical conductivity, Chloride, DO, BOD, COD, Phosphate, Nitrate, Ammonium, Sulfate, Sodium, Potassium, and Silicate) and heavy metals analysis (Aluminum, Boron, Iron, Manganese, and Zinc).

The sampling of water was carried out by using 1 liter clean polyethylene bottle from northern to southern bank of the estuary, and stored in ice box at 4°C temperature, and then brought to the laboratory for further analysis. For the immediate estimation of Dissolved oxygen, samples were fixed in 300 ml BOD bottles for estimation of Biochemical Oxygen Demand (BOD) after 5 days of incubation at 20°C in the incubator. The parameters like Temperature, pH, Electrical conductivity and Dissolved oxygen were assessed at the time of sampling on site.

Analysis of Water Quality Parameters: After the sampling, hydro-chemical parameters were assessed within 7-15 days using the standard procedures prescribed in American Public Health Association (APHA) [10] and Handbook of Environmental Studies [11]. Water temperature was measured by the Thermometer (Bel-Art; Model: B60800-3100), Electrical Conductivity was determined through the digital conductivity meter (DiST: Hanna instruments) and pH was measured by a digital pH meter (pHep®: Hanna instruments) on site during sampling. Digital Turbidity meter (Model: 331) was used to assess the Turbidity. Colour was assessed in SICART (Model: HACH-DR 2010). Testing of Salinity was carried out by using Salinometer (Model: SSM 21). Gravimetric procedure was applied to check the contaminations of TSS, Total solids, and TDS. Alkalinity, Free CO_2, Chloride, Total Hardness and Calcium hardness were investigated through the Titration method. Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) were tested by using the Winkler method. Chemical Oxygen Demand (COD) and Ammonium were assessed in SICART (Model: HACH-DR 2010). Nitrate, Phosphate and Silicate were determined through the help of Spectrophotometer (Model: 302). Sodium and Potassium were analyzed through the Flame photometric method with sensitivity 1 (ESiCO - Digital flame photometer model: 381; ESiCO - Compressur unit model: 380). The turbidometric technique was applied for Sulfate analysis (Model: 302). Heavy metals were analyzed with the help of the Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) (Model: Perkin Elmer, USA) in SICART, Vallabh Vidyanagar.

Water Quality Index (WQI): The water quality evaluation method involved two steps. First, the important water quality parameters (Chloride, Sulfate, Alkalinity, Iron, Nitrate, Colour, DO, pH, Boron, COD, Temperature, Phosphate, and TDS) were chosen from 29 parameters in order to reflect the specific characteristics of water of the study area, followed by the quality curves, and weights of selected parameters to derive, an integrated WQI score.

$$WQI = \Sigma\, QiWi / \Sigma\, Wi \quad (1)$$

(Qi = Rate to the parameters based on Quality; Wi = Relative weight to the parameters)

Water quality grades are classified with reference to the grades provided in Table 2.4.

Statistical Analysis: Univariate (Normal Probability Distribution) and Multivariate (Cluster analysis) statistical analysis were carried out by using PAleontological STatistics (PAST) 3.0 software.

Table 2.4: Coastal water quality ranking criteria [12].

Range	Category
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
> 300	Unsuitable

RESULTS AND DISCUSSION:

Water Quality: Water quality parameters and its seasonal variation in aquatic resources depends on rainfall, river flow and anthropogenic activities [16]. The physical, chemical and biological parameters of water body varied with freshwater and tidal influences. During the present study, Total Solids (1745.74 ± 229.62), Total dissolved solids (1162.37 ± 319.68), Total suspended solids (643.37 ± 99.94) and pH (7.60 ± 0.14) showed more concentrations during monsoon period at downstream compared to upstream during winter season (Figure 3.1). Similar result was reported from Weir Cum-Causeway, Tapi river [16]; Industrial division of Hazira, Tapi estuary [18]; Mahanadi Estuary, East Coast of India [22]. Low photosynthetic nature during winter lead to minimum pH and more algal productivity and less microbial activity because of the reduced rate of decomposition during rainy season lead to maximum pH [16]. Photosynthesis releases carbon dioxide by the bicarbonate deduction, influx of freshwater diluted marine water, low biomass, reduced salinity and temperature, and degradation of organic compounds attributed to the fluctuations in pH during various seasons [18]. The humic components consisting of colloidal suspension commonly have acidic nature, which are in large amount transported by the currents of water; when colloidal materials meshup with oceanic water forming coagulated compounds thereby pH varies from low to high value [23]. Total suspended solids are in form of silt and clay materials, carbonic and inorganic components, planktonic organisms, and other aquatic microorganisms; the size of the particles range from 1 Å to 0.01 Å [18]. Disposed waste water, upper reaches run-off, and feed of fishes used for fishing increased the total suspended solids in the downstream [23]. Total suspended solids and Total dissolved solids can be affected by fluctuations in pH because fluctuated pH will influence the solubility of the suspended materials [18]. More TDS content caused pollution through the extraneous sources, which adversely influence the quality of flowing water and make it unsuitable for purpose of drinking and irrigation. The salinity plays a role as a limiting variable for distribution of autotrophs. The dilution and evaporation caused fluctuations in loadings of salinity, which affected the fauna of intertidal field. Salinity during summer and monsoon were more (13.26 ± 0.99) and less (6.92 ± 0.33) in contamination consecutively at the downstream and the upstream in this study (Figure 3.1). The similar findings were observed in Weir Cum-Causeway, Tapi river [16]; Mahanadi estuary, India [22]; Merbok estuary, Malaysia [23]. The maximum salinity during summer may be due to more degree of evaporation and minimum durimg monsoon from heavy rainfall and huge influx of freshwater. The narrow and broader salinity gradients during wet and dry seasons respectively were observed from Mandovi, Zuari, Sal, and Talpona river's estuaries as well as low salinity towards the upstream [24]. Free carbon dioxide during summer were more (26.28 ± 1.54) and less (10.77 ± 0.77) during monsoon at the downstream and upstream respectively (Figure 3.1). Total and Calcium hardness were more (2919.00 ± 79.19; 465.50 ± 27.57) during summer and less (1098.00 ± 76.36; 177.50 ± 7.77) during monsoon in contamination consecutively at the downstream and the upstream (Figure 3.1). This observation was affiliated with the observation from Hazira industrial division, Tapi estuary, Gujarat [18]. Metallic ions called cations and certain anions in the water formed hardness. The domestic and industrial application suitability of water is determined by the hardness content [16]. The transparency of water is influenced by turbidity. It is caused by suspended materials such as silt, degraded carbonic and acarbonic compounds, clay, other micro and planktonic organisms. More turbidity was reported (18.36 ± 1.43) during rainy period and less (11.83 ± 1.21) during summer consecutively from downstream and upstream during this assessment (Figure 3.1). These seasonal variation of turbidity can be because of flowing rate of water and turbulent condition. During rainy period, the wave action intensity is very high which lead to turbulent condition in the water body caused through the sedimental resuspension from benthic surface due to stirring activity causing poor transparency of water [18]. The more (680.03 ± 71.30) and less (240.12 ± 30.89) electrical conductivity from the downstream and upstream stations noted consecutively during the rainy and summer seasons (Figure 3.1). Similar findings was recorded from Merbok estuary, Malaysia [23]. The reason might be the continous influx of water. The mineral and ionic contents are responsible for electrical conductivity of water. The significant amount of dissolved salts govern the electrical conductivity [21]. Because of this estuarine field, the most desirable parameter Chloride showed high concentration than other parameters; its contamination was higher during the period of winter (1840.91 ± 570.30) at the downstream site than rest of the two seasons because of the decreased current rate of water and lower during monsoon (900.11 ± 103.90) at the upstream station in this study area (Figure 3.1). The reported outcome was associated with the outcomes from Weir Cum-Causeway, Tapi river [16] and Industrial division of Hazira, Tapi estuary [18]. This might be due to the good salinity amount, fresh water influx, circular movement, and flow of tides. The industrial and animal originated organic wastes caused pollution which is indicated by chloride contamination in the water body. The high chloride contamination create troubles to irrigation water as well which is dangerous to aquatic life [16]. Dissolved oxygen is the significant metabolism of oxygenated organisms and an indiactor of healthy aquatic environment. The respiration in aquatic ecosystem purely depends on the dissolved oxygen in the water; thereby the water quality and aquatic life are gorverned by the optimum content of dissolved oxygen [18]. In this case, dissolved oxygen was more during winter at the downstream (4.54±0.08) and less during monsoon at the upstream (2.74±0.18) (Figure 3.1). The similar result was observed from Oum Er river, Morocco [21]. The lower concentration of dissolved oxygen could be the turbulent condition of water as well as high organic components from industrial effluents, sewage, anthropogenic activities which lead to lower concentration of dissolved oxygen in the estuary [22]. Higher Dissolved oxygen of water may be because of the combined effects of freshwater influx and wind energy [23]. Biochemical oxygen demand (BOD) (4.87±0.08; 2.91±0.26) showed same result as dissolved oxygen. The degraded carbonic matter and decayed biomass in riverine ecosystem mixup with marine water that increases the BOD level [18]. During the winter season, municipal sewage garbages, discharged industrial effluents directly enter in to the estuary and lead to high biochemical oxygen demand [22]. The introduction of additional organic components in to the freshwater through the runoff and erosion of soil attribute the fluctuation of BOD [18]. Chemical oxygen demand (COD) is the measurement of the inorganic as well as organic compounds from water [16]. It is inter connected to the transportation and leaching of industrial wastes, agricultural wastes, and domestic wastes [21]. COD was higher during winter (13.02 ± 4.62) and lower during monsoon (8.27 ± 0.49) at the upstream (Figure 3.1). Similar finding was observed from Tapi river, Gujarat [18]. The vital source of nutrients like nitrate, phosphate, and silicate is the rainy shower. More nutrient loadings were reported towards the head of the estuary [24]. Phosphate had higher concentration during winter (0.0267 ± 0.0013) and lower concentration during monsoon (0.0171 ± 0.0009) at the upstream (Figure 3.1). This might be due to the industrial and anthropogenic discharges. This seasonal variation of phosphate was also reported from Oum Er Rbia river (Morocco) [21] and Mahanadi estuary, East coast of India [22]. The industrial and domestic discharges and farming and land fertilizers in the drainage increased the phosphate concentration [21]. A contrast observation about phosphate concentration was reported from Hazira industrial area, Tapi River, Gujarat which revealed the high concentration of phosphate during monsoon possibly due to the intrusion of upper reaches's sea water in the creek and low concentration during dry season attributing to the high salinity, phosphate utilization by aquatic microorganisms, and limited freshwater flow [18]. The variations in nitrate concentration was observed because of the decomposition of organic components [16]. During the tide period, the organic compounds release nitrate concentration from the catchment area attributing to nitrate concentration in the water. The terrestrial run-off and freshwater influx lead to high concentration of nitrates and high biomass production activity leading to low concentration of nitrates [18]. During the winter, higher concentrations (26.69 ± 2.72) and during the monsoon, lower concentrations (16.76 ± 0.68) of nitrate was observed during this study (Figure 3.1). Similar outcome was found from Oum Er river, Morocco [21]. The winter concentration of nitrate may be due to the riverine freshwater runoff as well as agricultural influx and industrial discharges [22]. The concentrations of silicate were found higher at the downstream (11.27±2.75) and lower at the upstream (5.53±0.32) during winter and rainy season respectively (Figure 3.1). Silicate contamination in the water body is due to the more siliceous content from the catchment area [22]. Ammonium is the nitrogenic carbonic compound which comes from the gaseous exchange between the atmosphere and the water; it also released in a gaseous form through the biodegradation of waste materials from industries, domestic as well as agriculture [21]. During this study, ammonium had fewer (5.99 ± 0.056) concentration during monsoon while more (8.63 ± 0.29) loading during summer at the upstream (Figure 3.1).The identical seasonal variation observation of ammonium was recorded from Weir Cum-Causeway, Tapi river [16]; Mahanadi estuary, India [22]; Merbok estuary, Malaysia [23]. Higher ammonium concentration during summer may be due to the rise from low precipitation localized anthropogenic sources and heavy rainfall diluted the water body which decreases the ammonium amount. During monsoon period, more Alkalinity (142.72 ± 9.51) and Sodium (615.55 ± 41.50) at downstream and less (104.00 ± 18.38; 393.80 ± 6.36) during summer at the upstream is due to the decomposition of organic matter (Table 3.1). The similar result was recorded from Weir Cum-Causeway, Tapi river [16]. Potassium had higher (173.60 ± 2.54) and less (69.20 ± 4.66) concentration during summer season at the downstream and upstream station respectively (Table 3.1). An agricultural runoff raise the concentration of potassium [16]. The contamination of Potassium showed major difference during the period of summer from upstream to downstream; apart from this Sodium and Potassium both showed less contamination during the period of summer at upstream station. In the present study, high values of sodium and potassium are attributed due to the possible contamination by sewages and effluents. The observation of color showed higher intensity during monsoon at upstream station and lower intensity during winter season at downstream station. The bio-chemical activities of water influenced by temperature; it governs the rate of biomass production in aquatic ecosystem. Its fluctuation is commonly affected by rainy shower [23]. Temperature was identical at the both stations during the period of winter (20.00 ± 1.41) which is lower to reported value than other two seasons and it was higher during the period of summer (27.50 ± 2.12) at downstream station (Figure 3.1). This observation was identical with the observation from Weir Cum-Causeway, Tapi river [16] and Industrial division of Hazira, Tapi estuary [18]; Ennon estuary [19]. The shower of heat from sunlight or fluctuated solar radiation leads to seasonal fluctuation of water temperature; normally intensity of sunlight, freshwater run-off, cooling of riverine water and mix-up with ebb, evaporation affected the temperature of surface water [20]. The component loading of sulfate recorded higher (357 ± 25.50) and lower (151.51 ± 45.64) at the downstream and upstream station respectively during the period of summer and winter respectively (Table 3.1). The low tide water flow had more concentrations of the above nutrients while high tide had less concentrations. The primary source of nutrients in the marine water is the terra influx through the riverine water [22]. The increasing urbanization as well as industrialization in Vapi, Daman, Silvassa and Dadra and Nagar Haveli is found to have unfavourable impacts on the aquatic life of Damanganga river, its estuary and coastal environment.

The principal sources for presence of metals in riverine waters are atmospheric deposition, human actitivities like agricultural run-off, domestic sewage, industrial discharges, and geologic weathering [25]. The geothermal-hydrothermal waters, water-rock interactions, volcanoes, and saline soils also are the natural sources [29]. The marine geochemists have more interest in boron due to its role in marine alkalinity and its application as isotope systematic and to determine the paleo-pH of oceanic water and paleo-pCO_2 of atmosphere as B/Ca ratio; it shows both conservative and non-conservative behavior by the distribution in global estuaries [28]. Present day, natural and mankind both sources contribute to the concentration of boron in aquatic ecosystem. In the case of heavy metal assessment, the result showed that boron and manganese were more concentrated during winter season (1.9699 ± 0.9557; 0.9218 ± 0.1451) and less concentrated during monsoon (0.0438 ± 0.0205; 0.0133 ± 0.0019) period at the downstream (Figure 3.1). Similar findings about boron was observed from Tapi, Narmada and Mandovi estuaries [28]; Zuari estuary, Goa [30]. The contamination of boron and manganese was attributed due to additionl of anthropogenic sewage and industrial discharges along the water body. Aluminum had higher (1.1521 ± 0.4593) concentration during monsoon period and lower (0.0734 ± 0.0215) during winter period at the downstream (Figure 3.1). Iron showed higher (1.7803 ± 0.3296) and lower (0.0956 ± 0.0117) contaminations during monsoon at the upstream and during winter at the downstream station respectively (Figure 3.1). This record was similar with the report from Ennor estuary, Madras [31]; also the identical report on iron from upstream was found from shallow estuary [27]. The precipitation of Iron hydroxide under alkailine nature of water leads to the less iron concentration in estuarine water as compared to fresh water [25; 27]. Naurally, due to the oxides of zinc and lack of free metal’s solubility, zinc is a minor constituent [25]. The concentration of zinc was more (1.3547 ± 0.6048) and less (0.0066 ± 0.0011) at the downstream during summer and monsoon season respectively (Figure 3.1); which may be due to the effluent discharges, effect of dilution, geochemical, hydrochemical and biochemical activities. The toxicity of zinc varies depending on the characteristics of water quality and aquatic life being considerd [26]. The concentrations of heavy metals were higher at the downstream than upstream during summer and winter seasons with fluctuations and monsoon season showed less heavy metal loadings (Table 3.1). The contaminations of the parameters beyond the standard desirable limit values due to the effluent discharges were from the surrounding industries hence it is predictable that the water quality of Damanganga estuary is highly polluted and unsuitable water for any kind of utilization by mankind.

Water Quality Index: Water quality index (WQI) is calculated on the basis of twelve water quality factors (pH, TDS, Temperature, Ca Hardness, Turbidity, Chloride, DO, Phosphate, Nitrate, Ammonium, Sulfate, Silicate) with five heavy metals (Aluminum, Iron, Manganese, Boron and Zinc) for all three consecutive seasons (Winter, Summer and Monsoon) of the year (2019) to understand the estuarine water quality - dynamics. A lower value of WQI proposed better quality of water and higher value of WQI proposed poor water quality (Table 2.4). The calculated values of WQI for Damanganga estuary from all three seasons ranged between 122.84 to 173.82 which suggested poor water quality of the water body (Table 3.2). As per the result of WQI, the downstream station is more polluted than the upstream station. According to seasonal variation, during the period of winter the water body is more polluted due to more components loading followed by summer and monsoon. The poor water quality of the study area may be due to the dominant surrounding industrial zone as well as other anthropogenic activities.

Table 3.1: Statistical description of water quality parameters.

Parameters (Mean ± SD)	Winter		Summer		Monsoon	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
Color (Hazen)	87.59 ± 7.74	77.71 ± 13.02	88.18 ± 10.09	89.85 ± 1.71	116.91 ± 9.97	109.76 ± 10.21
Alkalinity (mg/L)	106.67 ± 13.67	120.32 ± 3.28	104.00 ± 18.38	122.50 ± 13.43	113.37 ± 16.08	142.72 ± 9.51
Total Solid (mg/L)	1245.11 ± 166.10	1732.77 ± 238.97	817.17 ± 88.72	969.40 ± 105.93	914.70 ± 40.65	1185.74 ± 129.62
TDS (mg/L)	796.07 ± 91.87	1177.85 ± 322.51	386.41 ± 103.10	541.34 ± 96.85	579.05 ± 79.47	562.37 ± 89.68
TSS (mg/L)	419.02 ± 104.26	596.92 ± 96.46	446.76 ± 51.83	428.06 ± 80.92	415.65 ± 31.18	643.37 ± 99.94
pH	7.05 ± 0.21	7.25 ± 0.21	7.10 ± 0.42	7.10 ± 0.28	7.20 ± 0.14	7.60 ± 0.14
Temperature (°C)	20.00 ± 1.41	20.00 ± 1.41	25.50 ± 2.12	27.50 ± 2.12	21.50 ± 2.12	24.00 ± 2.82
Free CO_2 (mg/L)	16.79 ± 1.27	16.69 ± 2.88	25.75 ± 4.48	26.28 ± 1.54	10.77 ± 0.77	16.51 ± 4.09
Salinity (ppt)	8.03 ± 0.50	10.93 ± 0.53	8.84 ± 0.38	13.26 ± 0.99	6.92 ± 0.33	10.02 ± 0.91
Total Hardness (mg/L)	1403.50 ± 211.42	2365.50 ± 36.06	1795.00 ± 38.18	2919.00 ± 79.19	1098.00 ± 76.36	2237.00 ± 59.39
Ca Hardness(mg/L)	221.65 ± 5.65	374.00 ± 25.45	267.50 ± 43.13	465.50 ± 27.57	177.50 ± 7.77	318.50 ± 91.21
Turbidity (NTU)	12.11 ± 2.23	12.42 ± 0.96	11.83 ± 1.21	16.04 ± 0.098	15.34 ± 1.40	18.36 ± 1.43
EC (μs/cm)	300.77 ± 70.04	433.18 ± 101.48	240.12 ± 40.89	385.84 ± 52.14	320.12 ± 62.53	680.03 ± 94.30
Chloride (mg/L)	1675.18 ± 680.07	1840.91 ± 570.30	1365.79 ± 104.59	1577.22 ± 78.99	900.11 ± 103.90	1174.23 ± 204.83
DO (mg/L)	3.20 ± 0.12	4.54 ± 0.08	3.00 ± 0.11	3.78 ± 0.0420	2.74 ± 0.18	3.48 ± 0.23
BOD (mg/L)	3.06 ± 0.57	4.87 ± 0.08	2.95 ± 0.33	3.90 ± 0.51	2.91 ± 0.26	3.20 ± 0.33
COD (mg/L)	13.02 ± 4.62	12.71 ± 1.37	12.37 ± 2.46	12.35 ± 0.53	8.27 ± 0.49	9.12 ± 0.42
Phosphate (mg/L)	0.0267 ± 0.0013	0.0257 ± 0.0019	0.021 ± 0.0025	0.0234 ± 0.0031	0.0171 ± 0.0009	0.0210 ± 0.0022
Nitrate (mg/L)	21.22 ± 2.22	26.69 ± 2.72	19.01 ± 0.90	25.24 ± 1.81	16.76 ± 0.68	20.41 ± 1.48
Ammonium (mg/L)	8.20 ± 0.22	8.56 ± 0.94	8.63 ± 0.29	8.50 ± 0.34	5.99 ± 0.056	6.18 ± 0.57
Sulfate (mg/L)	151.51 ± 45.64	248.61 ± 15.35	230.37 ± 27.08	357.11 ± 25.50	165.09 ± 59.75	289.55 ± 32.68
Sodium (mg/L)	427.00 ± 20.50	602.05 ± 4.45	393.80 ± 6.36	561.40 ± 3.25	508.90 ± 118.51	615.55 ± 41.50
Potassium (mg/L)	75.60 ± 9.75	170.65 ± 16.61	69.20 ± 4.66	173.60 ± 2.54	96.50 ± 87.11	167.60 ± 36.91
Silicate (mg/L)	7.70 ± 1.06	11.27 ± 2.75	8.06 ± 0.34	10.97 ± 0.58	5.53 ± 0.32	6.92 ± 0.49
Aluminum (mg/L)	0.0885 ± 0.0200	0.0734 ± 0.0215	0.4781 ± 0.5591	0.3341 ± 0.4100	0.9990 ± 1.3129	1.1521 ± 0.4593
Boron (mg/L)	0.2015 ± 0.1628	1.9699 ± 0.9557	0.7356 ± 0.8586	1.0311 ± 0.3079	0.2466 ± 0.2694	0.0438 ± 0.0205
Iron (mg/L)	1.3548 ± 0.3711	0.0956 ± 0.0117	1.2136 ± 0.2225	0.5564 ± 0.1453	1.7803 ± 0.3296	0.9354 ± 0.5890
Manganese (mg/L)	0.5342 ± 0.2245	0.9218 ± 0.1451	0.2956 ± 0.1984	0.6348 ± 0.1438	0.1263 ± 0.0605	0.0133 ± 0.0019
Zinc (mg/L)	0.4261 ± 0.1720	1.1937 ± 0.3558	0.9514 ± 0.1616	1.3547 ± 0.6048	0.0124 ± 0.0084	0.0066 ± 0.0011

Statistical Analysis: Normal Probability Distribution: The normal probability plot was derived for studied habitat and seasonal periods. A formal test of normal probability distribution for data was fabricated in form of normal probability plot (NP plot). The points on the NP plot are the correlation coefficients that indicate probable normal distribution of data. The distribution of correlation coefficient on the NP plot is suitable to determine that the data set arises from the group with almost normal distribution [13]. A NP plot is very significant for testing of normality hypothesis. A straight line of NP plot evinced that data set has a normal probability distribution. In this study, probability for normal distribution of water quality data is 71.40% at the downstream and 73.00% at upstream during winter season; during the period of summer 70.30% for downstream and 73.50% for upstream and during the rainy period for the downstream and upstream are 74.30% and 80.90% respectively.

Table 3.2 Water Quality Index from Damanganga Estuary

Season	Water Quality Index (WQI)	
	Downstream (Site 1)	Upstream (Site 2)
Winter	173.82	149.17
Summer	168.35	143.49
Monsoon	126.02	122.84

Table 3.3 Water quality standards for coastal waters (See the below references).

Sr. No.	Parameters	Units	Prescribed Standards
1	Chloride	mg/L	1000.0*
2	Boron	mg/L	0.7****
3	Phosphate	mg/L	0.001-0.01**
4	Sulfate	mg/L	250***
5	Silicate	mg/L	2.8**
6	Ammonium	mg/L	2.2*****
7	Zinc	mg/L	0.5**
8	Aluminum	mg/L	0.1*****
9	Manganese	mg/L	0.1***
10	Iron	mg/L	0.3***

* Water Quality Standards for Coastal Waters Marine Outfalls. SW-II Standard. Central Pollution Control Board, New Delhi.; ** South African Water Quality Guidelines for Coastal Marine Waters, 1996. International Target Values for the Natural Marine Environment, Vol.1, pp B-1-B-3. and Chap. 4.2. pp 31.; *** KepMenKes No. 51/MENKES/SK/VII/2004. quality standards of the Environment Decree No. 51 in 2004 on Marine water quality standard for marine biotas.; **** UK Marine Standards.; ***** Canadian Water quality standards for Marine fisheries and aquatic life, Environment Canada, 1987 CEC, 1978, 1980 committee for fisheries, 1993.

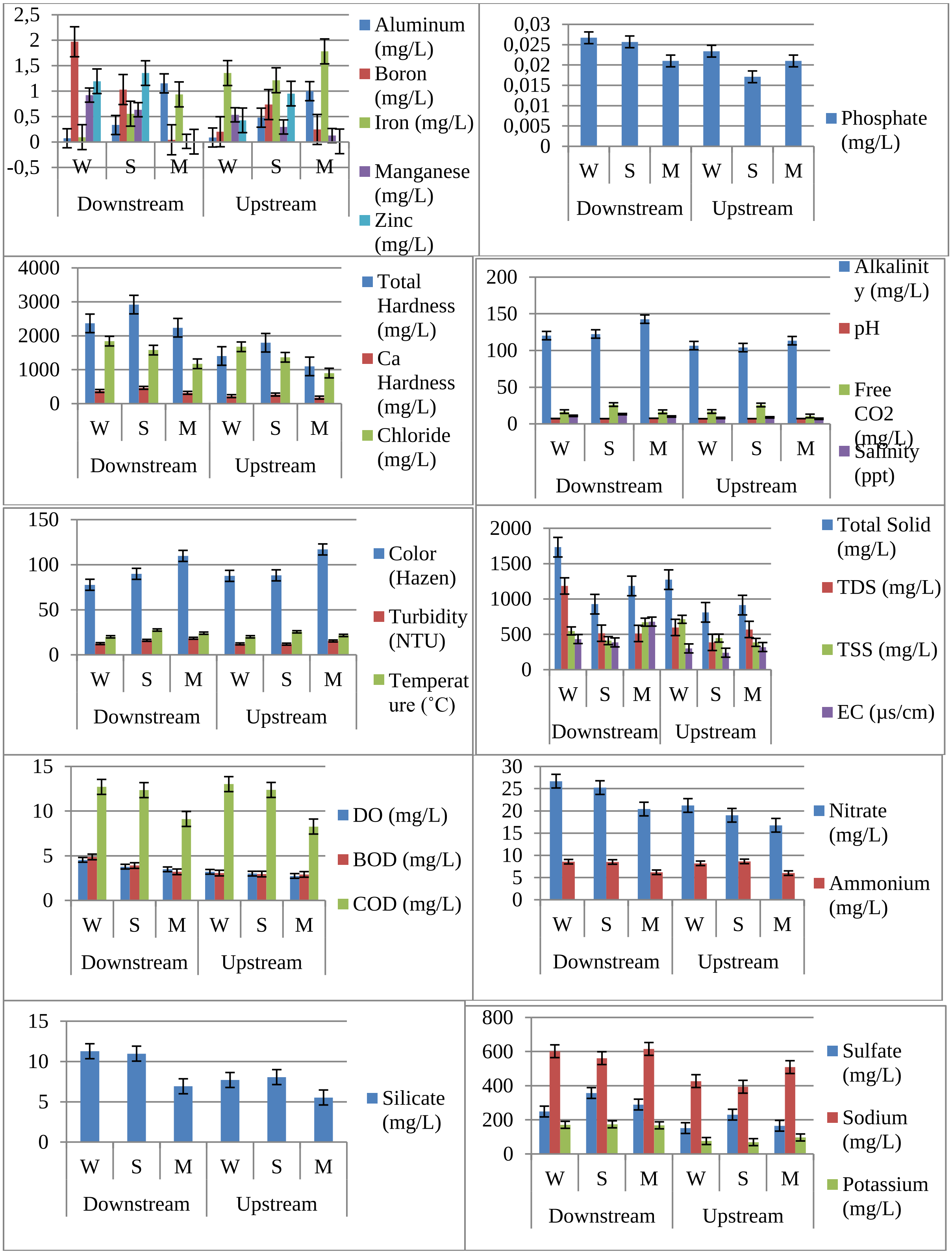

Figure 3.1. Seasonal variation of all water quality parameters

Cluster Analysis: Cluster analysis (CA) is a multivariate statistical technique, which allows the grouping of objects on the basis of their similarity [14] and therefore it is a very useful tool for the assessment of water quality data to get the relationship. The most significant perspective of cluster analysis is Bray-Curtis analysis that explores the intuitive resemblance association within one sample and the whole dataset and is usually demonstrated through a dendrogram (tree diagram). The clustering process gives rise to a visual summary of the data by the dendrogram, which represents the figure of the assemblages with their proximity in addition to a considerable reduction in dimensionality of the actual data [15].

In this investigation, the principal variables that have the impact on the water body give rise to strong spatial and temporal relationships exhibited by cluster analysis and indicated that the mankind activities affect the water quality are spatially and temporally variable. CA generated a dendrogram on the basis of percentage of similarity and dissimilarity of water quality parameters. The Bray-Curtis similarity analysis confirmed that there is about 98 % similarity between DO and BOD; approximate 96.5 % similarity between Total solids and Sulfate; 95 % similarity of sodium with Total solids and Sulfate. There is 93 % similarity between Salinity and Silicate; 91.5 % between pH and Ammonium and between Temperature and Nitrate 90.5 % similarity. In the case of heavy metals Aluminum with Iron, Boron with Zinc, Manganese with Boron-Zinc and Aluminum-Iron with Boron-Zinc-Manganese cluster showing 64.5 %, 77 %, 68.5 % and 35 % similarity respectively. Total hardness and Chloride showing 81 % similarity; Total solids-Sulfate-Sodium-Potassium community showing 70.5 % similarity with TDS-TSS-Ca hardness community and Alkalinity-color group representing 45 % similarity with them. There is 88.5 % similarity by Temperature and Free CO_2as well as pH and Salinity (Figure 3.3.2).

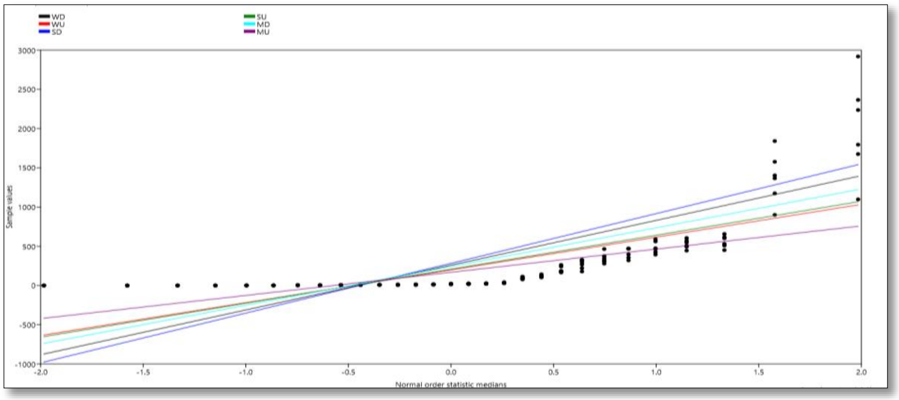

Figure 3.3.1: Normal Praobability plot of selected two habitat and studied seasons.

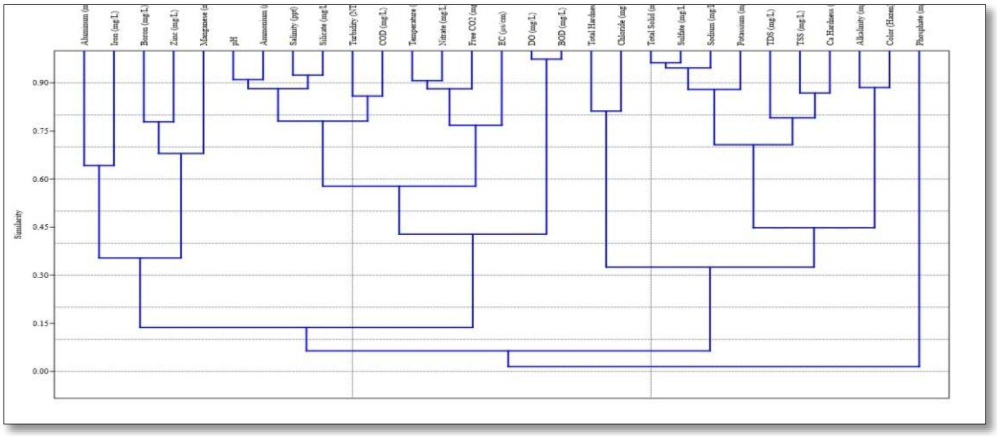

Figure 3.3.2: Bray-Curtis cluster analysis of water quality parameters.

As the conclusion, this investigation indicates excess amount of chloride, sulfate, ammonium, silicate, phosphate and heavy metals (Al, Fe, Mn, B, Zn) in the water sample. The above parameters were found to be beyond the standard desirable limitations (Table 3.3). There are about 5105 Nos. industries around the basin of Damanganga River so it is predictable that the level of water pollution have reached to an alarming stage. Anthropogenic sources, industrial and urban sources, natural weathering and various polluting factors are contaminating the riverine as well as estuarine water. The overall view of higher WQI indicates deteriorated water quality hence the water is unfit for human consumption for any kind of purpose. Hence, regular investigation and management of water quality is required to observe the rate and type of contamination.

ACKNOWLEDGMENT

The authors are thankful to N. V. Patel College of Pure and Applied Sciences. They are also grateful to SICART.

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Received: 27thOctober 2020; Accepted: 03th December 2020;

First distribution: 04 January 2021.