Of all the natural resources, water is unarguably the most essential and precious. It is the elixir of life, a precious gift of nature to mankind and millions of other species living on the earth. Water resources comprising of surface water (river and lakes), ground water, and marine and coastal waters support all living organisms including human beings. Surface Rivers have always been the lifelines of development and with the course of time have borne the impacts of development and industrialization in the form of abstractions of water besides other wastewater releases. The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem. Good quality of water resources depends on a large number of physico-chemical characteristics. Physico-chemical analyses of water provides a good indicator of the quality of the aquatic system and gives discrete information on the effects of pollutants (Venkatesharaju et al., 2010).

The River Godavari is the largest of the peninsular rivers and the second longest river in India next only to Ganga. River Godavari serves as a source of water for drinking, domestic use, agricultural irrigation and industries in Ambad stretch. Therefore, present investigation was carried out to study the physico-chemical properties of Godavari River water at Ambad stretch during 2012-2014. Five different locations were identified and water samples were collected from each sampling station in every month during June 2012 to May 2014. The collected water samples were studied for temperature, turbidity, pH, total dissolved solids (TDS), total alkalinity (TA), total hardness, phosphate, nitrate, chlorides, dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) as per the standard methods. The results of the present investigation revealed that, the water of Godavari River at Ambad stretch was found moderately polluted at site C and A, whereas the average quality of water was satisfactory with respect to the day today activities except direct consumption. The identified sources of water pollution included discharge of sewage water, religious activity, agriculture runoff, nitrogenous waste from farms and industrial effluents.

Key words: Godavari River, water pollution, water quality.

The River Godavari is the largest of the peninsular rivers and the second longest river in India next only to Ganga. The people believe that taking a holy dip in the river relieves them from all the sins. Being the ultimate sink of anything and everything drained through surface runoff, the river has been subjected to considerable stress. As a result, the water is being polluted by indiscriminate disposal of sewage, industrial waste and plethora of human activities, which affects its physico-chemical characteristics and microbiological quality (Koshy and Nayar, 1999).

River Godavari serves as a source of water for drinking, domestic use, agricultural irrigation and industries in Ambad stretch. Therefore, present investigation was carried out to study the physico-chemical properties of Godavari River water at Ambad stretch during 2012-2014.

MATERIALS AND METHODS

Study area: Present investigation was carried out on Godavari River water at Ambad Stretch starting from Paithan to Shahagad. The total length of the Godavari River under present study was around 12 km in which five different locations viz. Paithan being the reference site (unpolluted), followed by Balegaon, Gandhari, Shahagad-A and Shahagad-B were identified for collecting the water samples (Table 1).
Water sampling and analysis: Water samples were collected from each sampling station (Table 1) in first week of every month during June 2012 to May 2014 in morning hours (between 7.00 to 10.00 am). Water temperature was recorded and dissolved oxygen was fixed at sampling site. The collected water samples were analyzed in laboratory for different physical and chemical parameters as per the standard methods (APHA, 2005; Trivedi and Goel, 1984). The parameters studied were temperature, turbidity, pH, total dissolved solids (TDS), total alkalinity (TA), total hardness, Phosphate, nitrate, chlorides, dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD).

RESULTS AND DISCUSSION

The average results obtained from the analysis of the Godavari River water sampled at different locations are presented in Table 2.

Water temperature: The average water temperature was observed between 23.3 and 23.6°C among different sampling locations (Table 2). The monthly average temperature of the Godavari River water at Ambad stretch ranged from 19.6°C in December to 27.9°C in May followed by April (Table 3). The seasonal variation in the water temperature was clearly observed during the study. The lowest water temperature was observed in winter season followed by monsoon. The highest temperature (26.9°C) was observed in summer season (Table 3).

Temperature plays very important role in the physiological behavior and distribution of aquatic organisms. The variation in river water temperature usually depends on the season, geographic location, ambient air temperature and chemical reaction in a water body (Ahipathi and Puttaiah, 2006). It also governs solubility of the oxygen, carbon dioxide, bicarbonates-carbonates equilibrium (De, 2002). The catabolic energy released in the form of heat during decomposition of organic matter and respiration may lead to rise in water temperature (Murthuzasab et al., 2010). The highest water temperature in summer season especially in May month attributed to the highest ambient air temperature (Zingde, 1981). Similar trend of results were also reported by Trivedy et al. (1990), Kathiresan (2001), Sawane (2002), Adebowale et al. (2002), Petronella et al. (2009), Singh et al. (2010), Khinchi et al. (2010), Sharma et al. (2011), Mithani et al. (2012) and Garnaik et al. (2013).

Turbidity: Turbidity measures water clarity or the ability of light to pass through water. In present investigation water

Table 1: Details of sampling stations

<table>
<thead>
<tr>
<th>Sampling Station</th>
<th>Code</th>
<th>Geographical Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paithan (Reference)</td>
<td>R</td>
<td>19°29'08.3&quot;N,75°22'40.8&quot;E</td>
</tr>
<tr>
<td>Balegaon</td>
<td>A</td>
<td>19°23'17.5&quot;N,75°36'54.0&quot;E</td>
</tr>
<tr>
<td>Gandhari</td>
<td>B</td>
<td>19°22'05.4&quot;N,75°40'21.5&quot;E</td>
</tr>
<tr>
<td>Shahagad-A</td>
<td>C</td>
<td>19°22'32.3&quot;N,75°43'21.0&quot;E</td>
</tr>
<tr>
<td>Shahagad –B</td>
<td>D</td>
<td>19°22'35.4&quot;N,75°43'29.5&quot;E</td>
</tr>
</tbody>
</table>

Table 2: Physico-chemical properties of Godavari River water at different sampling site

<table>
<thead>
<tr>
<th>Sampling Station</th>
<th>Temp</th>
<th>Turbidity</th>
<th>pH</th>
<th>TDS</th>
<th>TA</th>
<th>TH</th>
<th>PO₄³⁻</th>
<th>NO₃⁻</th>
<th>Cl</th>
<th>DO</th>
<th>BOD</th>
<th>COD</th>
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<tbody>
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<td>27.1</td>
<td>6.7</td>
<td>4.3</td>
<td>12.2</td>
</tr>
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<td>231.7</td>
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<td>45.7</td>
<td>5.8</td>
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<td>23.4</td>
<td>7.85</td>
<td>674.4</td>
<td>485.9</td>
<td>316.2</td>
<td>4.67</td>
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<td>109.2</td>
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<td>37.8</td>
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<td>133.6</td>
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<tr>
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<td>674.4</td>
<td>485.9</td>
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<td>109.2</td>
<td>6.7</td>
<td>37.8</td>
<td>215.0</td>
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<tr>
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<td>284.3</td>
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</table>

Note: All parameters are in mg l⁻¹ except temperature (°C), turbidity (nephlometric turbidity unit i.e. NTU) and pH.
Turbidity was observed between 7.0 and 23.4 NTU among different sampling sites (Table 2). The lowest average turbidity was observed at reference location (R) followed by B and D site. The highest turbidity was recorded for site C (23.4 NTU) followed by site A (17.1 NTU). The monthly data recorded with respect to the turbidity of water samples revealed that, it ranged between 5.9 NTU and 26.4 NTU in different months (Table 3). The seasonal data showed that, the water turbidity was found highest in monsoon (24.7 NTU) season followed by winter (8.8 NTU) with least in summer (6.5 NTU) season. Surface-runoff, stream flow and overland flow in natural waters increase the turbidity levels in water. The high turbidity during rainy season might be attributed to the inclusion of silt, clay and other suspended particles in the water and contributed to the higher turbidity values, while during winter and summer season settlement of silt, clay resulted in lower turbidity of water (Dagaonkar and Saksena, 1992; Garg et al., 2006). Similar observations have also been reported by Kitt (2006), Yadav and Kumar (2011), Sharma et al. (2011), Medudhula et al. (2012) and Garnaik et al. (2011).

**pH:** The present investigation reflects the water pH was slightly basic at all the sites and in all seasons during the study period (Tables 2, 3 and 4). It ranged from 7.5 to 7.9. The pH in monsoon season was found highest as compared to the summer and winter season. In monsoon season the pH was 8.2, whereas a value of 7.4 was recorded for both winter and summer seasons (Table 4). The mild alkaline nature of river water attributed to the presence of CO$_2$ in water as bicarbonate (Azeez et al., 2000). The leaching of basic rock material by rainwater and carried by surface runoff to river stream attributed to the higher values of water pH during rainy season (Lalparmawii, 2007). Similar observations have also been reported by Adoni (1985), Singh (1995), Sivasubramani (1999), Jakher (2002), Fakayode (2005), Saksena et al. (2008) and Rosli et al. (2010).

**Total dissolved solids (TDS):** In the present investigation TDS showed variation at all the sites during study period. The TDS ranged between 288.7 mg l$^{-1}$ and 674.4 mg l$^{-1}$ among different sampling locations (Table 2). The highest value of TDS was observed at site C followed by site A (622.8 mg l$^{-1}$).

<table>
<thead>
<tr>
<th>Month</th>
<th>Temp.</th>
<th>Turbidity</th>
<th>pH</th>
<th>TDS</th>
<th>TA</th>
<th>TH</th>
<th>PO$_4^{3-}$</th>
<th>NO$_3^-$</th>
<th>Cl$^-$</th>
<th>DO</th>
<th>BOD</th>
<th>COD</th>
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<td>8.3</td>
<td>537.2</td>
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<td>205.7</td>
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<td>20.8</td>
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<td>1.9</td>
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<td>7.0</td>
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<td>7.5</td>
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<td>5.9</td>
<td>7.2</td>
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<td>180.7</td>
<td>1.7</td>
<td>15.0</td>
<td>52.3</td>
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<td>8.3</td>
<td>537.2</td>
<td>333.7</td>
<td>231.7</td>
<td>3.2</td>
<td>21.0</td>
<td>65.5</td>
<td>7.0</td>
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</table>

**Note:** All parameters are in mg l$^{-1}$ except temperature (°C), turbidity (nephelometric turbidity unit i.e. NTU) and pH.
Similar to the site specific variation in TDS, the seasonal and monthly variations were also observed in Godavari River water (Table 3). The highest value of TDS was observed in monsoon season (527.7 mg l\(^{-1}\)) followed by summer and winter season (Table 4). Total dissolved solids (TDS) are a measure of the amount of dissolved materials in the water and mainly contains minerals (Senthlinathan et al., 2011). There was marked effect of seasons on TDS as all sites showed high TDS in monsoon and low TDS in winter and summer which might be attributed to the addition of solids from runoff water. Tope (2008) reported higher TDS values during rainy and autumn seasons. Similar results were also reported by Masood and Krishnamurthy (1990), Khatavkar and Trivedi (1992), Patka and Rao (1997), Rao et al. (2003), Kirubavathy et al. (2005), Tiwari (2005), Nduka et al. (2008), Moniruzzaman et al. (2009), Kataria and Kumar (2010) and Imtiyaz et al. (2012).

Total alkalinity (TA): The alkalinity of water is its capacity to neutralize acids. Alkalinity is the measure of buffering capacity of the water. It is generally imparted by the salts of carbonates, bicarbonates, phosphate, nitrates etc. (Yellavarthi, 2002). In present investigation the TA ranged from 201.0 mg l\(^{-1}\) (site D) to 485.9 mg l\(^{-1}\) (site C) among different sampling sites (Table 4). The average monthly data showed that, the total alkalinity ranged between 241.3 mg l\(^{-1}\) and 333.7 mg l\(^{-1}\) in different months (Table 3). As far as seasonal variation is concerned, the highest TA was observed in summer followed by winter and monsoon season (Table 4). In general the maximum values of total alkalinity at all the sites were observed during summer and minimum were recorded during monsoon season. Sankaran (1988) also reported high values of alkalinity in summer and low during rainy season while studying physico-chemical properties of Adyar River. The higher total alkalinity during summer season might be attributed to the higher water temperature which resulted in an increase in the rate of decomposition and decrease in water level. Similarly, the increase in total alkalinity due to various religious activities, domestic waste and especially due to soaps and detergents were also reported by Patil (2003). Similar trend of results were also reported by Mithani et al. (2012).

Total hardness (TH): Hardness of water is a measure of its capacity to produce lather with soap (Garnaik et al., 2013). Total Hardness is an important parameter of water quality whether it is used for domestic, industrial or agricultural purposes (Jothivenkatachalam et al., 2010). In our study, the TH ranged from 133.6 mg l\(^{-1}\) at site R to 316.2 mg l\(^{-1}\) at site C (Table 2). The monthly data in Table 3 revealed that, the total hardness ranged between 180.7 mg l\(^{-1}\) to 231.7 mg l\(^{-1}\) with an average value of 199.4 mg l\(^{-1}\). The highest value of TH was observed in winter followed by summer season whereas the lowest TH was observed in monsoon season (Table 4). The cations of calcium, magnesium, iron and manganese contribute to the hardness of water (Shrivastava and Patil, 2002). The widespread abundance of these metals in rock formations leads often to very considerable hardness levels in surface and ground waters (EPA, 2001). Similarly, the Ca and Mg that enter the water bodies through residues of soaps, detergents and parent bed rock materials made up of Ca, Mg and other metal ions also significantly contributes to total hardness of water (Nanda, 2005). In present investigation, the total hardness was observed higher in summer and winter while lower in monsoon season.

<table>
<thead>
<tr>
<th>Season</th>
<th>Temp.</th>
<th>Turbidity</th>
<th>pH</th>
<th>TDS</th>
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<th>TH</th>
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<th>NO(_3)</th>
<th>Cl</th>
<th>DO</th>
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<td>6.5</td>
<td>7.4</td>
<td>461.0</td>
<td>322.9</td>
<td>202.9</td>
<td>2.1</td>
<td>15.9</td>
<td>62.0</td>
<td>4.8</td>
<td>13.0</td>
<td>112.6</td>
</tr>
<tr>
<td>Min</td>
<td>20.3</td>
<td>6.5</td>
<td>7.4</td>
<td>407.3</td>
<td>253.2</td>
<td>192.2</td>
<td>2.0</td>
<td>15.9</td>
<td>56.3</td>
<td>4.8</td>
<td>13.0</td>
<td>89.9</td>
</tr>
<tr>
<td>Max</td>
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<td>24.7</td>
<td>8.2</td>
<td>527.7</td>
<td>322.9</td>
<td>203.2</td>
<td>2.9</td>
<td>19.9</td>
<td>63.5</td>
<td>6.8</td>
<td>20.1</td>
<td>112.6</td>
</tr>
<tr>
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<td>9.93</td>
<td>0.47</td>
<td>60.35</td>
<td>35.44</td>
<td>6.27</td>
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<tr>
<td>Sem</td>
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<td>5.73</td>
<td>0.27</td>
<td>34.84</td>
<td>20.46</td>
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<td>0.30</td>
<td>1.29</td>
<td>2.21</td>
<td>0.60</td>
<td>2.14</td>
<td>7.10</td>
</tr>
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</table>

Note: All parameters are in mg l\(^{-1}\) except temperature (°C), turbidity (nephlometric turbidity unit i.e. NTU) and pH.
The lower values of total hardness during rainy season attributed to dilution on account of heavy precipitation. Our findings are in conformity with the findings of Rajalakshmi and Shreelatha (2005) who observed higher TH in summer than monsoon season while studying physico-chemical properties of Gautami River water. Similarly, Jain et al. (2004), Yadav and Kumar (2011); and Garnaik et al. (2013) have also reported similar results with respect to the seasonal variation in total hardness of surface water.

**Phosphate (PO\(_4^{3-}\))**: The phosphate concentration in Godavari River water at different sampling location ranged between 0.19 mg l\(^{-1}\) and 4.67 mg l\(^{-1}\) (Table 4). The highest phosphate concentration was found at site C followed by site A and site B. The seasonal mean biannual concentration of the phosphate in Godavari River water ranged from 2.0 mg l\(^{-1}\) in winter season to 2.9 mg l\(^{-1}\) in monsoon season (Table 4). Phosphorous is widely used as an agricultural fertilizer and as a major constituent of detergents, particularly those for domestic use. Run-off and sewage discharges are thus important contributors of phosphorus to surface waters (EPA, 2001). The higher concentration of phosphate in monsoon season might be attributed to the presence of heavy cultivation in the study area which acted as source for phosphates. Similarly, animal waste, agriculture waste and detergent in domestic wastewater also contributed towards the observed increment in phosphates (Anda et al., 2001). Sinha et al. (1998) have also reported higher phosphate content in lower stretch of Ganga River during monsoon season as compared to the summer and winter season. Similar trend of results have also recorded by Koshiy et al. (2000) and Khound et al. (2012).

**Nitrate (NO\(_3^{-}\))**: Nitrate concentration in Godavari River water sampled at different locations ranged between 3.35 mg l\(^{-1}\) and 39.1 mg l\(^{-1}\) with mean value of 17.3 mg l\(^{-1}\) (Table 4). The highest concentration of nitrate was found at site C followed by site A and B (19.5 mg l\(^{-1}\)). The lowest concentration of nitrate was observed at site D (3.35 mg l\(^{-1}\)). The mean monthly concentration of nitrate in water ranged from 15.0 mg l\(^{-1}\) and 21.0 mg l\(^{-1}\) in December and September months, respectively with an average of 17.3 mg l\(^{-1}\) (Table 3). Similarly, the data in Table 4 revealed that, the highest concentration of the nitrate was observed during monsoon season (19.9 mg l\(^{-1}\)) followed by winter (16.2 mg l\(^{-1}\)) and summer season (15.9 mg l\(^{-1}\)). Nitrate in surface water is an important factor for water quality assessment (Jhones and Burt, 1993) which is mainly contributed by waste discharges and artificial nitrogenous fertilizers. However, bacterial oxidation and fixing of nitrogen by plants also contribute to some extent (EPA, 2001). The higher values of the nitrate in monsoon season were mainly attributed to the nitrate rich runoff from agricultural fields and large amount of contaminated sewage (Mithani et al., 2012). Similar results were also reported by Laiparmawii (2007), Singh and Gupta (2010) and Khound et al. (2012).

**Chloride (Cl\(^{-}\))**: The chloride in Godavari River water ranged from 60.6 mg l\(^{-1}\) to 109.2 mg l\(^{-1}\) at various sampling locations (Table 2). The highest concentration of chlorides was observed at site C followed by site A and site B. The average monthly data in Table 3 revealed that the chloride concentration in Godavari River water ranged between 52.3 mg l\(^{-1}\) and 65.5 mg l\(^{-1}\) (Table 3). The seasonal variation in chloride concentration in the river water revealed that it was highest in winter season followed by summer and monsoon season (Table 4). Khound et al. (2012) also observed higher concentration of chlorides in dry season as compared to the wet seasons. The higher chloride content in the dry seasons than those of the wet seasons is mainly attributed to the dilution of water in rainy season and evaporation of water in summer season (Adoni, 1985; Yardi, 1999). Our results are in conformity with those observed by Khataforkar and Trivedi (1992), Chandrashekhar (1994), Kumar (2000), Zafar and Sultana (2008) and Venkatesharaju et al. (2010).

**Dissolved oxygen (DO)**: The sampling station wise mean dissolved oxygen data in Table 2 showed that, DO ranged between 4.2 mg l\(^{-1}\) to 6.7 mg l\(^{-1}\). The highest DO values was recorded for sampling site R followed by D and B. The mean monthly DO concentration showed that, it ranged between 4.7 mg l\(^{-1}\) and 7.0 mg l\(^{-1}\) (Table 3). Similarly, the seasonal data revealed that, the highest concentration of DO in Godavari River water was observed during winter season followed by monsoon and summer season. The DO in different seasons ranged from 4.8-6.8 mg l\(^{-1}\). Dissolved oxygen is one of the important parameter in water quality assessment as it regulates and governs metabolic activities and metabolism of the biological community as a whole, respectively and also acts as an indicator of trophic status of the water body (Saksena and Kausshik, 1994). Its presence is essential to maintain variety of forms of biological life in water. Oxygen is generally reduced
in the water due to respiration of biota, decomposition of organic matter, rise in temperature, oxygen demanding wastes and inorganic reductant such as hydrogen sulphide, ammonia, nitrites, ferrous iron, etc. (Sahu et al., 2000).

During study there was marked effect of seasonality on DO, sites C reflects low DO in monsoon and DO at all the site were found maximum in winter and minimum in summer, low DO content during rainy season may be due to high rate of organic matter decomposition, as more organic matter from surroundings was discharged into river water through surface runoff (Hannan, 1979). Rani et al. (2004) also reported lower values of Dissolved oxygen in summer season due to higher rate of decomposition of organic matter and limited flow of water in low holding environment due to high temperature. Maximum values of DO in winter might be due to the fact that the solubility of D.O. increases with the decrease in water temperature (Kumar, 2000). Similar observations were also recorded by Bansal and Samidha (1989), Mohanta and Patra (2000), Kamaruzzaman et al. (2008), Zannatul and Muktadir (2009), Singh and Gupta (2010) and Khinchi et al. (2011).

Biological oxygen demand (BOD): The biological oxygen demand of Godavari River water was observed between 4.3 mg l\(^{-1}\) and 37.8 mg l\(^{-1}\) among different sampling sites (Table 2). The highest BOD was observed at site C followed by site A (20.9 mg l\(^{-1}\)). The lowest BOD was observed at site R (4.3 mg l\(^{-1}\)) followed by site D (4.4 mg l\(^{-1}\)). The mean seasonal values of BOD were observed in the range of 13.0-20.1 mg l\(^{-1}\) in different season (Table 4). The highest BOD was observed in monsoon season (20.1 mg l\(^{-1}\)) followed by winter (14.7 mg l\(^{-1}\)) and summer season (13.0 mg l\(^{-1}\)).

Biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Abida, 2008). BOD remains the most critical parameter and high BOD content deplete oxygen more rapidly in the aquatic body resulting into low oxygen availability for aquatic life. Major sources of BOD in water include leaves and woody debris, dead plants and animals, faecal waste, effluents from pulp and paper mills, feedlots and food processing plants. During study there was marked effect of seasonality on BOD, all sites reflect high BOD in monsoon which might be attributed to increased metabolic activities of microbes present in the water bodies and low decomposition rate of organic matter (Kumar and Sharma, 2005). BOD increases with organic matter addition, wastewater or urban storm water runoff took place at the river water. Fokmare and Musaddiq (2002) recorded high value of biochemical oxygen demand (BOD) in River Purna during monsoon season due to organic enrichment, decay of plants and animal matter in the river water. Similar results with respect to higher BOD in monsoon season compared to winter and summer season were also reported by Mishra and Tripathi (2000), Zainudin et al. (2010) and Garg et al. (2006).

Chemical oxygen demand (COD): The COD is a measure of oxygen equivalent to the organic matter content of the water susceptible to oxidation and thus is an index of organic pollution in river (Khaiwal and Anubha, 2003). Chemical oxygen demand is used as reliable parameter for judging the extent of pollution in water. High organic inputs trigger depletion of dissolved oxygen and enhance the COD. In present investigation the COD was observed 12.2 and 215.0 mg l\(^{-1}\) among different sampling sites (Table 2). The highest value of COD was observed at site C followed by site A (136.9 mg l\(^{-1}\)) and site B (108.5 mg l\(^{-1}\)). The lowest value of COD was observed for site R (12.2 mg l\(^{-1}\)) followed by site D (20.1 mg l\(^{-1}\)). The seasonal data in Table 4 revealed that, the COD varied between 89.9 and 112.6 mg l\(^{-1}\) during different seasons. Highest value of COD was observed during summer followed by winter and monsoon. Highest COD at site C indicated the higher pollution of water while lower level of COD indicated low level of pollution of water at the study area (Waziri and Ogugbuaja, 2010). Similar results were also reported by McCuaig et al. (1974), Choudhary et al. (2004), Kulshrestha and Sharma (2004); and Bamniya et al. (2011).

The results of the present investigation revealed that, the water of Godavari River at Ambad stretch was moderately polluted at site C and A, whereas the average quality of water was satisfactory with respect to the day today activities except direct consumption. The identified sources of water pollution were discharge of sewage water, religious activity, agriculture runoff, nitrogenous waste from farms and industrial effluents. Most of the pollutants are contributed by surface runoff in monsoon season, hence watershed management would play crucial role in managing the pollution of Godavari River.

REFERENCES


Maharashtra University (M. S.).


