In aquatic ecosystem, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter, reaeration (Granier et al, 2000) and physico-chemical properties of water (Aston, 1980). Dissolved oxygen is probably the most important parameter in natural surface water system for determining the health of aquatic ecosystem (Yang et al, 2007). Higher values of dissolved oxygen (DO) during monsoon season may be due to heavy rainfall during this period led to increased aeration of river water. Similar result was also observed in Ogum River-Nigeria (Adebisi, 1981). However, throughout the study period concentration of dissolved oxygen was very less in the site Panchgram which receives untreated industrial wastes. The statistical analysis of different sites and seasons also showed significant variations (ANOVA, P< 0.01). Chang (2005) has suggested that a minimum of 3 mg/l dissolved oxygen is necessary for healthy fish and other aquatic life. DO is regulator of metabolic activities of organisms and thus governs metabolism of the biological community as a whole and also acts as an indicator of trophic status of the water body. 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.

Most of the free carbon dioxide in water comes out from the decomposition of organic matter and respiration of organisms (Singh, 1999). In Barak River, higher values of CO$_2$ during monsoon season in all the sites may be attributed to the heavy input of sewage and other organic and inorganic ingredients due to surface run off as a result of heavy shower during this period. These materials in course of the time get oxidised which led to their decomposition and consequent release of CO$_2$ into water, whereas lower values of CO$_2$ was observed during summer and winter seasons which may be due to less incorporation of exterior organic matter and more photosynthesis by algae and cyanobacteria (Michael, 1984). In most of the sites, the free carbon dioxide values were above the maximum permissible limit prescribed by WHO (1998). Minor concentrations of carbon di oxide are important in water chemistry. Carbon di oxide constitutes 0.03% of the atmosphere and is formed mainly due to biota respiration and to some extent contributed by industrial combustion, while it is consumed during
photosynthesis by plants. Higher concentration of free carbon dioxide at sampling station Panchgram and Annapurnaghat during monsoon season might be due to discharge of industrial and municipal wastes and its degradation. Statistical analysis of different seasons also showed significant variations (ANOVA, P< 0.01).

Nitrate is the end product of aerobic degradation of organic nitrogen and it occurs very commonly in polluted water. Out of the nine oxidation states (-3 to +5) of nitrogen, nitrate is thermodynamically the most stable form of combined inorganic nitrogen in well oxygenated water. Variations in nitrate and its reduced inorganic compounds are predominantly the results of biologically activated reactions. The maximum values of nitrate were observed during monsoon season at the site Annapurnaghat due to addition of domestic waste. Statistical analysis of different sites and seasons showed significant variations in nitrate concentration in water samples (ANOVA, P< 0.05).

Alkalinity is a measure of buffering capacity of water and is caused by calcium carbonate and bicarbonate and also to some extent due to phosphate and organic matter. Therefore, alkalinity analysis helps to know buffering capacity of water to adjust pH. Rising trend of total alkalinity during summer and winter seasons may be due to higher evaporation of water during low rainfall period which led to an increase in the concentration of carbonates and bicarbonates of calcium and magnesium. On the other hand, decline in the alkalinity in monsoon season brought about by dilution due to heavy rainfall which was in agreement with the report of Sahu (1991). The highest concentration of alkalinity was found in the site Panchgram which indicated that the water was highly polluted in this point and lowest concentration was found in the site Annapurnaghat. The statistical analysis of different sites showed significant variations (ANOVA, P< 0.01). The alkalinity provides an idea of natural salts present in water. The cause of alkalinity is the minerals which dissolve in water from soil. The various ionic species that contributed to alkalinity included bicarbonate, hydroxide, phosphate, borate and organic acids.

Chloride is considered a conservative chemical species in water and is therefore, considered a good indicator of the amount of effluent being discharged at any given time (Kim et al, 2002). However, there was no appreciable seasonal variation in chloride concentration of different sites, although it was slightly higher in winter
season. The high chloride concentration at Panchgram and Annapunaghat site during winter indicated pollution due to industrial and domestic wastes.

The hard water is more productive than the soft water from fisheries point of view. Hardness may be defined as the sum of polyvalent cations presents in water, the most common such cations being calcium and magnesium. The degree of hardness depended on the type and amount of impurities present in water. Hardness also depended on the amount of carbon dioxide in solution. Carbon dioxide influenced the solubility of the impurities that caused hardness. The most common sources of water hardness are calcium and magnesium salts. Hardness is usually expressed in terms of the equivalent calcium carbonate or calcium oxide. Water with 50 mg/l of hardness is considered to be soft. Hardness of 30 mg/l is however, permissible for domestic use, where as it should be 2 to 8 mg/l for boiler feeders, 10-250 mg/l for various food processing industries and 0.05 mg/l for laundry and textile industries. For agriculture, an upper limit of 150 mg/l is usually recommended. The desirable limit of hardness for drinking water is 300 mg/l. the hardness beyond this limit causes encrustation of water supply structure and adversely affected on domestic use.

The phosphate and phosphorous is frequently the limiting nutrient for plant growth in fresh water systems and plays a key role in eutrophication (Varol et al, 2011). The increase in phosphorous concentrations in the running water leads to eutrophication and depletion of DO concentrations (Kannel et al, 2007). High phosphate during monsoon might be due to influx of rain water containing fertilisers from the fields which brings phosphate from catchment areas.. The statistical analysis of different sites and different seasons, however, did not show significant variation.

The hydrogen ion concentration of natural water is an important environmental factor. The variation in pH was linked with the species composition and life processes of animal and plant communities inhabiting them (Jhingram, 1982). There are two general ways of regarding the limnological value of pH, (1) as a limiting factor (2) as an index of a general environmental condition (Welch, 1952). The pH may give indirect information about free carbon dioxide content, alkalinity, dissolved oxygen content. The changes in pH of water bring about changes in the structural and functional variations in the organisms of the water body. High pH is due to high concentration of soda in water body (Wetzel, 1975). In the present study, irregular pattern of pH values over the
seasons as well as among the study sites may be due to high mixing rate of river water. Similar, result was also observed in Narmada River (Gupta et al, 2000).

Cluster analysis (dissimilarity) can be used an important tool for analysing water quality data (Satpathy et al, 2009) to understand the relationship among stations and months. For chloride content, bimonthly water quality parameters formed three clusters. This indicated that the water quality of river Barak over a period of two years exert three clusters in different seasons. The first cluster was formed from June to October which roughly corresponding to the monsoon season. This showed that during this period, the water quality of Barak River behaved similarly. The second cluster was formed from April to October. The third cluster was formed from December to February which was the period of winter season (Fig 9).

The station wise dendrogram showed two clusters. Cluster1 comprised of only Annapurnaghat and it was distinctly more polluted as it received high amount of domestic and municipal wastes. All other three sites have similar features forming the single cluster (Fig 10).

Based on pH of water samples, bimonthly water quality parameters formed three clusters. The first cluster was formed by the months from June to August which corresponding to the monsoon season. This indicated that during this period, the water quality of Barak River behaved similarly. Cluster2 included the months October and February. The third cluster was formed by the months from October to February and April which roughly corresponding to the winter season (Fig 11).

Based on pH, the station wise dendrogram showed two clusters. The first was formed by the sites Katakhal, Annapurnaghat and Sadarghat. The second cluster was formed by the site Panchgram which received untreated industrial effluent (Fig 12).

For DO concentration, bimonthly water quality parameters formed three clusters. The first cluster was formed by October, December, February and April. The second cluster was formed by April, June and October. The third cluster was formed by the months of June and August. It indicated that, during this period, the water quality of Barak River behaved alike (Fig 13).

The site wise dendrogram showed two clusters based on DO concentration. Cluster1 included Katakhal, Sadarghat and Annapurnaghat. The second cluster was
formed by the site Panchgram which was distinctly much more polluted than the rest (Fig 14).

On the basis of FCO$_2$ content, the bimonthly water quality parameters formed three clusters. Cluster 1 comprised December, February, April and December which roughly representing the winter season. June and October closely corresponding to the monsoon season formed the second cluster. The third cluster was formed by the month June, 2008 which distinctly showed much higher concentration of FCO$_2$ value than the rest (Fig 15).

Site wise dendrogram showed two clusters. The first cluster was formed by the sites Katakhal and Sadarghat which were less polluted sites. The second cluster was formed by the sites Panchgram and Annapurnaghat as these were heavily polluted by municipal and industrial wastes (Fig 16).

For total hardness of water samples, temporal water quality parameters formed three clusters. The first cluster was formed by the months of June, August and October roughly representing the monsoon season. The second cluster included December, April, February and October. The third cluster comprised August and June (Fig 17).

Spatial clustering for total hardness formed two clusters. Cluster 1 comprised of Panchgram and Katakhal while Annapurnaghat and Sadarghat sites formed the second cluster (Fig 18).

Temporal cluster analysis for nitrate content generated a dendrogram. Cluster 1 was formed by the months October and June. Cluster 2 was formed by the months June and August. The third cluster was comprised April, December and February approximately corresponding to the winter season (Fig 19).

Spatial clustering for nitrate rendered a dendrogram where Katakhal, Annapurnaghat and Sadarghat sites grouped into statistically significant cluster. Cluster 2 comprised only Panchgram site which was distinctly more polluted as it received untreated industrial wastes (Fig 20).

For phosphate content, bimonthly water quality parameters formed three clusters. The first cluster was formed by the months from December to February. This showed that, during this period, the water quality of Barak River behaves similarly. The
second cluster comprised June and October. The third cluster was formed by August, April and June (Fig 21).

The spatial clustering for phosphate rendered a dendrogram where cluster1 included Katakhal, Sadarghat and Annapurnaghat sites. Cluster2 comprised of only Panchgram as it was distinctly more polluted than the rest (Fig 22).

Temporal clustering for total alkalinity generated a dendrogram where the first cluster was formed by the months December and February representing the winter season. The second cluster was formed by the months June, August, October and April approximately corresponding to the monsoon season. The third cluster included August, June, April and October (Fig 23).

The station wise dendrogram for total alkalinity showed two clusters. Cluster1 included Annapurnaghat, Sadarghat and Katakhal. Cluster2 comprised of only Panchgram as it received high amount of untraeated industrial wastes (Fig 24).

The fungi isolated from different sites of Barak River were likely to be originated from soil or entered the water with plant remains. The genera that were isolated as dominant from Barak River were also isolated from rain water in Saudi Arabia (El-nagdy and Nasser, 2000). The isolated fungi from river Barak belong mainly to the category of transient accidental microorganisms, according to ecological classification of aquatic heterotrophic microorganisms. Transient and accidental microorganisms can develop sporadic activity and soil fungi may participate in microbiological processes in water bodies. Moreover the ability of certain soil fungi to live in sea and river water has been demonstrated (Alton, 1985). Among the fungal population Aspergillus was represented by highest number of species. This is in accordance with the statement of Barron (1968) that Aspergillus is biologically one of the most successful of all fungi and is expected to occur on all sorts of organic debris. Most of the isolated genera and species of terrestrial fungi are common mycobiota which were recovered from different water and mud habitats in other regions of the world. Most of the isolated species of terrestrial fungi are well known for cellulose-decomposing as reported by Ali and Nasser (2001). The diversity was highest at site Panchgram which may be attributed to high organic pollutants and sewage effluent. Cellulolytic filamentous fungi have the ability to penetrate cellulose substrate through hyphal extensions.
Population of aquatic microbiota is influenced by many environmental parameters. High level of pollution indicator bacteria in river water is also a common problem in urban and rural areas that often leads to outbreak of serious water borne diseases like cholera, dysentery etc. The bacteriological analysis revealed that the entire sample collected from four different sites of Barak River was contaminated with coliform, faecal coliform and some other pathogenic bacteria. In the present study, all sites were found to possess high total viable count. Hindustan Paper Corporation near Panchgram has direct connection with the river water of Barak and they are directly discharging the industrial effluents to the river. Although the total viable count (TVC) values suggested that discharging the industrial effluent to the river water should be avoided. The total viable count was relatively higher in the site Panchgram near Hindustan Paper Corporation which may be attributed to pollution by industrial wastes. The statistical analysis of different sites and seasons also showed significant variations (ANOVA, P< 0.01 and P< 0.05). The population of total fecal coliform (TFC) from all the sites showed more or less similar values but marked differences were observed in different seasons. In the present study, the Panchgram site showed the highest population of total coliform (TC) followed by Annapurnaghat site during monsoon season. The high bacterial population at Annapurnaghat site indicated mixing of some domestic wastes along with rain water in monsoon time. Similar pattern was obtained in Sadarghat and Katakhal sites. Statistical analysis also showed significant variations between different sites and different seasons (ANOVA, P< 0.01). The total coliform (TC) count was relatively higher in monsoon and summer seasons than winter. Similar observations were made in Gangetic River by Sood et al (2008). The highest coliform bacterial population in the monsoon season in the present study is similar with the reports of earlier studies (Badge and Verma, 1982; Badge and Rangari, 1999). The highest population of SA/SH was observed in the Panchgram site during monsoon season followed by Annapurnaghat and Sadarghat whereas population of SA/SH in the site Katakhal was almost negligible. Therefore, significant variation was noted between different sites and different seasons (ANOVA, P< 0.01). Sewage contamination of river water particularly in the Panchgram site is detected by enumerating the coliform groups of bacteria (Fujioka, 2002). Panchgram site near the Hindustan Paper Corporation and Annapurnaghat showed relatively high level of total coliform, total viable count, SA/SH and Pseudomonas spp. High value of bacterial population near Panchgram site might be
due to discharge of high amount of pulp paper mill wastes. This result coincided with observations of Gola River by Ram Chandra et al (2006). Higher sewage contamination would lead to increase number of coliform and faecal coliform in natural water bodies. Hansen and Bech (1996) clearly suggested the proliferation of allochthonous microflora in the river environment. Further, as inestimable pathogenic bacteria constituted the microflora of effluents discharged from different activities, quantifying different groups of pathogenic bacteria were part of such surveys. Occurrence, abundance and distribution of potent human pathogens, *Vibrio cholera* (causing cholera in humans), *Vibrio parahaemolyticus* (gastroenteritis), *Salmonella* and *Shigella sp.* (typhoid fever, food poisoning), *Streptococcus sp.* (meningitis and skin infections) and *Pseudomonas aeruginosa* (pulmonary and lung infections) in aquatic environment may prove useful in public health management. The highest population of all the examined groups of bacteria was observed during monsoon season. Kistemann et al (2002) observed that in the case of rainfall, the microbial loads of running water may suddenly increase and reach reservoir bodies very quickly. Pathogenic bacteria which may cause serious problem for human health have been studied mostly for their survival in the aquatic ecosystem (Nagvenkar and Ramaiah, 2009). The presence of *Pseudomonas spp.* in all the sites during all seasons may be attributed to human activities and sewage discharge to these sites.
Table 54: Class limits values for microbial pollutions assessed by bacteriological standard parameters according to Kohl (1975, modified).

(a)

<table>
<thead>
<tr>
<th>Classification of fecal pollution</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Fecal pollution</td>
<td>Little</td>
<td>Moderately</td>
<td>Critical</td>
<td>Strongly</td>
</tr>
<tr>
<td>E. coli (fecal coliforms *)</td>
<td>In 100 ml water</td>
<td>≤100</td>
<td>&gt;100-1000</td>
<td>&gt;1000-10,000</td>
<td>&gt;10,000-1,00,000</td>
</tr>
<tr>
<td>Intestinal enterococci</td>
<td>In 100 ml water</td>
<td>≤40</td>
<td>&gt;40-400</td>
<td>&gt;400-4000</td>
<td>&gt;4000-40,000</td>
</tr>
<tr>
<td>Total coliform</td>
<td>In 100 ml water</td>
<td>≤500</td>
<td>&gt;500-10,000</td>
<td>&gt;10,000-1,00,000</td>
<td>&gt;100000-1,000 000</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Classification of organic pollution</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Organic pollution</td>
<td>Little</td>
<td>Moderately</td>
<td>Critical</td>
<td>Strongly</td>
</tr>
<tr>
<td>Heterotrophic plate count</td>
<td>In 1 ml water</td>
<td>≤500</td>
<td>&gt;500-10,000</td>
<td>&gt;10,000-100,000</td>
<td>&gt;100,000-7,50,000</td>
</tr>
</tbody>
</table>
Microorganisms with the ability to resist heavy metal may be used for detoxification of water contaminated with heavy metals. A wide variety of mechanisms exist for the removal of heavy metal from aqueous solution by bacteria, fungi, ciliates, algae, mosses, macrophytes and higher plants (Pattanapipitpaisal et al, 2002; Rehman et al, 2007). These mechanisms could be utilised for detoxification and removal of heavy metals from polluted environment (Ahmed et al, 2005). Among the various mechanisms the cellular response to the presence of metals is the most important phenomenon. The cellular response to the presence of heavy metals includes various processes such as biosorption by cell biomass, active cell transport, binding by cytosolic molecules, entrapment into cellular capsules, precipitation and oxidation reduction reactions. Isolation of bacteria from polluted environments would represent an appropriate practice to select metal resistant strains that could be used for heavy metal removal and bioremediation purpose (Malik, 2004).

Association between resistant to antibiotics and heavy metals has been reported by several workers (Verma et al, 2001). The presence of such metal tolerant microorganisms is ecologically important particularly if they are antibiotic resistant. This study also dealt with the chromium tolerance with other metal resistance. Multiple metal resistance has been found in many bacteria and the resistance mechanisms and genes involved are typically not common (Trajanovska et al, 1997). Multiple heavy metal resistance determinants for Cd, Co, Zn, Co, Ni, Cr and Hg have been isolated from plasmids (Verma et al, 2001). Large numbers of chromate tolerant microorganisms, especially coliforms were capable of multiple antibiotic resistant.

The selected bacterial isolates showed varying levels of Cr (VI) resistance and reduction. The ability of these isolates to reduce Cr (VI) is widely described and is not an exclusive characteristic of some bacterial groups or populations. Francisco et al (2002) found that resistance and reduction were both shared abilities, probably reflecting horizontal genetic transfer. Presence of such metal tolerant bacteria in a given environment may be an indicator that such area is affected by heavy metals. Such an area may foster adaptation and selection for heavy metal resistant organisms (Clausen, 2000). Chromium resistant bacteria capable reducing chromate have been reported from chromium polluted environments (Ganguli and Tripathi, 2001; Srinath et al, 2001),
serpentine soil (Pal and Paul, 2004) but no report was available from bacteria isolated from river water contaminated with pulp effluent to reduce chromate. In this study, one strain which was identified as *Bacillus cereus* (MTCC-JN202315) showing 28.75% reduction rate. However, few studies reported the ability of *Bacillus spp.* isolated from chromium polluted environment as well as from serpentine soil (Pal et al, 2005; Sundar et al, 2010). The presence of high chromium tolerant bacterial strains also revealed that the river water of Barak near Hindustan Paper Corporation may be contaminated with chromium. Reduction of chromium by these isolates can be considered as an effective tool for bioremediation. The selected chromium resistant bacterial isolates were showing resistance to other heavy metals also. Results of this investigation suggested that selected bacterial isolates have some unique biochemical properties and these isolates could be potentially effective in aerobic Cr (VI) reduction.