
DISCUSSION

Present investigations were designed to study the biological impacts of industrial pollution in a lentic ecosystem both under in situ and experimental conditions. It is revealed from the study of several environmental impact assessment reports that such studies involve more of the physiochemical, microbiological and environmental engineering components. However the floral and faunal components are comparatively neglected, therefore, in present case, biological impact assessment was considered for comprehensive impact assessment studies. It was realized from environment component based studies from this department and from other researchers that the water quality parameters of a lentic ecosystem would not differ significantly over 2-3 years time period unless any catastrophic event occur. The continuous study of water quality parameters for 2-3 years therefore may not provide much information than that generated over a yearlong study, therefore, in present investigations physicochemical analysis to establish abiotic qualitative status of pond was carried out for one year duration.

The biological component analysis was considered most significant since it could provide the functional status of the lentic system. The biota is sensitive to both natural and anthropogenic activity induced stress. The resultant adaptive modifications represent an integrated effect over a long time period. The biota responses to abiotic qualitative changes in turn can be studied as modifications in distribution, diversity and density of a species or at much integrated level in the form of the modified food web. Thus biological impact assessment provides an opportunity and possibility of integrated ecosystem analysis.

The findings of in situ analysis describe the outcome of complex conditions in the form of an impact on or the response of biota. On the other hand, experimental studies provide manipulative possibilities to modify exposure conditions very distinctly to assess the pathophysiological implications of toxicant exposure in monitored experimental conditions. Although in situ and experimental conditions are extremely different, mostly the researchers have carried out experimental studies and extrapolated their findings to the ecosystem level effects. To overcome bias inferences and conclusions, in present investigations both the in situ and experimental conditions were studied to assessed the pollution impact on the lentic ecosystem.

As stated in the introduction section, the complexity of lentic system increase multi folds due to prominent climatic and seasonal influences and variable inputs; as diverse as precipitation inflow, domestic waste and industrial pollutants. Under such circumstances it is necessary to comprehensively analyze and integrate the biotic and abiotic components. The responses of animals may be seen as generalized or specialized adaptations, alterations in reproductive strategies or even evacuation of habitat (Adam, 2000). If the pollution sensitive taxa decrease in diversity or are lost then the food webs are disturbed and overall diversity and density of several other groups may get reduced. On the other hand, pollution tolerant species may flourish even at the cost of other taxa (Nassar, 2009).

During past few decades aquatic toxicology, particularly in stream and river systems, has been the major area of research owing to pollution inputs from domestic and industrial wastes (Beck, 1954; Desai et al., 1981; Cottenie et al., 2001; Nanda, 2001; Begum et al., 2003; Sharma, 2006; Rejomon et al., 2008). Studies both on freshwater and marine systems have reported toxic potentials of various pollutants on planktonic and benthic fauna as well as demonstrated that zooplankton accumulate metals several thousand times more than those detected in water (George and Kureishy, 1979; Khan and Rao, 1981; Gajbhiye et al., 1985; Gautam, 1990; Zauke et al., 1996). Experimental studies in fishes to assess the toxicity of individual chemicals are innumerable both in international and Indian literature. In several cases researchers have exposed the fishes to a group of toxicants to mimic the natural exposure conditions. The toxicant exposure in natural or experimental conditions is reported to alter the reproduction and development, general physiology and even behavior of the fishes (James and Sanpath, 1999; Witeska and Jezierska, 2003; Scott and Sloman, 2004; Viana et al., 2005; Sloman, 2007). The toxicant induced generation of oxidative stress and consequent alterations in metabolism have been studied the most in various tissues of fishes the world over (Oladimeji, 1987; Pandey et al., 2003; Lefebvre et al., 2004; Farombi et al., 2007; Mohamed et al., 2008; Slatiinska et al., 2008; Jeane et al., 2009). The biomagnification of pollutants, especially heavy metals, is one of the major concerns for research on aquatic systems. The food chain contamination ultimately leads to accumulation of metals in the tissues of fishes (Sharma 1992; Vander et al., 2003; Asagba et al., 2008). This may pave its way to humans (Sharma, 1995).

Vadodara has seen extensive industrial growth in past 50 years. The land use pattern has drastically changed from agricultural fields to industrial units. Before two decades larger areas surrounding the industries were used as solid waste disposable sites. In recent times some of the sites were sealed off and at other sites new industrial units have developed. Closure of the solid waste disposable sites or discontinuity in solid waste disposal in this region has not resulted into actual reduction in pollution. Since industries have been focus of development in this region, civic infrastructure development has been neglected; therefore flooding during monsoon has always been a recurrent problem in this area. This ultimately would lead to extensive distribution of hazardous chemicals both in surface and ground water. Thus the entire subsurface area of the industrial area around Vadodara is being polluted over more than 3 decades and has polluted variety of resources leading to biomagnification of toxicants in various trophic status of different ecosystem. Several studies carried out in the industrial areas of all over world (Alaoui, 2008) and various states in India have distinctly reported pollution of surface and ground water sources (Gupta and Saxena, 1996; Prasad and Jaiprakash, 1999; Rai, 2009). In some areas heavy metals were also found in ground water (Rajmohan, 2005). Heavy metals are the most important form of aquatic pollution since they have very long biological half life and hence long environmental persistence and toxicity, and also remarkable degree of bioaccumulation through the trophic chain (Rao, 1998; Bishop, 2000). The net accumulation of heavy metals in an organism is a difference between uptake and excretion and this is the most important factor in metal bioaccumulation (Krishnamurthy1999; El-shalaby, 2009). Concentration of heavy metals in water, found at many sites of major industrial complexes of the state, and the sediments of the rivers/ agricultural field soils show significant enrichment definitively indicating inputs from industrial sources. Sixty five organic compounds were isolated from the water sample and sludge collected from the industrial area locations (Santillo et al., 1996).

The extent of pollution of the Mahi River and related fish loss was first reported in October 1968 and was correlated with contamination of well and pond waters of the villages especially around the confluence of Mini and Mahi rivers. The discharges of effluent wastes into the Mahi and Mini rivers made their waters unsuitable for aquatic life and for human consumption. This followed with the construction of a 56 kilometer long effluent channel, the effluent channel project (ECP), to divert the industrial wastewaters from Nandesari to Jambusar, for discharge into the Mahi estuary at the Gulf of Khambhat. Over the years, unfortunately, this channel has been used by the farmers in surrounding areas as a free source of irrigation water. Analysis of groundwater from wells located 50–200 meters from the effluent channel showed high levels of total solids, total dissolved solids, and chemical oxygen demand, as well as chlorides, sulphates, nitrates, and metals. In addition, fruits, vegetables, and cereal grains grown in the channel areas have a much higher metal content than do those grown in other areas (Sharma, 1995). There has also been rapid erosion in the quality of estuarine flora and fauna at the Gulf of Khambhat (Nanda and Vachhrajani, 2002). Interactions between groundwater and surface water are complex. Consequently, groundwater pollution is not as easily classified as surface water pollution. Groundwater aquifers are susceptible to contamination from sources that may not directly affect surface water bodies, and the distinction of point vs. non-point source may be irrelevant. There are records of numerous complaints made during the 1970s and 1980s by local people about the quality of water in the surrounding areas. The groundwater has been severely contaminated to a depth of about 60 m. There are reports that prove that pesticide; agro-chemicals and dye factories in the region have been dumping untreated effluent in the rivulets. Many ponds in Vadodara are known to be polluted due to increasing industrial and agricultural waste discharges. In the past few decades, attempts have been made regarding the evaluation of aquatic pollution in certain parts of Vadodara but the assessment of pollution of aquatic bodies and pollutant accumulation in biota has been neglected and there are no data regarding the pollution of the aquatic bodies located in the vicinity of about 300 industries.

In present studies, the pH of pond water at Koyali was neutral, this may be because of introduction of alkaline substance particularly detergents, therefore, nullifying the effects of pollutants. High value of TDS, BOD and COD confirm the pollutant input at Koyali, these values are high particularly in July, early monsoon phase, when the possibilities of pollution by surface and sub-surface drains increases. The status of surface and ground water of other sampling sites of the industrial area also confirmed pollution inputs. The studies were able to detect some of the heavy metals from Koyali pond and other sites within the industrial area. It is suspected that the level of pollution is more than detected in the analysis since, the instruments used were not highly sensitive to low levels of metals (the Below Detection Limits indicated low sensitivity). Further, the recommended standard values are for individual metal or organic component. However, the pollution is always heterogeneous and therefore, a possibility of cumulative and/ or synergistic effects cannot be ruled out. Studies from the investigator's lab have demonstrated that heterogeneous toxicant exposure to laboratory rats at 100 or 1000 times low doses compared to the LD_{50} values of each compound; induced toxicity in the animals (Morya and Vachhrajani, 2009). Seasonal variations in the abiotic status of the pond may be due to usages pattern variation, particularly the domestic use and also the climatic and precipitation association factors. The correlation of among the parameters at Koyali in most cases indicated significant positive relation, therefore, it can be suggested that the variations in parameter values at Koyali compared to that noted at Dumad are due to pollutant inputs.

Contents of dissolved gases were estimated during initial period of study; when the estimations were made during different time periods of the day, the dissolved oxygen (DO) levels significantly differed from one site itself. Although it is well known that dissolved gases influence the diversity and density of biota, the findings could not be co-related with other biotic and abiotic parameters. Further, DO in particular is dependent on temperature, so the temperature variation during the day also influenced DO levels. It was therefore decided to consider the BOD and COD levels to correlate with the oxygen status with the ponds. During past 10 years few hundred research papers have been published in India, detailing with the physicochemical status of variety of aquatic bodies, although in several cases these are not correlated with biotic and pollutant data, therefore such huge literature is not compared here with our findings.

The occurrence of 19 species of planktonic Rotifera and 24 species of Arthopoda, altogether at the sites is indication of comprehensive planktonic analysis. Among the Rotifers, 16 species occurred at Koyali while 18 were found at Dumad. The occurrence of species during the year was most significant observation, as it permitted to precisely define that at Dumad 13 of 18 species occurred throughout the year. Only 4 of 16 species occurred throughout the year at Koyali. At Dumad, only 3 of 18 species were noted to be present for 1-4 times in a year while at Koyali, 10 of 16 species had such low occurrence during the study period. This very significantly suggested of the susceptibility/ tolerance potential of the Rotifers, particularly in polluted sites.

The species of Rotifera observed only at Koyali and absent at Dumad was Ploesoma. However, *Platyais longispinosus, Scaridium, Tricocrea porcellus, Filinia, Lecane ploenensis* were found at Dumad through out year but remained absent at Koyli and recorded once during monsoon. Such drastic variations were not noted for Arthropods at study sites, although variations in occurrence were noted. Analysis of data suggested that the annual average occurrence of Rotifers at Koyali was about 50% less than that noted at Dumad. For Arthropods the variation was about 10-20% only.

It was interesting to note that monthly variations in total planktonic density at both the sites exhibited much similar pattern, although the planktonic density at Koyali was comparatively less. Analysis of seasonal variation data suggested that percentile contribution of Rotifers at Koyali was significantly low and that of copepods significantly high as compared to planktonic composition at Dumad during different seasons. This can be considered a significant deviation in planktonic composition at polluted site which is supposed to alter the food web specifications as compared to non polluted site Dumad. Density wise Cladocera and Ostracoda group was abundant followed by Rotifers and Copepods at Dumad, while at Koyali Copepods were most abundant followed by Cladocera plus Ostracoda and Rotifers respectively. Importantly the total zooplankton numbers were significantly low at Koyali, compared to that at Dumad and the population composition also significantly varied at the study sites.

The occurrence of larval forms during particular season and monthly variations in the adult forms can be correlated with reproductive cycle of different species of various groups, however it may also be noted that the reduction in smaller size Rotifers may also be attributed to predatory Arthropods and fishes, besides the pollution impact. However, when the planktonic Arthropods are also reduced at the polluted site, the predation pressure associated decrease in size of Rotifers may not be the most plausible reason or a directly co-related hypothesis. Therefore, the variation noted over the 12 months of study period may be due to direct impact of toxicants present at Koyali.

The zooplankton have been extensively studied as potential bioindicators of aquatic pollution. Community size of selected major zooplankton can indicate the trophic status of aquatic system and also describe the shifts in trophic status. The Rotifers feed on smaller zooplanktons (chiefly Protozoa and bacterio plankton), are susceptible to pollution (Ferdous and Muktadir, 2009) but increase in large quantity rapidly under favourable environmental conditions (Dhanpati, 2000). The occurrence of few Rotifer species almost throughout the year at both the study sites indicates their partial pollution tolerance.

Cladocera is responsive against pollution; the Ostrocods are mainly bottom dwellers but are easily obtained as Planktonic forms in shallow water bodies. The Copepods, most numerous among the crustacean planktonic forms, have toughest exoskeleton and comparatively longer and stronger appendages than that of all other planktonic forms(Islam and Bhuiyan 2007). They are further classified as Calanoid, Cyclopoid and Herpacticoid Copepods. The first two groups are common occurrence in fresh water bodies and feed on variety of zooplanktons. They are highly adaptive to various environmental conditions and therefore also referred as opportunistic planktonic fauna. It is also suggestive that although Copepods thrive in better quality systems, they can survive in polluted water also (Murugan, et al; 1998). Present studies revealed that while at Koyali the population of zooplankton consequently reduced, the Copepods were most abundant which clearly suggested their adaptability to the pollution status. Earlier studies carried on the zooplanktonic population of the Mahi River also reported similar findings with reference to overall community structure and population size of Rotifers and Copepods (Nanda, 2001). The inter relationship between physicochemical status of the aquatic system and the planktonic community have been very well suggestive of significance of zooplankton as bioindicators (Islam, 2007; Rahman and Hussain, 2008).

Studies of Pinto-Coelho et al. (2005) categorically established consistent relationship between crustacean zooplaktonic species richness, assemblage and abundance with various trophic indices like chlorophyll a content and certain physicochemical parameters. They also suggested that more nutrient enriched lentic system support greater crustacean zooplankton diversity and density. Koyali pond received considerably high inputs of domestic sewage and therefore it was supposed to be phosphate and sulphate rich area, the basic nutrients determining the status of pond, however since pollution inputs were also high, the zooplankton diversity was low at Koyali. The zooplankton abundance and composition is reported to be responsive to fish-culture practice, while at Dumad the pond was is not leased for fish culture but the wild stock does exist and is harvested by local people. The predation pressure thus may play significant role in the abundance and biomass of zooplankton (Irigoien et al., 2009).

At a polluted site the biomagnifications of toxicant through the food-chain play significant role with reference to the ultimate level in the biotic and abiotic components of the system. Consideration of zooplankton population composition, density, diversity etc. for the biological impact assessment studies has been criticized also and it is recommended to combine both biological and chemical monitoring. Nevertheless, biological monitoring, if applied repetitively over a period of time, has proven potential for consideration as standard methodology.

Ravera (2001) proposed that since the aquatic organisms potentially accumulate the toxicants, it is important to consider the state and extent of such pollution biomagnifications in particular species. However the toxicological investigations at organism level may reveal very individual specific toxicant interactions and responses but not population or ecosystem level responses although the findings can be used as guidelines but not for the ecosystem level interpretations. Such studies can be useful if the animals located at different trophic level are considered collectively. It may be noted that where heterogeneous pollution inputs from variety of sources in different contents and qualities are concerned, the biomagnification profile of individual species would be different. On the basis of review of various studies on pollution response of organisms in lentic and lotic fresh water ecosystem, an "Intermediate Disturbance Hypothesis" was proposed suggesting that moderate instability and disturbance in the qualitative status of aquatic body would induce better organism diversity and density. It is assumed that unexpected and unpredictable monthly variations in density of the some of the zooplankton species may be the result of such intermediate disturbances. Attril and Depledge (1997) suggested that moderately polluted ecosystem were represented by greater species richness, abundance and biomass. They also categorically suggested that organism community analysis is as sensitive in detecting pollution impacts as the other methods targeted at individual/ cellular or molecular level. Since the habitat specifications and their sustainability are pivotal in maintaining biodiversity status in an ecosystem, level of pollution and tolerance limit of ecosystem (carrying capacity) may become the important action-response criteria. If the habitat modification is not significant the community structure may change but with least deterioration of the overall quality of aquatic system. Certain better tolerant and opportunistic species may occupy the niche as explained on the basis of "Disturbance Compensatory Hypothesis" to buffer the disturbance effect.

In present study, the Dumad pond was considered as non polluted site and the Koyali pond as the polluted site, being in the middle of the industrial area. A comparison of the zooplanktonic community structure, population density and species richness clearly describe the deteriorating status of Koyali pond. Unfortunately, the pond is routinely used for fish culture practice, posing threat to the consumers (chiefly local residents) and to the ecosystem as a whole.

In view of the recommendations of Ravera (2001), organism level in-situ and experimental studies were also considered for present investigation. It was believed at the initiation of the study that organism level investigations may be useful in understanding following components precisely:

1. The types of the pollutant present in the system and those consequently identified in an organism of a particular trophic level. It is possible that of the several pollutants present in the aquatic body only a few might get accumulated within the organism. The possibility of dilution, dispersion, chemical modification or transfer of pollutant form surface water to the sediments and even groundwater leading to their decline in surface water and thus that of exposure level to the organism cannot be ruled out.

2. A comprehensive analysis of pollutant level in surface, ground water and in animal tissues may give proper idea of overall ecosystem burden.

3. When organs and tissues are analyzed for pollutant level, the total body burden and its compartmentation within can be identified.

4. If more individuals of different species located at different trophic levels are studied, it can potentially provide information on comparative susceptibility and responses of different animals.

5. The presence of pollutant in aquatic system and simultaneously in the test animals is an evidence of pollutant biomagnification and bioavailabilty, suggesting the potential hazards.

6. The variability in the accumulation pattern of a pollutant over a period of time is further suggestive of variations and heterogeneity of pollutant inputs.

7. The mechanism of toxic manifestation as well as responses of the animals (absorption/ biotransformation/ excretion) may be understood.

Although the responsiveness of the animals may be correctly understood in experimental set up of defined environmental conditions, however, such experiments provide true picture for single toxicant or group of toxicants with similar pharmacological properties or toxicological profile. Since the industrial pollution of aquatic bodies is heterogeneous with compounds exhibiting widely variable pharmacological and toxicological profile, it is more difficult to delineate toxic manifestation and organism responses.

Heavy metals have very long biological half life and possess greater potential to get absorbed easily owing to their lipophilic nature. Their accumulation in animal tissues is studied the most (Rao, 1998; Metwally and Fouad, 2008). The organic pollutant in most cases is chemically modified in the aquatic system; therefore, their levels are shown to be different or not recordable in the animal tissues.

In present studies also, attempts were made to analyze metals and certain organic compounds in tissues of the fishes, collected from the polluted site or exposed to the pollutants under the experimental setup. Kidney and liver potentially accumulated metals compared to gills and muscles. Since the experimental model is located at the higher trophic level, presence of these metals in pond water and accumulation in the tissues of fish established a direct link and evidence to suggest that the pollutants bioaccumulated through the food chain. It further implies that much of the observed changes in the physiology of fishes may be due to the accumulated toxicants/ metals.

The mechanisms of toxic manifestation of variety of chemicals have revealed that pollutants stimulated reactive oxygen species (ROS), production and the resultant oxidative stress are the prime factors in toxicity induction. The generation of the free radicals by toxicants is shown to be responsible for variety of physiological alterations.

The ecosystem/ community/ population studies may be the direct indicators of pollution impact in an aquatic body. However, it is always difficult to establish inter-relationship and influencing interactions among the wide range of abiotic parameters and the organisms distributed at different trophic levels. On the other hand, the study of structural and functional components of an organism provides significant information of the toxic manifestation at organ/ tissue/ cellular levels. Although the generated information is precise, it is very difficult to correlate the toxicant influences with reference to structure and the functional alterations. To establish the “action–response-relationship” it is necessary to access level of toxicants within a tissue, histoarchitecture alterations in that tissue and then correlates with the functional impairment in the same tissue.

The liver is an important organ associated with biotransformation of toxicants. The important enzymes of toxicant biotransformation are concentration in the pericentral region (Rani and Ramamurthi, 1986 and 1989; Madrasmi, 2007). The hepatocytes of this region were severely damaged in the high dose group in the Koyali pond fish. Considering biomagnifications through the food chain, ingestion is the most probable mode of exposure for the fishes under study. The entero-hepatic circulation exposes primarily the liver tissue to higher toxicant concentration, thus increase probability of toxicity (Staicu et al; 2005). This also gives an opportunity to liver to accumulate the toxicants. Present findings very clearly demonstrate that in Koyali pond water the metal toxicants are present which get accumulated in the liver tissues of the fishes and induce severe structural alterations.

The gills carry out important function of respiration, osmoregulation and excretion. The occurrence of variety of cell types and their specific location are suggestive of functional specialities of gills. The gills are in continuous contact with the external environment and therefore are sensitive to the changes in the quality of water. They are generally considered as primary toxicant targets. The observed pathological changes may be the reaction to the toxicant intake or an adaptive response to prevent toxicant entry through the gills. In view the principles of toxicology, gill membrane show a significant barrier for transportation and dispositioning of toxicants. The hyperplasia and hypertrophy of various cell types of gill filament, thickening of basement membrane and fusion of the tips of the secondary lamellae can be regarded as adaptive responses of cellular defence. In the experimentally exposed fishes gradual and moderate modifications in histoarchitectural integrity of gills were noted in different dose groups over a period of 30 days. These pathological alterations are expected to compromise with respiratory mechanism of gills.

Muscles are physiologically important to animals but more so economically with reference to the fish culture practice. Since their organisation is complex within the connective tissue layers, the toxicant accumulation is much reduced. However, their exposure to toxicant through integument pose toxicity hazard. The observed pathological changes like connective tissue dissolution, fibril disorientation and degeneration and oedema are indicative of severe damage. Present findings demonstrated that metal does accumulate in muscles to much less content as compared to liver and gills. Several researchers have demonstrated similar findings following toxicant exposure to fishes. Exposure to water born copper under experimental conditions for 21 days induced severe cellular changes both in liver and gills (Dhanpakkium and Ramaswamy, 2001; Henson et al., 2006; Figueiredo-Fernandes et al; 2007). Exposure to aluminium also caused damage to fish tissues (Hadi et al; 2009).

Experimental exposure of fishes to wide variety of toxicants at different concentrations over acute to chronic durations has exhibited much similar type of lesions (James and Sanpath, 1999; Jaroli and Sharma, 2005; Madraswami, 2007). The gills are shown to be partially dose responsive in present findings. Studies by Mohamed (2009) on tilapia from the pollution receiving site lake Qarun, Egypt, demonstrated findings comparable to those observed in fishes from Koyali pond. Both the studies are direct in-situ evidences to correlate environmental pollution and toxic manifestations in an aquatic system. Peebua (2005) exposed tilapia for different durations to variety of toxicants including pesticides and metals. In view of the fact that any aquatic body located in the vicinity of industrial region receive variety of industrial pollutants, domestic discharges and agricultural runoff result into distinctly heterogeneous environmental conditions. Most researchers have assessed toxic manifestation of a single compound. The findings reported here are the outcomes of the heterogeneous toxicant exposure (industrial effluent) at low doses. The correlation of toxic manifestations in experimental and in situ exposure suggest that pathological changes induced in organs of Koyali fish are comparable or little more severe than those noted for low dose exposure for 30 days in experimental groups. In the experimental set up, the environmental conditions are much less diverse since they are well controlled/ regulated, while in-situ exposure involve diverse and wide array of environmental conditions. The routine physicochemical parameters, nutrient distribution and availability, natural food availability and quantity altogether influence the toxicant uptake and effects. Under such circumstances also the toxicants accumulate within the tissues of fishes indicating the signification of regular environmental monitoring and importance of pollution control measures.

The metals and organicals are shown to induce oxidative stress in different experimental animals and these have been used as biochemical markers of toxicity. The molecular oxygen is essentially required by the animals for metabolic oxidation, during this process it undergoes tetravalent reduction to form water molecules. However, partial reduction of oxygen leads to formation of reactive oxygen species (ROS) including both radical species such as super oxide anion radical, hydroxyl cat ion radical and non radical species such as hydrogen peroxide (H_2O_2). The ROS is highly reactive and react instantly virtually with all organic molecules. In a cell, the ROS and pro-oxidant products, induced by toxicant exposure, are detoxified by anti oxidants including the free radical scavengers and certain enzymes like Glutathione (GSH), Ascorbic acid, Super oxide dismutase (SOD) and Glutathione peroxidise (GP_X). Therefore, the protective role of these antioxidants is significant in maintaining the defensive mechanisms. However, an increase in reactive oxygen species production can overcome antioxidant defences resulting into oxidative damage to macromolecules and alterations in critical cellular processes. The status of oxidative stress in fishes with reference to aquatic pollution was reviewed and it was suggested that although pollutant induced ROS increase and depletion in glutathione has been studied by many workers, the findings do not establish direct quantitative or dose response relationships in several cases (Handy, 1996; Livingston, 2001 and 2003; Hamed, 2004; Humtsoe, 2007; Valkova, 2007; Shen et al., 2007; Laura, 2008; Hossam, 2009). Glutathione is postulated to protect the cell from damage by H_2O_2, it catalyzes glutathione dependent reduction of hydro peroxide and of H_2O_2, thus protecting against oxidative damage due to lipid peroxidation. The toxicants are reported to induce GP_X

activity in fish tissues (Vinodhini and Narayanan, 2009). In present findings, the enzymes of antioxidant mechanism were not altered by 15 days in all the organs studied. However, the alterations were noted, though not significant always, on 30 days in 20% dose group and in the Koyali pond fish. The antioxidant enzyme activity slightly increased with corresponding increase in glutathione level. The phosphatases are also indicator of cellular functions which were altered to various levels of significance in the experimental and in the Koyali pond fishes. Heavy metal exposure induces oxidative stress and alter their biomarkers (Lanartova, 1997; Rao et al., 2006; Farombi et al., 2007; Tejeda-Vera, 2007, Firat et al., 2009). It is suggested from these studies that metal accumulation in tissues of fish could generate free radicals and superoxide anions to induce the activity of enzymes like SOD, GP_X, and Catalase. Since GSH is the substrate for GST activity, it also increases correspondingly.

In gills, the level of these enzymes and metabolites was reduced following metal exposure which has been attributed to higher lipid peroxidation and severe pathological changes (Kurutas et al., 2009). In present findings the increments in the representative enzymes and free radical scavengers of antioxidant system were comparatively less conspicuous.

The molluscan and other invertebrate fauna at Koyali and Dumad were almost comparable since many of these animals occur in the ecologically degraded sites (Pandya and Vachhrajani, 2010). Therefore, they may not be considered as good indicators of the pollution status of the aquatic body. A wide variety of birds use wetland habitat either throughout their life or for a part of their life. However, few studies have been carried out on the effect of water quality on the wetland dependent birds. The toxicants seeping into the wetlands adversely influence the water quality and can be one of the reasons for less avian diversity at Koyali pond. The disturbances in ecosystem can be the major reason of temporal and spatial heterogeneity in avian communities. The avian fauna at Dumad represent distinct diversity and community composition while it was much restricted at Koyali clearly indicating environmental influences. Studies carried out by (Chakrapani, 1986; Pandya and Padate, 2009) on the avian community structure of two ponds suggested that urbanization influences and degrading status of the ponds restrict the visits of migratory birds while a non polluted, undisturbed site generally support greater diversity and density of birds. Gavali et al. (2006) cited some of the birds listed in our records at Koyali ponds and correlated their presence in the industrial area with the polluted environment. Other study carried out on the avian diversity of Mahi river stated that the higher avian diversity in Mahi river upstream and midstream can be probably attributed to the appropriate feeding landscape available for aquatic birds and the adjacent bushy habitat in the gorges and ravines for terrestrial birds (Pandya and Vachhrajani, 2010). The increased human interventions in the Mahi river upstream areas and the pollution stress on the downstream habitat have pressurized the estuarine complex and if not mitigated can eventually result in future decrease in avifaunal diversity. A few studies have been carried out earlier in this region of Gujarat to list diversity of birds, however, these were not with reference to the polluted and non polluted aquatic/terrestrial sites and therefore, a distinct comparison cannot be madePadate et al., 2001; Patel, 2008). It is envisaged that such more studies are required to comprehensively study the biota of the pollution influenced sites to appropriately evaluate the impacts on various components of ecosystem as a whole.

The management of aquatic bodies along with the industrial development is perhaps very challenging aspect. Present and other studies revealed that the aquatic bodies have reached to a state of degradation which has resulted from the accumulative action and impacts of the activities carried out over the years/decades. The pollution status of the pond, pollutant levels in the surface and groundwater of the study area and the pollutant accumulation pattern in the fish tissues can be directly correlated to interpret the impacts. Present studies put forward distinct evidences of dispersal of pollutants in the ecosystems and their consequences leading to biomagnifications. The water resources are one of the most important natural resources available since the life depends on it. The inadvertent uses and over exploitation of such resources may lead to severe consequences challenging survival of life. It is therefore necessary to manage such resources.

As discussed in the Introduction section, the pond is a close type of aquatic system and therefore, the hydrodynamics are very different then the freshwater lotic systems or marine systems. The dispersal of pollutants is least possible and possibly much less effective. The sub surface and ground water management could be the primary component for enhancing the quality of the aquatic body in the industrial vicinity. Measures are required to be taken to protect the ponds from the surface run off which usually are pollutant enriched.

The disposal of solid waste is probably the second most important aspects to be addressed appropriately. The part of industrial area around Vadodara was earlier extensively used as solid waste depositing sites and therefore, the sub surface strata are highly contaminated with hazardous substances. The industrial areas in Gujarat are now equipped with the advance technology and Government of Gujarat is committed to implement such stringent measures to protect the environment from land pollution. It may be noted that the environment of today is the result of the activities carried out over past few decades. The solution of pollution is not dilution but regulation of discharge, qualitative remedial measures and technological advancement is.

Delineation of extensive recommendations on this brief study are not possible and also do not form part of the scope of the thesis. However, briefly the recommendations are outlines below:

1. The industrial effluents processing and their disposal should be regulated by strict vigilance and effective legislation. Environmental laws should be referred for public awareness.
2. Solid waste disposal should be given a careful thought as it only plays significant role in subsurface pollutant accumulation and distribution.
3. A general long term biomonitoring programme for the aquatic systems should be considered.
4. Assistance of technological development should be thought for waste treatment, disposal and recycling.
5. The key to the problem lies in effective and sincere management.