Chapter 5

Discussion
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I. General Discussion

River water quality across the globe has been subjected to constant anthropogenic pressure resulting in deterioration beyond acceptable levels for various environmental, domestic and commercial consumption. For strategic management of a water body including river ecosystems, accurate and reliable information on the water resource system is vital (Gupta and Deshpande, 2004). Major anthropogenic factors affecting water bodies are alterations in vegetation, sediment transport, application of various chemicals, urbanization and industrialisation (Turner and Rabalais, 1991; Vitousek et al., 1997; Carpenter et al., 1998). In this regard, water quality monitoring is of the highest priorities in environmental protection policy where the main objective is to control and minimize the incidence of pollutant oriented problems, and to provide water of appropriate quality to serve various environmental purposes (Simeonov et al., 2002). The quality of water is identified in terms of its physical, chemical and biological parameters which are associated with various synergistic interrelationships influencing the overall nature of the water (Sargaonkar and Deshpande, 2003). A change in the physical as well as chemical properties of water often leads to excessive accumulation of the chemicals in the water system resulting in pollution (Saxena, 2007).

In the present study, in addition to the various physico-chemical variables of the River Nambul, the monitoring of heavy metal concentrations in water, sediment and biota samples found in the river and their subsequent analytical results have revealed a
major understanding of the overall nature of the water of this river. The study attempts to identify the nature of water of this river for its potential application to the state as whole and the inhabitants around the river in particular.

II. Spatial Cluster Analysis

Hierarchical Agglomerative Cluster Analysis as a tool for the classification based on their similarity on physico-chemical properties demonstrated the existence of three spatial clusters, namely Cluster 1 comprising the two downstream sites namely Langthabal (LN) and Wangoi (WN); Cluster 2 grouping together the two upstream sites Mayang Langjing (ML) and Iroisemba (IR) and Cluster 3 with the clubbing of Thong Nambonbi (TN), Keisamthong (KS) and Heirangoithong (HR), the three midstream sites of the Imphal City stretch (Figure 43). Cluster 1 can be depicted as moderately polluted group while Cluster 2 are the least polluted groups as per the overall data matrix obtained from the study. Cluster 3 on the other is the spatial group having most of the variables with higher concentration readings denoting the highest pollution level among the sites observed. Cluster 3 sites are associated with major anthropogenic activities including urban run offs, urban sewerages, domestic discharges and numerous contaminating sources from commercial chores coupled with high population density. Sites in Cluster 1 and Cluster 2 groups have moderate to high agriculture, vegetable cultivation, aquaculture and other domestic activities apart from few commercial and automobile/machinery repairing pockets along the bank of the river.

III. Spatial and Temporal Variation of Water Quality Variables
Spatial and temporal variation study of the physico-chemical properties of the water quality of River Nambul showed the varying levels of deterioration as revealed by the characteristic quantitative response of the thirteen variables investigated. It was noticed during the study that different rural and urban settlements, domestic and commercial activities and also lack of adequate water quality management practices along the river contributed grossly to the worsening water quality of this river.

Among the variables, water temperature is an important physical factor influencing the physical, chemical and biological characteristics of river water (Olajire and Imeokparia, 2000). Water temperature reveals the amount of heat present in the water. In a river system, water temperature varies in response to geographic location, marginal vegetation cover, groundwater seepage, substratum condition, channel flow and also orientation of the flow (Wetzel, 2006). During the study, water temperature followed a major temporal pattern where monsoon was found to exhibit the highest ranges among the seasons and lowest during winter. Nevertheless, water temperature never crossed 30°C in any of the seasons during both years of the study (Table 4 and Table 5). Similar comparisons can be made with various investigations by Satrawaha et al. (2008), Singh and Singh (2010) and Singh et al. (2013b). Statistically significant temporal water temperature difference (P < 0.001) with higher Tukey difference in case of monsoon than the colder periods of post-monsoon and winter was also observed during the study. This can be attributed to the higher atmospheric temperature and higher radiation absorption by the water during these seasons (Bartholow, 1989). According to Ficke et al. (2005), the temperature above which a
fish cannot survive called the upper incipient lethal temperature (UILT) for a typical tropical fish like *Telapia aurea* ranges from 28.9 °C to 38.9 °C, which in the case of River Nambul is quite below the level of inflicting serious heat stress to fishes in particular. Although the study did not observe any statistically significant spatial difference of water temperature, the Cluster 3 sites TN, KS and HR showed higher ranges than the other sites (Tables 6 and 7) which was also in the case of studies by Singh and Singh (2010) and Singh *et al.* (2013b) in the same river. This can be explained by the warm run-off during summer rains from the hard impervious urban surfaces like rooftops, metaled roads, concrete yards lying along the river banks as well as incoming urban domestic sewages with higher thermal profile (Haritash *et al.*, 2014; Anonymous, 2003).

Electrical conductivity of water is directly related to the concentration of dissolved solids in the water. Dissolved ion concentrations in water influence the ability of that water to conduct an electrical current (Wetzel, 2006). Temporal variation of EC showed that in the period 2011-12 (Table 4), lean seasons with lesser water flow during post-monsoon and winter had higher EC ranges as compared to the pre-monsoon and monsoon seasons (Tables 4). Satrawaha *et al.* (2008) and Mustapha (2008) also observed similar findings where the influence of increased intrusion of dissolved particles from anthropogenic sources on the more or less stagnant water volume was indicated. However, the year 2012-13 showed an inverse trend with the highest mean record during monsoon followed by pre-monsoon (Table 5) more so due to the flushing of more dissolved particles into the water with rain during the period
Statistical significance at $p < 0.05$ confirmed the existence of this temporal trend. Nevertheless, the overall Tukey comparison test for EC for the two annual cycles of study revealed higher difference in case of post-monsoon and winter signifying the tendency of higher EC accumulation during these lean periods. Spatially, it is of interest to note that most of the EC records of the Cluster 3 midstream sites located within the Imphal city are comparatively higher than the sites of the other two clusters. High statistical significance at $p < 0.001$ and higher Tukey differences for EC among these Cluster 3 sites support this trend of spatial significance in this study. Higher influx of various anthropogenic dissolved particles from the surrounding urban population and also transport of discharges from non-point sources upstream are the major causative factors here. This is supported by findings made by Singh and Singh (2010), Singh et al. (2013b) and Kosygin et al. (2007) on different rivers in Manipur.

McCutcheon et al. (1993) is of the opinion that EC qualitatively reflects the status of inorganic pollution in water which in turn is also a measure of the soluble solids and TDS in particular in the water. Total dissolved solids represent different inorganic salts mainly calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates as well as organic matters dissolved in water (Seth et al., 2014). Principal sources of TDS in water are erosion and degradation, sewage, urban runoff and industrial wastewater.

One-way ANOVA of TDS during the study showed statistically high spatial and temporal significance ($p < 0.001$). The spatial mean TDS difference observed was
higher among the Cluster 3 sites reaching up to 110.42±33.61 mg L\(^{-1}\) at KS in 2011-12 (Table 6) and 115.00±32.79 mg L\(^{-1}\) at the same site in 2012-13 (Table 7). In the other two clusters, Cluster 2 sites have shown lower mean TDS than Cluster 1 sites which was also quite evident from the statistical significance observed (p < 0.001) along with significant spatial Tukey differences. The trend infers to the presence of high organic and inorganic dissolved pollutant loads coming from the urban discharges of the city. Temporally too, significant statistical differences for TDS at p < 0.001 existed among the seasons showing higher concentrations during pre-monsoon and monsoon seasons in both years of study. Pre-monsoon 2011-12 showed higher mean concentrations reaching up to 101.10±26.19 mg L\(^{-1}\) (Table 4) while in 2012-13 it was monsoon with the highest mean of 92.86±26.97 mg L\(^{-1}\) (Table 5). This is in contrast to the higher EC found during the lean periods of post-monsoon and winter in the study. Vidyarani et al. (2008) reported decreased EC during monsoon season in this river. However, the existence of moderate positive correlation (r = 0.535) between TDS and EC signifies their relationship. The reason for higher concentration during monsoon and pre-monsoon is indicative of the flushing down of more dissolved pollutants and increased addition of decaying organic matter into the water with seasonal rains (Shiddamallayya and Pratima, 2008; Sachidanandamurthy and Yajurvedi, 2004). According to the BIS drinking water standards (BIS, 2012), TDS in the water of River Nambul was well within the permissible limit of 500 mg L\(^{-1}\).
Total alkalinity, according to Headley et al. (2005), is the sum of all the components in the water system that act to buffer the water against changes in pH (e.g., bicarbonate and carbonate from the carbonate system, as well as hydroxides, sulfides, silicates, and phosphates). It is a measure of the substances present in water that can resist fluctuating conditions in pH when acidic contaminants enter the water body. In other words, total alkalinity determines the buffering capacity of that water body to counter any acidic predation to it (Wetzel, 2006). During the study, spatial TA difference was higher in the Cluster 3 sites within the city in both the annual periods of study with statistical significance at $p < 0.001$ and higher Tukey difference among these sites. Significant temporal variations was also observed at $p < 0.001$ with higher mean ranges being exhibited by both monsoon and post-monsoon in 2011-12 and 2012-13. The level of TA was also found nearer to the BIS permissible limit of 200 mg L$^{-1}$, the reason of which may be corroborated by high intrusion of urban discharges and seasonal cycle of rainfall as well as other geogenic origins (Mustapha, 2008). This high TA also explains the observed stable pH in the river water. The pH of River Nambul was predominantly alkaline in nature. Alkaline nature is in accordance with previous report by Singh and Singh (2010) in this river. Less site wise significance in pH can be observed from the study while statistically significant pH at $p < 0.001$ can be observed with higher differences in the case of post-monsoon, monsoon and pre-monsoon respectively. Higher alkalinity is responsible for the stable pH in almost all the sites during the study period because of the buffering action of the TA. Significant positive correlation ($r = 0.282$, $p < 0.05$) can also be observed between TA with pH supporting the above finding.
Total hardness in water is caused by a variety of dissolved ions, predominantly calcium and magnesium cations (Headley et al., 2005). It is the traditional measure of the capacity of water to react with soap wherein more soap is required with harder water to produce a lather. Generally, water is classified as soft, moderately hard and hard with hardness values 0-60 mg L\(^{-1}\), 60-120 mg L\(^{-1}\) and >120 mg L\(^{-1}\) respectively (Mustapha, 2008). Nambul River water during the study was found soft to moderately hard with hardness increasing towards the Cluster 3 sites. Spatially, significant HRDS difference was observed at p < 0.001 and the same trend was also found temporally at p < 0.01. HRDS was quite below the BIS permissible limit of 200 mg L\(^{-1}\) with the highest observed HRDS value of 108.00±15.56 mg L\(^{-1}\) at KS during 2012-13. This can be explained by the increased discharged containing inorganic nutrients from the urban sewages as well as other domestic effluents (Singh et al., 2013b; Singh and Singh, 2010). Concentration was found higher during the summer seasons than the winter seasons as observed by Singh et al. (2013a).

Chloride, nitrate and inorganic phosphate are major inorganic ions in water, especially wastewater. Their concentrations in water are attributed mostly to industrial effluents, sewages and agricultural run-offs (Joshi et al., 2009; Kumar and Bahadur, 2009). During the study, Cl\(^-\), NO\(_3^-\) and PO\(_4^{3-}\) were observed to be higher among the Cluster 3 sites indicating the influx of raw and untreated sewage dumping. Even though agricultural run-offs can be considered as the major sources of nitrate and inorganic phosphate in the Cluster 1 and Cluster 2 sites, their overall concentration in the river has been overwhelmed by the concentration profile found in Cluster 3 sites due to the
influx of urban sewages. In their study on the nitrate and phosphate profile of Nambul river, Singh and Singh (2010) established the major impacts of nitrate and phosphate regulating the higher conductivity of the river. Pearson correlation study also supported the above fact showing highly robust positive correlation observed between Cl\(^-\) and NO\(_3^-\) (r = 0.809), Cl\(^-\) with PO\(_4^{3-}\) (r = 0.873) and NO\(_3^-\) with PO\(_4^{3-}\) (r = 0.840) at p = 0.01. Seasonally, these three variables also showed higher concentration during wet season explaining the increased flushing of sewage and agricultural run-offs by heavy rainfall. Singh et al. (2013a) recorded higher nitrate and phosphate during the summer seasons while conducting water quality of Moirang River.

Dissolved oxygen is the oxygen dissolved in water through photosynthesis of aquatic plants and diffusion from atmosphere (Wetzel, 2006). The study of DO is a fundamental part of water quality monitoring and assessment. During the study, DO was found higher in the Cluster 2 upstream sites whereas Cluster 3 sites showed lowest presence of DO indicating degradable organic matter input which is common in urbanized areas, Shreshtha and Kazama (2007) made similar observations while studying water quality of Fuji River Basin in Japan. Sources resulting into lower DO concentrations include discharges from residential activities, urban storm water run-off containing variety of organic materials, vehicular emission run-off, animal wastes, etc. (Andrews, 2006). This can also be associated with the higher BOD and COD readings observed at the Cluster 3 sites. This fact is also supported by the highly significant negative Pearson correlation coefficient between DO with BOD (r = -0.417) and COD (r = -0.434) at p = 0.01. Pearson correlation also showed significant
negative relations of DO with majority of the variables (HRDS, Cl$^-$, NO$_3^-$ and PO$_4^{3-}$) which are indicative of urban run-off, sewerages and solid waste dumps. Kosygin et al. (2007), Singh et al. (2013a) and Singh et al. (2013b) also reported similar finding of high organic load at the urban sites in river systems of Manipur.

The above observations are in accordance with the findings shown in the PCA where major pollutant loads of the river comes from organic and inorganic contaminants as well as seasonal influences experienced in the region. As a powerful pattern recognition technique aiming at dimension reduction of the datasets to derive lesser components that account for the variability observed in the relatively larger data structure, PCA in the present investigation revealed the significant relationships of organic, inorganic and seasonal influences on the overall water quality of the river. Additionally, varimax rotation, another powerful data interpretation tool based on the components derived from PCA have highlighted only those highly important variables in the form of varifactors accounting for the water quality scenario of the river in the present study (Mazlun et al., 1999; Shreshtha and Kazama, 2007; Singh et al., 2012 ). Liu et al. (2003) classified the factor loadings as ‘strong’, ‘moderate’ and ‘weak’, corresponding to absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30, respectively.

PC1 (eigenvalue of 7.405) explaining 56.959 % of the observed variance seems to be heavily influenced by anthropogenic actions along the course of the river as revealed by the heavy loadings of variables which are characteristic of human interference. The factors in this component were EC, TA, FCO$_2$, TDS, HRDS, Cl$^-$, NO$_3^-$, PO$_4^{3-}$ as well
as BOD and COD. HRDS, PO$_4^{3-}$ and COD showed the highest loadings of 0.901, 0.908 and 0.910 respectively. These factors indicate the major influence of anthropogenic organic contaminants changing the water quality. Similar studies around the world have supported above the findings of River Nambul (Mazlum et al., 1999; Singh et al., 2005a; Shrestha and Kazama, 2007; Singh et al., 2012). Results from varimax rotation of PC1 also conformed to the aforementioned scenario where the role of anthropogenic organic contaminants can be seen. It is observed that VF1 which explains 33.743 % of observed variance has strong positive loadings of EC, HRDS, BOD and COD with moderate significant loadings of TA, TDS and PO$_4^{3-}$. This factor can be representative of the heavy organic load coming to the river from wastewater discharge and dumping of garbage in the river during its course through the urban areas (Singh et al., 2005a; Simeonov et al., 2002; Simeonov et al., 2005). Singh and Singh (2010) gave the high PO$_4^{3-}$ load coming to the water of River Nambul to the extensive use of chemical fertilizers in agriculture along the basin of this river. Seasonal fluctuations assuming another major reason for the worsening water quality of the river can be found with the observed higher loadings of water temperature (0.710), pH (0.819) and free carbon dioxide with moderate negative loading (-0.608) in PC2. These factors indicated the influence of annual seasonal cycle which is closely related with the photosynthetic activity in water. Kosygin et al. (2007) have reported similar influence of seasonal cycles in the water quality of Moirang river in Manipur. Major variable contributors in VF2 (31.315 % of observed variance) are FCO$_2$, Cl$^-$, NO$_3^-$ and PO$_4^{3-}$ while TA and TDS are secondary contributors. VF2 has a strong negative loading of DO which is likely a factor for
nutrients run off from agricultural fields located at the upstream and downstream parts and sewerage. VF3 with 15.611 % of explained variance is dominated by TEMP and pH whereas FCO$_2$ shows significantly high negative influence. This factor points to the variability of water quality due the seasonal cycle.

The varifactor analysis indicates that the parameters responsible for water quality variations seen in this river is mainly related to conglomeration of organic pollution (domestic sewerage and urban run-off), nutrients (agricultural fields and sewage) and the annual cycle of wet and dry season.

**IV. Heavy Metals, Calcium and Magnesium in Water of River Nambul**

Heavy metals in water and sediment are a function of the substrate sediment composition, suspended sediment composition and water chemistry where the elements are subjected to numerous changes in speciation due to dissolution, precipitation, sorption and complexation during transportation (Mohiuddin *et al.*, 2012). Concentration profile study of heavy metals, Calcium and Magnesium in water of River Nambul revealed that Copper and Cadmium were present much higher than the WHO acceptable limits of 0.2 mg L$^{-1}$ and 0.01 mg L$^{-1}$ respectively in most of the sites studied whereas Lead and Nickel concentrations in all the sites were below the permissible limit of 5.0 mg L$^{-1}$ and 0.2 mg L$^{-1}$ respectively (Ayers and Westcot, 1985). It is interesting to note that Cu during post-monsoon was above the accepted range at ML, HR and LN while Cd crossed the acceptable limit at IR, KS and HR (Figure 33). This can be due to influx of agricultural run-off containing pesticide and fertilizer residues with Cu and Cd during this season along with geologic origins (El-
Mashali et al., 2015; Iqbal et al., 2011). Seasonally, post-monsoon was also observed to have higher concentrations of these metals during the period of study. Bouraie et al. (2010) observed the higher concentration of metals in water during drier post-monsoon or winter period due to increased organic matter accumulation in water, low pH resulting into higher mobilization of heavy metals from the underlying sediment bed and also microbial activities. 

Pearson correlation coefficient calculation showing moderate positive relationship of Cu, Pb, Cd and Mg with pH suggests the moderate affinity of these metals towards alkaline medium. However, Helena et al. (2000) and Singh et al. (2012) ascribed higher aggressiveness of ionic concentrations including heavy metals to acidic media of soil and rocks. The present findings, thus, suggest the possible sources of heavy metals primarily from anthropogenic loads coming to the river on seasonal basis. PC2 in Table 25 shows moderate to high loadings of water temperature (0.605), pH (0.715) as well as Cu (0.706), Pb (0.728), Cd (0.622), Ca (0.446) and Mg (0.892) and moderate negative loading of BOD (0.593). This association underlines the seasonal influence in the metal concentration, probably due to seasonal influx of organic contaminants from non-point agricultural and other cultivation activities using metal containing chemicals (Singh et al., 2005b). A high positive loading of 0.885 for Ni alone in PC5 suggests the non-association of this metal with the primary contaminating sources of the river water pollution in Nambul. Perhaps the presence of high concentration of Ni at TN during winter (Figure 34) indicates isolated source of this metal at this site which could not be confirmed during the study. However, Singh et al. (2013b) observed metal plating and use of nickel
plated stainless steel products like utensils as one of the major sources of Ni in this river, the level of which was much higher as compared to that of Loktak Lake.

In case of Ca and Mg, the concentrations observed were found to be much lower than the permissible limits for drinking purposes as laid down by BIS (2012). They were not observed with significant relationship to any other variables except Mg with TA, showing moderate correlation (r = 0.524). This was in contrast with several findings where Ca and Mg showed strong association with hardness of water (Ogwueleke, 2015; Mustapha, 2008; Juahir et al., 2011; Satrawaha et al., 2008; Haritash et al., 2014). Pertaining to their lower than acceptable limits, Ca and Mg do not pose any significant interference for the usability of water of the river.

V. Heavy Metals, Calcium and Magnesium in Sediment of River Nambul

Surface sediments owing to their surface area and sorbent capacity adsorb all kinds of pollutants occurring in water including heavy metals (Baran et al., 2002). Sediment contamination of heavy metals pose as one of the worst environmental problems in aquatic ecosystems particularly due to the toxic and persistence effects of the metals (Mucha et al., 2003). Many heavy metals collected by sediments are manifold higher in concentration than the same in the water (Bouraie, 2010). Nambul River also showed similar trend of increased concentration as compared to those of water during the same periods. This is particularly indicative of the strong influence of seepage, adsorption and chemical speciation of the metal ions with the low lying sediment core (Namminga and Wilham, 1976). The higher than permissible concentration of Cu at the Cluster 3 sites as well as Cluster 2 sites during monsoon season are probably due
to the longer association of the metal with sediment with time where there are numerous direct entry as well transportation of them from the upstream activities. The temporal pattern for Pb and Cd concentration in sediment was also highest during monsoon seasons while Ni was found higher during winter. Spatially, Cluster 3 sites have more pronounced heavy metal concentration in most of the seasons. Ruello et al. (2011) has emphasized the presence of high organic matter as a major factor leading to the formation of metal species in complex ions like humic acid during higher rainfall periods. However, Bouraie (2010) observed higher concentration during winter closing periods explained by smaller discharging water increasing precipitation on the sediments due to lower pH and microbial activities. Ca and Mg concentration in sediment showed fluctuations over time and place during the study. Their concentrations were lower than the permissible limits even though presence of organic contaminants were more pronounced in the water of the river. This could be explained by the increase absorption by the aquatic vegetation of the river since they are essential elements for metabolic processes (Anonymous, 2003).

VI. Heavy Metals in Biota of River Nambul

Bioavailability of toxic heavy metals is a factor of chemical speciation and relative concentration in water and sediment of the aquatic ecosystem. According to Kwon et al. (2001), bioavailability of heavy metals increased with ecosystem having higher enrichment factor values along with higher labile fractions of the metals in sediment thereby increasing mobility and bioavailability. Dundar et al. (2012) also observed the relative nature of different metal forms reaching aquatic organisms as exchangeable
forms > acid reduction forms > organic forms > residual forms. During the study, heavy metal accumulation in different parts of A. philoxeroides was found more or less fluctuated over the seasons as well as sites of study. However, during dry period, A. philoxeroides showed higher concentrations in root than shoot among all the metals, which probably can be due to unavailability of prominent leaf and shoot parts coupled with higher concentration and lower transportation of the metal species. In their study about the bioaccumulation potential of aerial and submerged parts of A. philoxeroides for Pb and Cd under controlled environment as well as natural conditions, Nimisha and Gupta (2015) found higher accumulation capability of roots than aerial parts. In case of water hyacinth, accumulation for all the four heavy metals were higher in the shoot parts than the root during the only studied dry period. The accumulation of heavy metals in E. danicus in the three sites during wet period was in the order Pb > Cu > Ni > Cd and Cu > Cd > Ni at the only sample analysed from WN during dry period. A reliable picture could not be established in this case due to irregular availability of samples during the period of study.