C:N ratio of Sediments in a sewage fed Urban Lake

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Abstract— C:N ratio of lake sediments provide valuable information about the source and proportions of terrestrial, phytogenic and phycogenic carbon and nitrogen. This study has been carried out in Varthur lake which is receiving sewage since many decades apart from large scale land cover changes. C:N profile of the surficial sediment layer collected in the rainy and the dry seasons revealed higher C:N values[43] due to the accumulation of autochthonous organic material mostly at the deeper portions of the lake. This also highlights N limitation in the sludge either due to uptake by micro and macro-biota or rapid volatilization, denitrification and possible leaching in water. Organic Carbon was lower towards the inlets and higher near the deeper zones. This pattern of Organic C deposition was aided by gusty winds and high flow conditions together with impacts by the land use land cover changes in the watershed. Spatial variability of C:N in surficial sediments is significant compared to its seasonal variability. This communication provides an insight to the pattern in which nutrients are distributed in the sludge/sediment and its variation across seasons and space impacted by the biotic process accompanied by the hydrodynamic changes in the lake.

Keywords— Sediments, C:N, sewage, urban lake, nutrients, macrophytes, algae

I. INTRODUCTION

Carbon and Nitrogen as nutrients plays a vital role in maintaining trophic levels in lake ecosystems. The dry weight ratio of total organic carbon to total nitrogen (C/N ratio) has been used as an indicator of the source of organic matter (OM) in sediments. Variations of C:N ratio's within sediments have aided to determine temporal and spatial of organic matter, steroid compounds and lignin phenols changes in sources of organic matter to lakes. Nevertheless the organic matter in the form of $^{13}C/^{12}C$ ratio is an essential

indicator. However due to the variability in isotopic ratio of planktonic OM adds to ambiguity in measurements [1-4] due to a wide range inorganic $^{\delta 13}C$ values [2]. Also as indicators analysis involves chemical complexities. In this context, the C/N ratio proves to be an efficient and straightforward indicator of organic source, particularly in depositional environments of lakes.

II. C/N RATIO

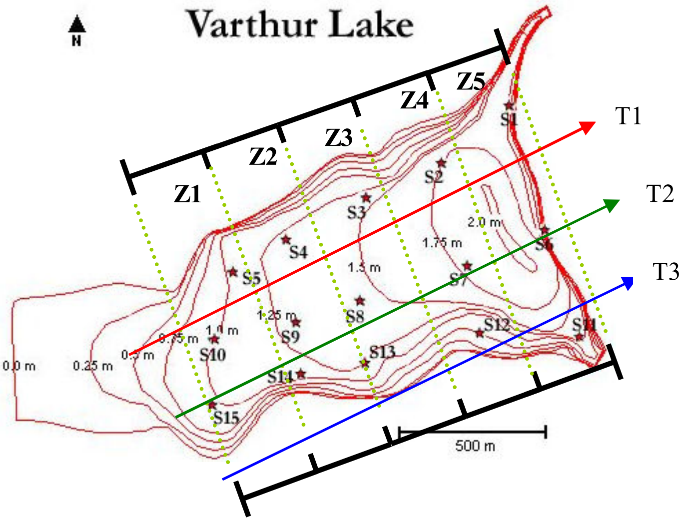
The C/N ratio has been used as a representative proxy to reconstruct the depositional environment of freshwater lake sediments [5-10]. Carbon and Nitrogen in aquatic ecosystems are governed by the mixing of terrestrial and autochthonous organic matter [11-12,5,13-14,4]. C/N ratios of 5 to 6 are reported in phytoplankton and zooplankton, which have proteins, which are primarily nitrogen compounds [15,16]. Freshly-deposited OM, derived mainly from planktonic organisms, has a C/N ratio of 6 to 9 [15, 17-18]; Phycogenic C/N ratio was found to be between 4 and 10 [3]. This is contrary to C/N ratios 15 or higher with [16,19-23] in terrestrial vascular plants and their derivates in sediments, and greater than 20 [3] in terrestrial organic matter and about 39.4 [22] for macrophyte materials.

In this communication we analyze the distribution of OM and the variability in the C/N ratio under the prevailing seasonal oxic and anoxic conditions, and evaluate the sensitivity of the C/N ratio to changes in the proportions of planktonic and terrestrial OM. Variations in C:N ratio within sediment have been used to understand lake's temporal depth profile apart from analyzing the period of high proportion of terrestrial OM input [24]. Conversely, lower C:N ratios help to identify periods when lake sediments have received a high proportion of algal OM [25]. C:N ratio to discern changes in organic matter sources has been the subject of discussion [26,27] as the C:N of terrestrial organic matter decreases during diagenesis, while that of algae increases [28]. In this backdrop, a study has been carried out to identify spatial and a short time temporal variability in nature and sources of organic matter to Lake Varthur, Bangalore (India) through the analysis of C:N of surficial sediments.

III. SPATIO-TEMPORAL VARIABILITY IN C: N RATIO

A significant spatial and temporal variability of water quality in terms of organic compounds and nutrients, with a considerable decrease in the organic matter as water flows from inlet to the outlets during the seasons devoid of macrophytes cover in the lake was observed. Varthur Lake serves as a source for irrigation to the cultivable lands and vegetable cultivation together with horticulture and floricultural activities and has a surface area of 220 ha (Figure 1). The lake was built by the Ganga Kings (Gazetteer of Karnataka) to store water. The lake initially was a deep with water which was used for drinking and other domestic purposes, intense urbanization have dwindled the catchments for the last few decades. During the last two decades there are large scale changes in land use paving way for rapid decline in the number of lakes and eutrophication.

Figure 1. Bathymetric map of Lake Varthur, Bangalore (India). The large dot with the star's indicate the sites where surficial sediments were taken (S1-S15) and contours represent the various depths of the Lake.



IV. SURFICIAL SEDIMENT ANALYSIS

Surficial sediments were sampled along three transects [shown as arrows] near north shoreline, middle and south shoreline, from different depths in Varthur Lake (Figure 1) during nonmonsoon (NMON-08,09) period (Aug-Oct) and monsoon (MON 09) period (Dec-Jan), 2010 to quantify, assess the nutrient quality, accumulation in sediments and its variability with respect to space (spatial) and with time (temporally). The lake was divided into imaginary zones from Z1 – Z5 taking the inlets as a refrence and considering the flow as a function of residence time (4.8 days). Representative samples were obtained from each site with the help of a sediment sampler; they were then placed into plastic bags, refrigerated at 4°C prior to analysis. The samples were dried; processed and homogenized for the CHN analysis. Organic Carbon content and Total Nitrogen and atomic C:N of bulk sediment samples were determined by combustion of the dried and processed surface sediments in a CHN analyzer (TRUE SPEC CHN Vers. 1.9X, LECO). Settling experiments were carried out to time required for 90% settling for non-monsoon, 08 sediment samples. Dry wt. was calculated for the samples and quantitaion of C and N was carried out for respective zones.

Figure 2a). % C content during Monsoon

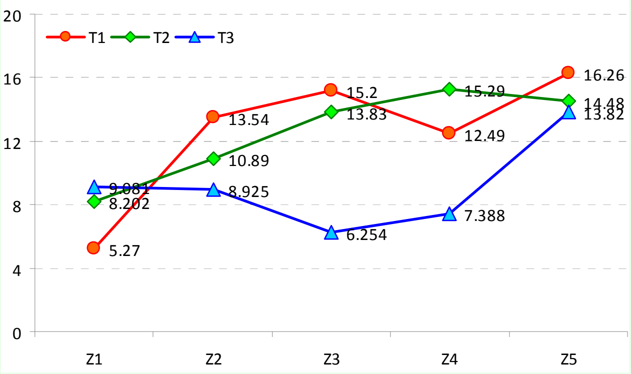


Figure 2b). % C content during Non-Monsoon

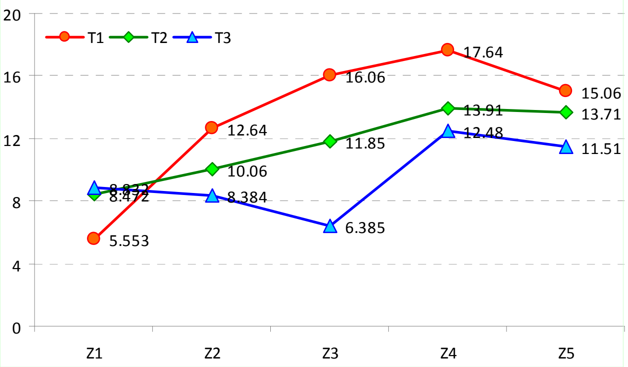


Figure 3 a). % N content during Monsoon

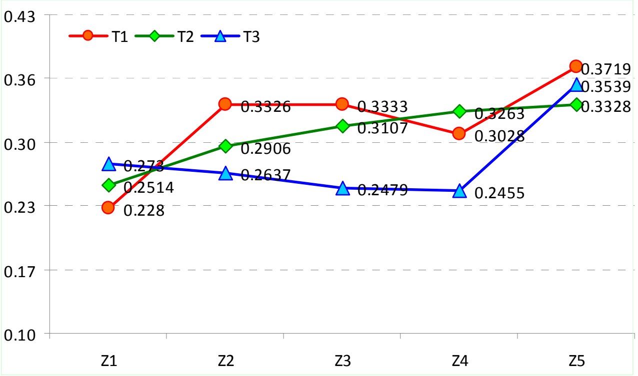


Figure 3 b). % N content during Non-Monsoon

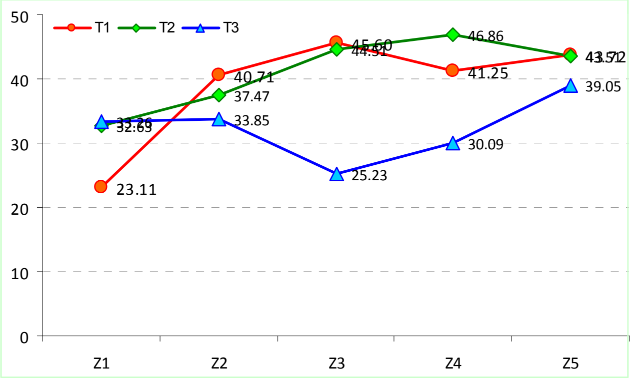


Figure 4 a). C/N ratio during Monsoon

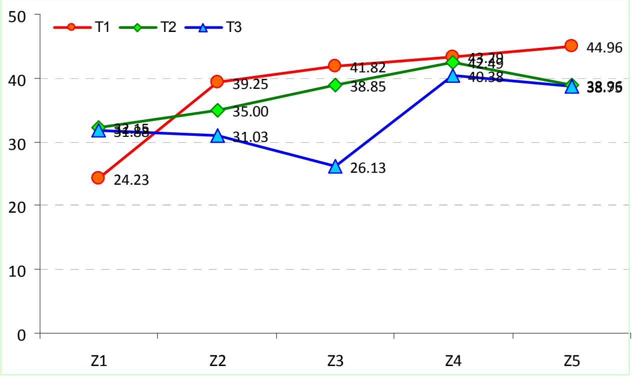


Figure 4 b). C/N ratio during Non-Monsoon

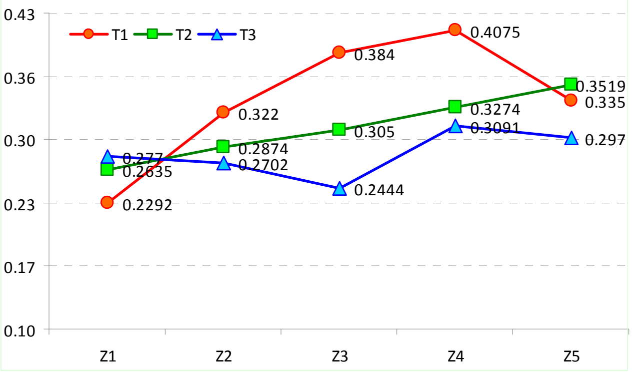
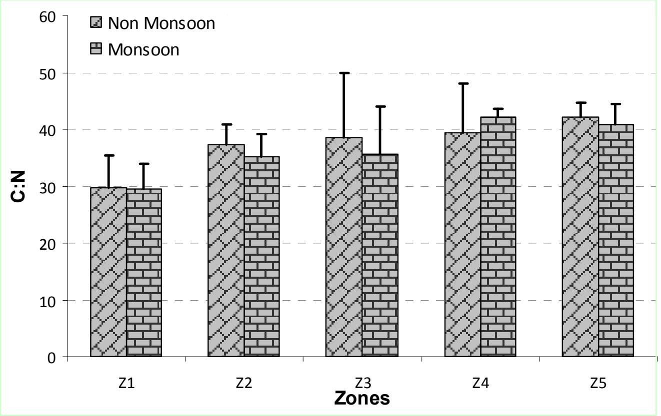


Figure 5.Variability in the C:N ratio at various zones in the lake

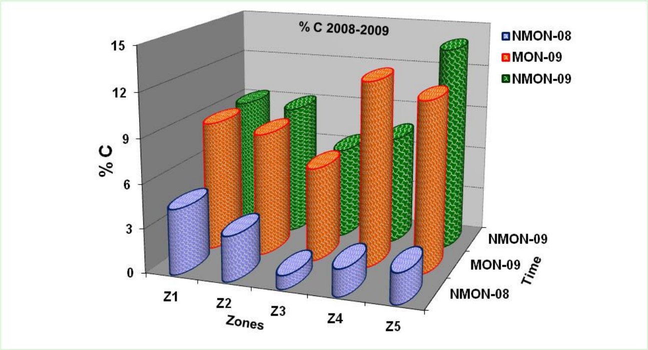


During 2009 analysis the surficial sediments C content for the non-monsoon at depths greater than 1.5 m-1.75 m (Z3 and Z4) showed higher values 17.64 g/100 g dry wt. compared to monsoon values (Figure 2.a & b) which could be due to persistence of organic decomposable and sludge at normal flow conditions. With high wind speeds and high flow rate during monsoon a phenomenal turbulence is created by churning followed by upwelling which releases the sludge from the bottom. The sludge escaping from the system was found to have a similar C and N content as was found in samples from greater depths (Z4 and Z5) where C/N = 50.05±3.02; C=33.66±5.12; N =0.68±0.07. The samples collected along north transect showed higher C values compared to the other regions of the lake. (Figure 2.). This is attributed to higher anthropogenic effects and terrestrial C sources like sewage from the urbanized pocket. A lower C value in the southern side is attributable to suburb type habitations with more agricultural fields in the immediate vicinity.

The N content analysis showed a similar trend in the way in which organic C is distributed across the lakes (Figure 3.a & b). However the entire system was found to be having a relatively lower N content compared to other studies [26]. The seasonal analysis showed a higher N content in the non-monsoon period. The N content was highest at the deeper regions (Figure 3.b). This is attributed to the rapid death and decay of the macrophytes during the late monsoon. The plants parts disaggregate; decompose and settle at a very high rate during the lean season. The N content in case of macrophytes were found to be ~2.25 g/100 g dry wt.[water hyacinth]. This difference in the surficial sediments and the macrophytes indicates substantial N loses from the sediments which can either due to rapid N mineralization followed by volatilization or denitrification which should be looked at systematically.

The seasonal observations showed higher C/N values in the deeper reaches during the monsoon however the ratio becomes more or less constant at those placed during the lean period (Figure 4. a&b). From the figure 4, it was observed that the middle regions of the lake had gained a higher C/N

Figure 6. Temporal variability in C content



* NMON: Non-monsoon; MON: Monsoon

Figure 7. Temporal variability in N content

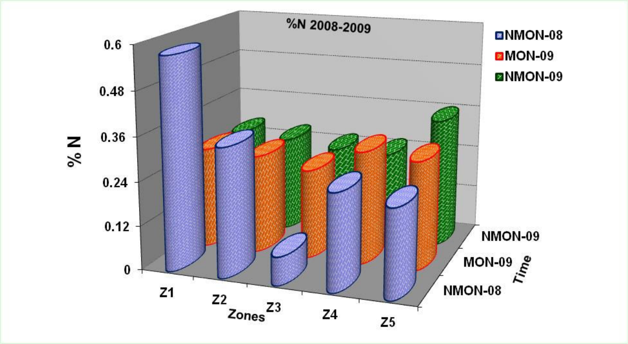
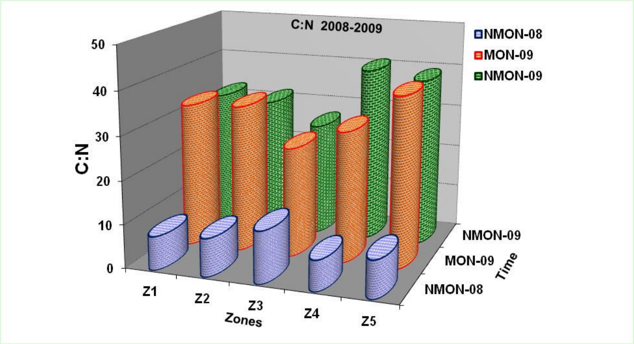


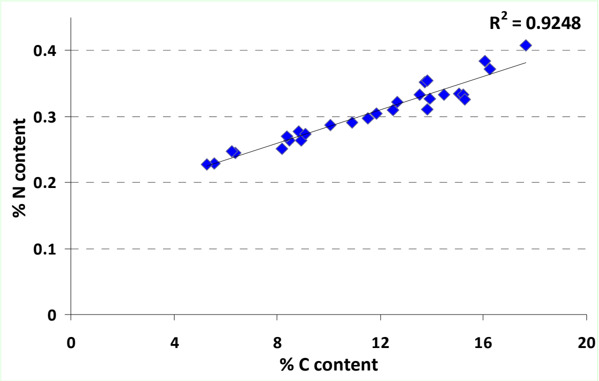
Figure 8. C/N variability in the lake across time



value than the other regions which indicated the flows in both the sides of the lake and the middle regions being undisturbed. The analysis carried out during wet and dry periods reveals that as a function of residence time the C/N ratio increases as we move from inlets towards the outlets as illustrated in Figure 5.

This indicated that the inflowing stream primarily transporting sewage was an important source of terrestrial organic matter. However there was a marked increase in the C as well as N content towards the outlets as a function of residence time which could be because of more organic matter settling at these regions. The preponderance of higher C:N ratio again reveals that, there may not be adequate C assimilation at the same time the Organic N in the forms of Ammonia and nitrates are either readily assimilated by bacteria's or are denitrified and are released to the atmosphere in the form of N_2O and N_2. This could result in an altered C:N values as the C:N of terrestrial organic matter decreases during chemical, physical, or biological change undergone by a sediment after its initial deposition, while that of algae and aquatic plants increases [28].

Figure 9. Correlation between % C and % N content in the sediments



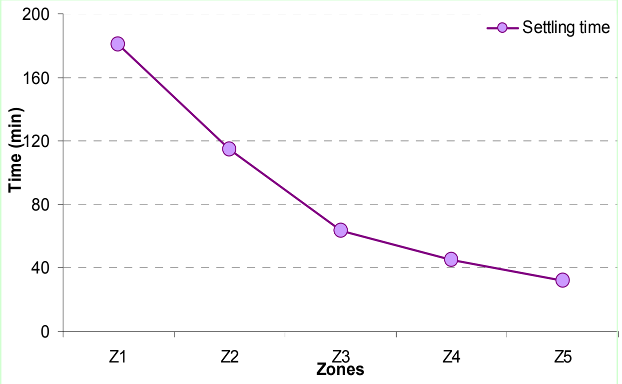
The present investigation confirm that C:N ratio's in lake sediments can be used reliably to identify sources of sedimentary organic matter, and reveal the changes in the lake catchment such as land cover changes, aquatic weed infestations, discharge of untreated wastewater, etc. Large physico-chemical and biological changes in C:N, which would have led to an overlie of terrestrial, phytogenic and phycogenic C:N, were not evident in the surficial sediments.

It was also observed that the natural variability of C:N of surficial sediments at the center of Varthur Lake is small compared to the changes in C:N ratio near by shoreline regions of north and south sides of Varthur lake. Temporally there was a significant increase in C:N during the last two years [to values similar to surficial sediments near the inflow] due to changes in the dynamics with an increase in the proportion of terrestrial organic matter in the lake's central sediments. However, this has varied settling patterns in different seasons. The proportion of terrestrial organic matter could have risen because of increased particulate matter loads [29] and wastewater discharges [Hornbeck et al., 1986] from the upstream lakes through the channels and also direct inflow of sewage from the households near the lake boundary. As the water flow passes the beds of aquatic macrophytes as *Typha* sp. which checks its velocity, most of the particulate organic matter is trapped at the inlet regions. The Lake has a higher OM at the centre and near the outlets, due to rapid decay and settling of the autochthonous organic matter. Morphometry plays a very vital role in deciding the flow patterns. The maximum depth of the lake was observed to be 2m which is near the outlet region. During early monsoon period the north outlet was blocked and persistent stagnation was observed. During the summer the sludge churns and floats on the surface near the stagnant regions. With the removal of blockage at the outlet there was more deposition of OM at the deeper portions of the lake. Relatively higher values of C:N at the deeper points in the middle of zones Z4 and Z5 shows the proportion of terrestrial organic matter incorporated into central sediments probably declined due to stream discharges and sediment loads [30,29]. Consequently, the C:N of the lake sediments in our study are increasing after weed infestations and unrestricted discharges of sewage.

V. SEDIMENTATION RATES

In the sludge settling experiments, it was observed that the sediments near the inlet regions in zones Z1 and Z2 were consisted of 3 different types of sludge. However the sediments near the outlet regions were similar. In the non-monsoon seasons (08) the sludge near the high flow regions were having a higher C content (which is attributed to particulate organic matter and rapid sludge formation). The sludge near the inlet zones was highly organic as seen in the earlier (Dec, 08 samples) but as we approach towards the outlets an improved and a matured sludge (Fig. 9) was observed. This is primarily due to unprecedented discharge of untreated sewage and due to external input from the catchment and surface run off which is in agreement with earlier studies [31]. Figure 9 shows the time taken for the sludge for 90% settling. It is well observed that the sludge settles fast near the outlets unlike the inlet where it takes a much longer time. However the Organic content of the sludge was found to be significantly higher in Dec, 09 which showed a higher organic C content throughout and was more prominent towards the bund region and the outlets. This links to the morphometry of the lake which has the deepest portions near the bund. The sedimentation rate is lowest in the deepest part of the lake, but increases progressively towards the inlets and the shorelines on either side of the lake.

Figure 9. Time required for 90% of the sludge for settling



VI. ELEMENTAL CONCENTRATIONS

A significant variation of organic carbon flux in terms of BOD was observed with space and time in Varthur lake and is ~ 14.8 kg/ m^2 year, which is comparable to eutrophic lakes [32-35]. The variation in TOC can be due to differences in particulate grains; a constraint of C uptake and breakdown due to N limitation or could be due to early stage diagenetic alteration. Limited OM degradation in the anoxic sediments was reported earlier [36-39].

The atomic C/N ratio in Varthur sediments near the inlet regions (Z1) was recorded to be 23–33. The macrophyte derived material as the primary source of sediment OM near the south shoreline has C: N of 23.11 compared to slightly higher value of 33 in the middle and the north side. There was higher accumulation of C near the north side of the lake due higher terrestrial anthropogenic impact. These results are comparable to C/N ratios about 20 attributing to input of vascular plants, and lower C/N ratios [5–8] to algal-derived OM [3, 39].

The N values were consistently very low below 5% of the dry wt., which shows an N deficient system. It indicates that either the N is already leached into the system, or N forms are rapidly up-taken by the microbes. The volatilization and denitrification could be significant processes responsible for the lower sediment N values. The Organic N in the sediments can however be transformed to various inorganic forms as nitrites, ammonia, nitrous oxide or molecular nitrogen. The presence of inorganic N in sediments can alter C/N ratios and thereby confound the interpretation of OM sources [40]. This confirms that the OM source in Lake Varthur sediments is essentially autochthonous macrophyte-derived near the outlets and terrestrial N near the inlet zones. However the middle part OM in phycogenic in origin. Moreover, the C/N ratios indicate that run-off waters from the catchment can increase the terrestrial OM component, as the lake is surrounded by agricultural and horticultural lands nearly 67%.

VII. CONCLUSIONS

The analysis of the sediment the C:N ratios indicated a strong correlation between the elemental composition of C and N. This also showed that the sludge/sediments were acting as a major sink for C and N. The C and N values were found to be significantly higher in the deeper areas than the shallow inlet regions. This showed that 60 % of the nutrients are terrestrial in origin. These parts mostly are silt laden which is the reason for low organic Carbon compared to the other parts of the lake. The quantity of C and N stored on the sediments in a daily basis was large which accounts to 9 t C and 2.9 t N. The north side of the lake was anthrpogenically more impacted than the other parts which is evident from the higher C/N ratio.

Therefore, proper wastewater management strategies should consider approaches to minimize indiscriminate sewage ingress and losses of nutrients from agricultural fields into the lake systems. The results indicated that, once nutrients are delivered into the lakes, a substantial part in taken up by biota which ultimately die, decompose and settles as sludge sediment in the lake bottom and with high turbulence created by high wind velocities and overflow of water during monsoon they are likely to be transported downstream without much attenuation in the lake bottoms. Future investigations that would account for nature of various pollutants entering the lake system, the lake bottom soil types, and nutrient loadings from all sources must be conducted to examine impact of the wastewater ingress on sediments at different levels. (Vegetated, non-vegetated, dredged, and non-dredged).

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