Nitrogen and Carbon Flows through Bellandur Lake – role of Bellandur lake as a natural wetland treating Bangalore wastewater.

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Abstract:

Much of the Bangalore sewage is treated in three streams namely Bellandur (K&C Valley), Vrishabhavati and Hebbal-Nagavara stream systems. Among these it is estimated that a total of about 500 MLD of partially treated sewage is let into the Bellandur tank. We estimate that a total of about 77 t N non-industrial anthropogenic nitrogen efflux (mainly urine and excreta) originates in Bangalore city. This is distributed between that handled by the sewage streams, soak-pits and land deposition. About 17-24.5 t N enters the Bellandur tank daily. This has been happening over a few decades and our observations suggest that this, approximately 380 ha, tank is functioning as a C and N removal system with reasonable efficiency. The ammoniacal and nitrate nitrogen content of the water at the discharge points were estimated and found that over 80% of the nitrogen influx and over 75% of the C influx is removed by this tank system. We observed that there are three nitrogen sinks namely bacterial, micro-algal and macrophytes. The micro-algal fraction is dominated by *Microcystis* and *Euglenophyceae* members and they appear to constitute a significant fraction. Water hyacinth represents the single largest representative of the macrophytes. This tank has been functioning in this manner for over three decades. We attempted to study this phenomenon from a material balance approach and showed that it is functioning with a reasonable degree of satisfaction as a natural wetland. As the population contributes and as the concomitant influx into this wetland increases, there is a potential for the system to be overloaded and collapse. Therefore, a better understanding of its function and the need for maintenance is discussed in the paper.

Keyword: Wetlands, Bellandur Lake, Wastewater, Carbon flow, Nitrogen flow

Introduction

In many cities of India the sewage streams are treated as natural and quasi-natural ecosystems evolved at the location. For example, in Kolkata the tidal lakes, in Chennai two riverine systems and in Bangalore man-made lake systems are responsible to a large extent for the treatment of sewage. Each of these ecosystems displays unique interspecies balance that tends to take up various amelioration functions in the removal of carbon, nitrogen and phosphate. Sewage transport and treatment in Bangalore follow natural water courses along the three directions of Vrishabhavaty, Koramangala-Challaghatta (K&C) and Hebbal-Nagavara valley systems. In the case of Bangalore there have been attempts to provide primary treatment to sewage before it enters a lake or other waterbodies. However, the capacities of the treatment plants have always fallen short of the actual discharge. Thus, Bellandur tank (K&C Valley) has always been required to provide the necessary remediation function for this man-made neglect. While assessing damage it is important to note that urban ecosystems significantly differ from the rural crop ecosystems in typical semi-arid zones such as Bangalore with regard to the C and N cycling. While rural crop ecosystems usually function as C and N deficient systems, there is a far higher deposition of C and

N in urban soils, including a high degree of variations. They are limited by the rates of mineralisation and return to the resource pool.

C and N Dynamics

The need for efficient C and N-cycling is best described by Janzen (2004) in which the probability of each of us inhaling one molecule of N that has passed through Julius Caesar is estimated to be close to 0.995. It serves as a powerful example to show how dependent we are in ensuring that the carbon and nitrogen we use are returned and recycled quickly. In today's context of sustainability we also need to ensure that we do not compromise the ability of the future generations' to re-use this C and N resource. In Bangalore, with manifold increase in its population, much higher levels of carbon and nitrogen use exists. Consequently, deposition is high and hence the cycling time needs to be short and as the quantities involved are higher, the fluxes intensify. Today, when we use so much more of the C and N resources, it is necessary to rephrase the question - how many times does an average N molecule cycle through each one of us in our own lifetimes?

Currently there is very little knowledge about C and N dynamics of urban soils especially with regards to the pool sizes and their relationships with transfers and losses from and to these pools. Usually recourse is possible to taking up a well established mass-balance approach (Lauver and Baker, 2000; Rodriguez and Macias, 2005. Chanakya and Sharatchandra, 2006). In the case of semi-arid agriculture around Bangalore, typical land use and agronomic practices lead to soils and crops being constantly in an N-deficit regime and consequently such soils function as N-sinks (Muller, 2005). Urban soils suffer from large influxes of C and N in various forms. In a developing country situation characterised by frequent C and N influxes brought about by open urination and/or defecation, use of septic tanks, soak-pits, open sewerages, etc., it may said that there will be a disproportionately large C and N influx into soils with few natural mechanisms that function as a sink. From a soil perspective, it is similar to over-manured crop stands where plants accumulate large quantities of photosynthetically inactive soluble proteins (functionless proteins- Bauera et al, 2004). Such phenomenon of C/N-accumulation in the absence of soil disturbance could mean accumulation of C and N in soil with potential for very high N-leaching losses (Brye et al, 2003). In a location where population depends to the tune of 25% on groundwater, high N-leaching potential requires resource consuming interventions remediate high C and N in drinking water. Such efforts require interdisciplinary knowledge driven decisions and trade offs between perceived damage, actual damage and anticipated costs of efforts.

In the case of Bangalore, (at potential per capita deposition of 20 g N capita^{-1}.d^{-1}, Lauver and Baker, 2000) a population density of 200 person.ha^{-1} this translates into a N-flux of 1.5 t.ha^{-1}.yr^{-1}. Obviously the quantities are far too large for any soil-plant-water system to assimilate. However, like in a cropping system it is important to disaggregate the various N-cycle processes for an urban setting at a city level /settlement level and determine N-movement and problems. Typically N–pool sizes may be determined as input-output mass balances (Rodriguez and Macias, 2005: Chanakya and Sharatchandra, 2006)

$$N_{dep} + N_{fix} = N_i + N_u + N_{ad} + N_{fire} + N_{eros} + N_{vol} + N_{le}$$
(where dep=deposition, fix-microbial fixation, i-immobilization, u-uptake, eros-erosion, vol-volatilization and le-leaching).

In resource-constrained Indian ecosystems, where re-use and recycle have long been in practice, we need to reexamine these issues and processes at a higher hierarchic level of sustainability

assessment. The cases of carbon and nitrogen are taken as an example for discussion in this paper. The human wastes are deposited on land as well as discharged as sewage and within 15 km of flow it enters the Bellandur tank system. The N in sewage is an important N-resource that is now appreciable in size and can be considered as a resource inadequately and improperly utilised.

Much of the urban soils could be compared to typical wastelands that have very tight C&N-cycles that tend to deteriorate with abuse. When human wastes are deposited on land it significantly influences the C&N-cycles making it favourable only to a few plant and animal species to thrive typical 'waste/barren lands'. C&N fractions that cannot be held by the soil system quickly enter the groundwater system and causes quality deterioration. When human wastes are transported through sewage systems, a significant decomposition occurs near the entry points of waterbodies or where the flow slows down. Some of the C is released as methane and/or carbon dioxide depending on the redox levels during its decomposition. We firstly estimate and validate the size of C and N pool that enters the Bellandur lake system. We also examine how sewage abuse in peri-urban agriculture can threaten water quality in terms of nitrate toxicity in drinking water. We target resource recycling and to some extent environment and remediation objectives in a larger perspective of sustainability goals.

Estimation of C and N

We first estimate the overall C and N deposited as excreta and urine (human and animal origin) in the city of Bangalore. It has been previously estimated that about c.88% of this enters the overall sewage systems. This sewage fraction may be either as underground drainage (UGD) sewage systems or as household (HH) level septic tanks. About 40% of UGD sewage load in Bangalore is estimated to reach Bellandur lake. From this we have estimated the total C and N input into the lake. In volume terms, it is estimated that 384-500 million litres per day (MLD) enter this lake. From the concentrations of water discharged from the lake, we attempt to estimate the overall functioning of the lake to remove C and N from the waters. As the composition of sewage entering the lake is highly variable, we take recourse to using deposition estimates as the extent of C and N entering the lake.

Table 1: Estimates of carbon and nitrogen generated in Bangalore and that entering Bellandur lake system (all values are in tons per day except percentage figures, extracted from Chanakya and Sharatchandra, 2006)

Source	DM	Sewage fraction %	OM in sewage	Urine N	Excreta N	Total N	total to sewage
Human	372	88	327.4	51.4	11.2	62.5	54.7
Major animals	392	30	117.6	7.0	5.3	12.3	3.4
Minor Animals	37.5	25	9.4	NA	2.0	2	0.3
Total	805		454.4	58.4	18.5	76.8	58.4
Bellandur Lake			109.06				14.02

Chanakya and Sharatchandra (2006, Table 1, Figure 1) have determined the quantities of carbon and nitrogen that enter the sewage systems from various human and animal sources in the city of Bangalore. They also identified that human and animal excreta are subject to four different kinds of treatment /disposal namely the fractions:
  i.   entering the underground sewage lines to be disposed by Bangalore sewerage system,

ii.   discharged as sewage but into household level soak-pits,
iii. subject to open discharge (open defecation in case of human beings) and
iv. subject to composting – more of animal wastes and very little of human waste (experimental).

It is also important to note that while nearly 89% of human excreta enter the sewage system, only about 28% of the milch and meat animal wastes enter the sewage system. A larger fraction of the animal wastes is subject to composting. While the carbon fraction of sewage originates largely as human excreta (@ 60 g TS/capita/d) the nitrogen is derived from two sources namely, human excreta and urine. It was estimated that about 60% of the overall human waste and urine only enters the conventional sewage system and a significant fraction is disposed through household level soak pit systems or through open defecation /urination. In their study it has been estimated that 40% of the overall sewage generated in the city reaches the K&C valley system (the Bellandur tank). From this as indicated in Table 1, about 109 t of C and 14.02 t of N enter the sewage stream that finally enters the Bellandur tank. This is the load on to the tank.

Table 2: Water composition of Bellandur lake 18 Nov 2006

Parameter	Inlet Airport	Outlet Bellandur	Ground Water	Tap water
pH (1)	7.35	7.96	6.97	6.9
pH (2)	7.38	7.96	6.99	7.65
NO_3 mg/L(1)	12	6.94	52.3	9.04
NO_3 mg/L(2)	11.7	7.33	60.2	6.29
NH_4 mg/L	31.4	31	6.37	30.1

Influx
Human excreta (residential)
(51.6t)

Human excreta (floating
population) (10.9t)

Animal excreta (major)
(12.3t)

Animal excreta (minor)
(2.0t)

Bangalore
city

Efflux (sewage)
Human residential
(60%, 31t)

Human non-residents
(60%, 6.5t)

Major animals' waste
(28%,3.4t)

Minor animals' waste
(9.7%, 0.2t)

Efflux continued →
in situ drying
(10%, 7.3t human wastes)
(30%, 3.7t, Major animals)
(19%, 0.5t, minor animals)

Composted
(1%, 0.5t human waste)
(42%, 5.2t Major animals)
(52%, 1.3t Minor animals /birds)

soak pits
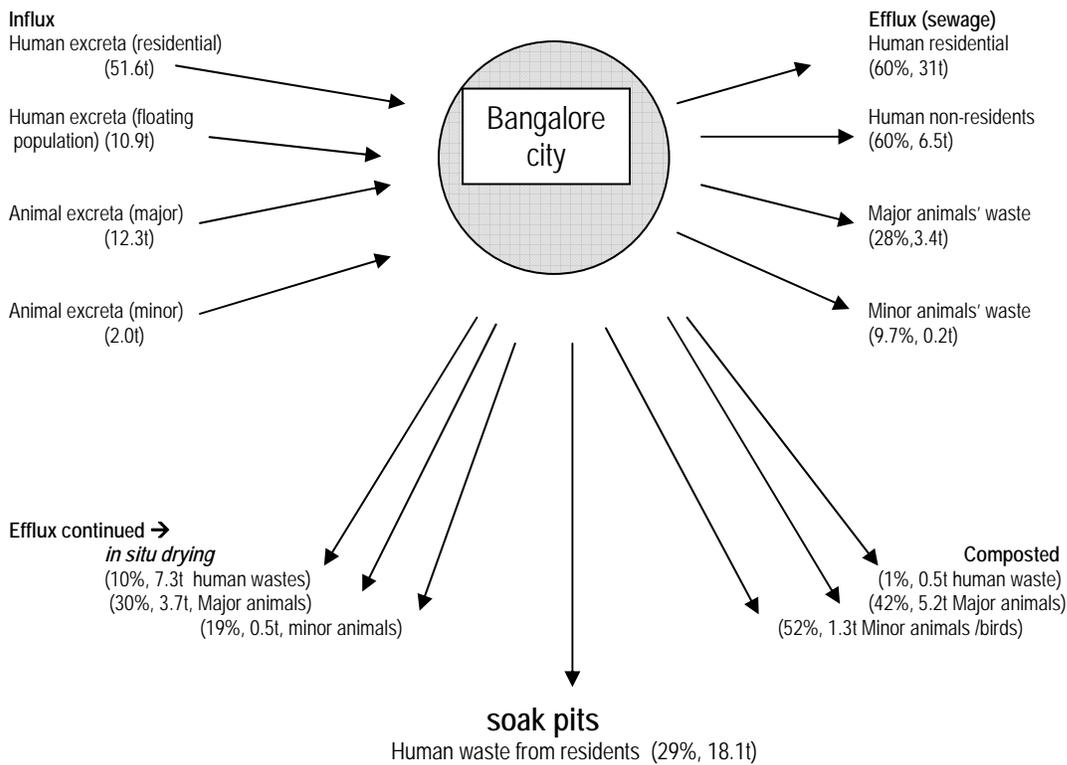Human waste from residents (29%, 18.1t)

Figure 1. Nitrogen input and output pathways and size related to human and animal wastes in Bangalore city (excreta + urine: N as t/d).

It is estimated that between 384 (as per Lake Development Authority reports, 2006) and 500 million litres per day (MLD) of sewage is received at the inlet of the lake. With a water spread area of 380 ha and an average depth of 2 m, this extent of sewage entering the lake provides a residence time of 15.2 d [(380X10000X2)÷500000] at a high inflow of 500 MLD and 19.8 d at 384 MLD. As this lake also receives a large quantity of storm water during rainy season, the residence time is expected to be even lower than 7d. For an input of 109 t C and 14t N the expected BOD load is between 218-280 mg/L and the N load is between 28-37 mg/L. The loading rate works out to be 14.34 and 1.84 g COD and N m^{-3}d^{-1}, respectively into the lake. While this is not a high loading rate to a typical lagoon, it is important to note that the contents of the lake do not mix and could have many high concentration pockets.

The water at the inlet and outlet of the tank (Table 2) and water at various points of the lake (Table 3) have been analysed for various chemical and biochemical parameters. The nitrate nitrogen significantly reduces from the inlet to the outlet as well as at various points within the lake. The rapid loss of nitrate may be ascribed both to denitrification as well as due to uptake. The fate of urea-N and organic-N and their conversion to NH_4 and NO_3 (deamination, urease and nitrification activities) brought about by various microorganisms has not been quantified adequately for Bellandur lake. It is however clear that the high concentrations of ammonia-N remain unconverted by nitrification to nitrate. The low dissolved oxygen concentrations suggest that it is not conducive for efficient nitrification. While EC, chlorides, pH, temperature, DO and COD remain reasonably

similar at all locations within the lake (Table 3), there is appreciable variation in PO_4 concentrations around the lake and it needs further research to explain the same. Compared to the N content the PO_4 levels are low. The available data represent different time periods, yet the N:P ratio may be considered low. This kind of high N and low P is conducive for unique ecological niches and species domination, which is discussed later.

Table 3: Water composition of Bellandur lake 21-May-2005.

Parameter	Jetty 1	Diffuser 1	Diffuser 2	Diffuser 3	Midlake	Jetty 2	Diffuser 4
COD mg/L	80.00	79.47	79.65	79.30	80.18	80.18	79.65
Cl mg/L	115.33	115.73	111.32	112.92	115.73	112.52	115.53
PO_4 mg/L	0.41	0.37	1.06	0.46	0.29	1.33	0.89
NO_3 mg/L	2.18	2.39	2.70	2.38	2.20	2.14	1.84
pH	7.76	8.00	7.84	6.14	7.68	NA	NA
Temperature	28.4	28.4	27.8	29.8	28.1	NA	NA
EC µS/cm	950	956	950	934	947	NA	NA
DO mg/L	1.91	1.48	NA	6.43	NA	NA	NA

The high concentrations of N and low P are conducive for the proliferation of green algae and macrophytes. The predominant alga was found to be Microcystis (Figure 2) followed by members of Euglenophyceae. The algae consuming species were predominantly Ostrocods and Pediastrum species. The presence of such high concentrations of N is usually conducive for growth and proliferation of Microcystis that often comes up at the cost of diversity. It is also interesting to note that even at the end of a 15.2 d HRT a significant proportion of the NO_3 and NH_4 is left unused in the water and there are not adequate indices to understand the reason. It is found that in the presence of such high numbers of Microcystis and Euglenophytes, it is not possible for other species to compete. Such restriction on the biodiversity reduces the redundancy of the system to very low levels and has a potential to go into total failure in case one of these species fail due to other reasons. Therefore, a lot more research is required in this area such that the functioning of the lake is made sustainable. There are also a significant number of macrophytes that have colonised the lake and move freely in the blowing wind. It may be seen that from an estimated COD in the range of 300 mg/L the COD was brought down to about 80 mg/L – approximately 70% reduction. Further, if the COD estimate is corrected for microphytes it may be expected that COD is quite low and there is an indication that the COD has been removed adequately by the lake. Further estimates are needed to determine what are the types of COD that are left under-graded in the discharge.

The overall balance determined for the lake is presented in Figure 3. It may be seen that there is still inadequate estimate on the total discharge because evaporation and seepage losses have not been estimated accurately. It is expected that there is very little seepage and groundwater recharge from Bellandur tank. The groundwater level around the Bellandur tank is approximately 100-150m and the water quality is different in the groundwater (represented by nitrate above permissible limits, Table 2). The COD is significantly reduced by about 75%. The EC levels are high but not high enough for intermittent application on land. The nitrogen removal is poor and it is suspected that in the absence of adequate P, growth of autotrophs – microphytes may be

restricted and attempts are required to enhance biodiversity and microphyte biomass. Further, these microphytes are not harvestable and hence the N and P recovered as microphytes do not represent economic products. Alternatives need to be found to provide economic viability to the system. There is potential for a significant fraction of C to have formed sludge. This is expected to gradually reduce the live storage of the tank and therefore its effectiveness as a C remover. Mechanisms to frequently remove the sludge accumulated at the upstream end where most C is removed is required to ensure sustainability of the system.
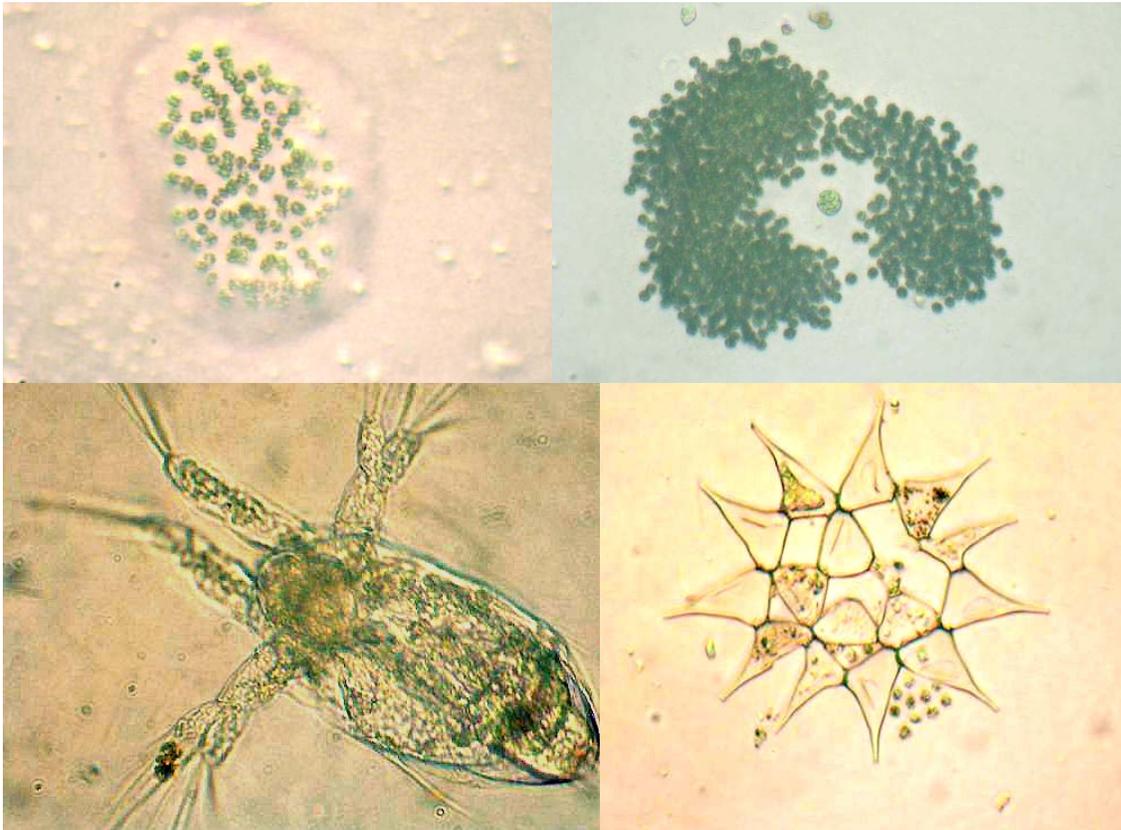

Figure 2: Microcystis (top two slides), ostrocods (above left) and Pediastrum (above right) are the dominant species in the lake.
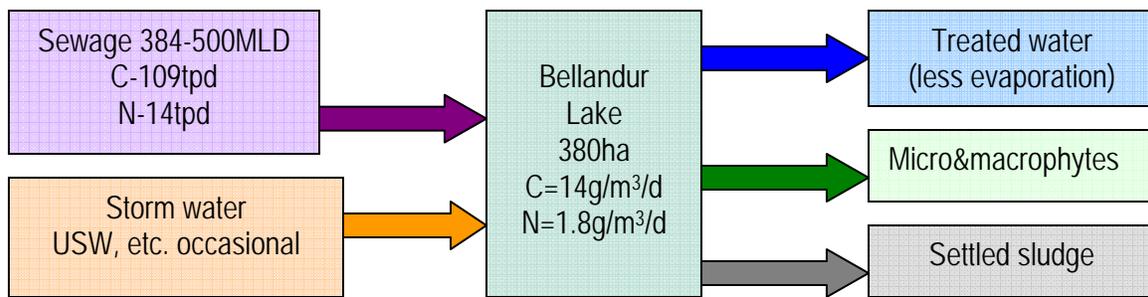
Figure 3: The overall material balance estimated for Bellandur tank. The estimates for outputs are still inadequate to determine efficiency, etc.

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