Lakes Series | Insight Article #6

How do we manage nutrient levels in urban lakes?

By Anjali V Raj, Priyanka Jamwal
Centre for Social and Environmental Innovation, ATREE
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Credits: *Apoorva R.*

Excess nutrients in lakes lead to depletion of dissolved oxygen and an increase in harmful algal blooms.

- To maintain lake health, we need to reduce the external and internal loading of nutrients into the lakes.
- Sewage treatment plants and constructed wetlands can control external loading.
- Physical, chemical and biological methods can control internal loading.
- Lake nutrient management needs to be a gradual, iterative process.

This article is the sixth in a multi-part series on lakes that aims to provide a comprehensive overview of lake-related problems in Bangalore and approaches to address them. This article discusses how lake nutrients, specifically phosphorus, can be managed.

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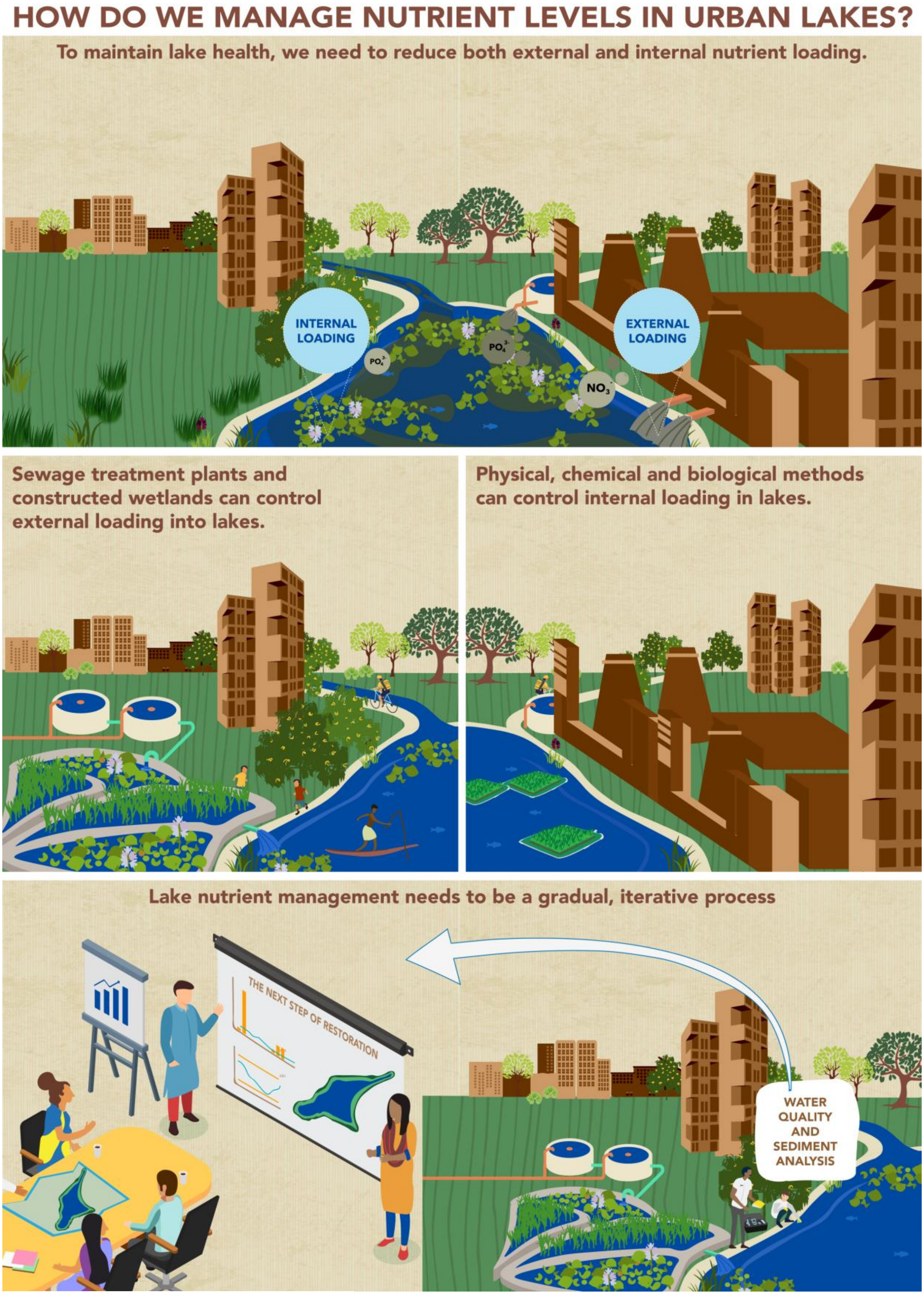

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Bangalore's lakes are hypereutrophic because they are enriched with nutrients. This leads to frequent occurrences of harmful algal blooms (HABs) and fish kills. To maintain lake health, lake nutrient levels must be controlled.

To maintain lake health, we need to reduce both external and internal nutrient loading into lakes.

There may be multiple sources of nutrients entering a lake. Nutrients enter the lake through external loading (i.e., wastewater or stormwater inflows) and/or internal loading (i.e., lake sediments and plant decay). The extent of external loading depends on the activities and the size of the lake catchment while internal loading depends on the physical, chemical and biological interactions in the lake.

External loading consists of nutrients entering lakes through treated or untreated wastewater or stormwater.

Treated and untreated wastewater from all activities in an urban lake catchment enters the lake. Point sources of nutrients include industrial effluents and municipal sewage. Non-point sources include agricultural runoff, urban stormwater runoff, residential runoffs and atmospheric inputs.

Nutrients typically consist of carbon, nitrogen and phosphorous. As carbon is addressed through sewage treatment, this article will focus primarily on phosphorous and nitrogen as the main nutrients of concern.

In urban catchments, the main source of phosphorus entering lakes is sewage, which contains residues of detergents and cleaning products, human waste and industrial effluents. The main source of nitrogen in lakes is also sewage [1]. Untreated sewage typically contains 20-70 mg/L total nitrogen and 4-12 mg/L of total phosphorus while secondary treated sewage typically contains 15-35 mg/L total nitrogen and 4-10 mg/L of total phosphorus [2].

Internal loading occurs when nutrients trapped in lake sediments are released back into the water column.

Eutrophic lakes are characterised by a high density of plant, animal and microbial biomass. The decay of plant and animal biomass recycles the nutrients that are assimilated by these organisms back to the lake sediments or water. Nutrients in particulate form also settle, adding to the sediments.

In eutrophic lakes, in addition to external loading, nutrients that are deposited into sediments due to immobilization and the decay of lake biota are released back to the water. Therefore, once lakes become eutrophic, just preventing further sewage ingress into lakes may not be enough.

If the lake sediments are nutrient-rich, even after rejuvenation and stopping sewage ingress, benthic organisms (lake bottom microbes) may release phosphorus that is bound to the metal ions in the sediment back to the water surface in bioavailable forms. The bound form of phosphorus is released back to water as orthophosphates when anoxic conditions develop at the lake bottom, once again creating a suitable habitat for algae and macrophytes to grow.

Nutrient transformation processes within lakes are dynamic and are influenced by other processes. The phosphorus level determines the fate of the lake.

Nutrients that enter urban lakes are either in bioavailable form or bound form. The bioavailable forms of nitrogen and phosphorus can be readily uptaken by macrophytes (like water hyacinth), microphytes (like algae) and other microorganisms (**Figure 1**).

The two primary nutrients, nitrogen and phosphorous differ in one fundamental respect. Nitrogen can be removed from lakes by bacterial action by conversion to nitrogen gas; in contrast, phosphorus does not have a stable gaseous state.

The dissolved inorganic forms of nitrogen present in lakes include nitrates (NO_3^-), nitrites (NO_2^-) and ammonium (NH_4^+) and these can be readily taken up by plants. Other forms of nitrogen including organic (urea, amino acids, nucleic acids, etc…) and gaseous forms (dinitrogen (N_2) and oxides of nitrogen) cannot be taken up readily by plants but they can be mineralised to ammonium and nitrates by microorganisms. Under suitable conditions (oxygen & pH), however, denitrifying bacterial communities convert nitrates to ammonia and nitrogen gases which are released into the atmosphere.

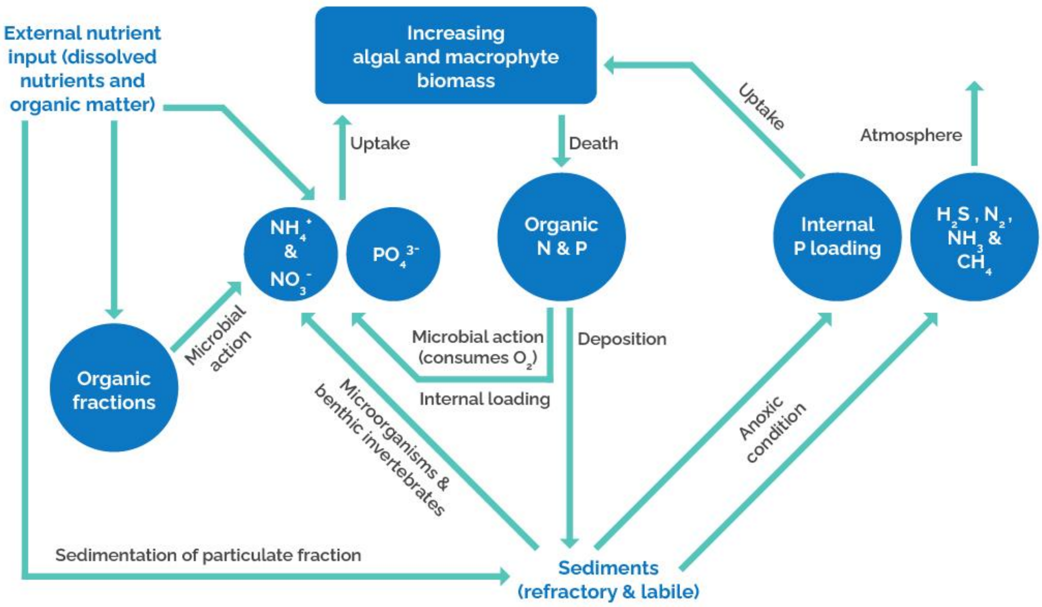

Figure 1: Nitrogen and phosphorus transformations within urban lakes

In contrast, orthophosphate (PO_4^{3-}) is the dominant form of dissolved inorganic phosphorus and it is the only bioavailable form that aquatic plants can uptake. Dissolved organic phosphorus (DOP) and particulate phosphorus (PP) are other major forms of phosphorus [3].

Sewage, dead plant and animal biomass contain PP and DOP, of which a fraction settles as sediments. The rest of the PP and DOP is transformed by aquatic organisms (using phosphatase enzyme), into orthophosphates.

Whether the orthophosphates remain in the water column or settle into the sediments depends on the level of dissolved oxygen in the water. Specifically, orthophosphates bind with metal ions (especially iron) and precipitate (settle down into the sediment) under oxic conditions (high DO) making them biologically unavailable, but they are released back as free phosphates during anoxic conditions (low DO)

Sewage treatment plants and constructed wetlands can control external loading into lakes.

The easiest way to manage nutrients in lakes is by preventing them from entering lakes in the first place; i.e., reducing the external nutrient loading into the lake. One way to reduce the nutrient inputs from external sources is by channelising raw sewage into sewage treatment plants (STPs). Constructed wetlands can offer secondary/tertiary treatment of treated sewage just before it is discharged into lakes.

Once nutrients enter lakes, there are various nutrient management techniques. Some of the in-lake methods are sediment dredging, biomanipulation, floating wetlands, phosphorus inactivation, and oxygenation.

Sewage treatment plants reduce external nutrient inputs into lakes.

A typical sewage treatment plant (STP) has three stages of treatment: primary, secondary and advanced tertiary treatment. Primary treatment removes large floating objects and suspended solids through screening and sedimentation. Secondary treatment targets the additional removal of organic matter present in the dissolved form via microbial action through methods like trickling filters, activated sludge process, bioreactors, etc. Advanced tertiary treatment aims for the removal of nutrients (nitrogen and phosphorus), metals and pathogens using various chemical and biological techniques.

Nitrogen removal in STPs is achieved by denitrification, effecting the transformation of nitrogen from wastewater to the atmosphere [1]. Removal of phosphorus in tertiary treatment of STPs, in contrast, involves the incorporation and removal of phosphates into suspended solids by deploying biological or chemical processes [2]. Although advanced tertiary treatment is expensive, the activated sludge from

STPs can be a potential source of nutrient-rich fertilisers.

Constructed wetlands reduce the nutrient load entering lakes.

Constructed wetlands (CWs) are engineered structures designed to treat wastewater using an assemblage of water, soil, wetland vegetation and microbial communities, mimicking natural processes. Compared to other secondary and tertiary treatment technologies, CWs have the advantage of aesthetic appearance and low energy requirement.

Constructed wetlands remove nutrients and organic matter through filtration, sedimentation, microbial degradation and plant uptake. CWs can be used to remove nutrients from primary or secondary treated sewage just before it enters aquatic ecosystems like lakes. CWs are also used to reduce in-lake nutrient levels by diverting lake water into CWs and then circulating it back to the lake. Constructed wetlands have been shown to remove 80-90 % of organic matter, 40-98 % nitrogen and 64-92 % phosphorus from wastewater [4], [5].

Physical, chemical and biological methods can control internal loading in lakes.

Once the external sources of nutrients are reduced, the next step in lake restoration would be to reduce nutrient loading from inside the lake.

Constructed wetlands (STRAINS) to treat sewage before entering Bellandur lake, Bangalore, 2020 [*Photo Credit: Ramya B]*

Physical and chemical methods to reduce internal loading are expensive and are often temporary fixes.

Physical methods include lake dredging, sediment capping, hypolimnetic oxygenation[1], aeration, hypolimnetic withdrawal and dilution.

Lake dredging involves the removal of nutrient-rich bottom sediments. Under aeration and hypolimnetic oxygenation, the lake water is aerated to maintain oxygen levels to prevent the release of phosphates and obnoxious gases from the sediments. Hypolimnetic withdrawal is a method where nutrient-rich water above the bottom sediment is carefully removed without mixing. Dilution or flushing involves adding nutrient-deficient fresh

[1] Supplying oxygen to the deep water/layer of water above the sediments without disturbing the stratification.

water into the lake to dilute the nutrient concentration of the lake.

Chemical methods control nutrients by adding chemicals to trap nutrients, improve reduction-oxidation (redox) conditions of water or kill algal blooms. The commonly used chemical methods are phosphorus - inactivation by the addition of lime, alum and iron salts; and use of algaecides to control algal blooms. In sediment capping, the lake bottom sediments are sealed with inert materials like clay or polythene to prevent the interaction of these sediments with water.

Phosphorus inactivation is a common restoration method for lakes with a long retention time[2], the method involves precipitation of phosphorus from water by the addition of phosphorus-binding substances like compounds of iron, aluminium or calcium. But the sedimented insoluble salts of phosphorus release phosphates back into the water during anoxic conditions. Hence, sediment capping and inactivation of nutrients work only as a temporary means of reducing nutrient levels in lakes.

For perennial shallow lakes in Bangalore, physical and chemical methods such as sediment dredging, capping and hypolimnetic withdrawal are ineffective and impractical. Aeration, algaecides, chemical methods can only serve as temporary solutions because the phosphorous remains in the sediment and can be released back.

Biological methods are effective and provide ecological benefits.

Once the sewage is treated in STPs, any excess nitrates and phosphates can be removed through biological restoration methods. These methods use macrophytes, aquatic fauna and microbes to reduce and remove nutrients from lakes. Prevalent biological methods are biomanipulation including food web manipulation and macrophyte biomass control (floating treatment wetlands). These methods are successful only if the external nutrient loading into the lake is reduced.

An important difference between biological and physicochemical approaches discussed earlier is the physical removal of phosphorous through biomass and fish removal from the lake. Specifically, the phosphorous is taken up by plants (macrophytes and microphytes), which are in turn consumed by the fish. When the fish are harvested, the phosphorous they contain is also removed from the lake.

Reducing nutrient levels through macrophyte uptake addresses the problem of HABs and depleting DO levels in Bangalore's lakes. Floating treatment wetlands attract butterflies, birds and are also aesthetically appealing.

Macrophyte biomass can be controlled through floating treatment wetlands.

Floating Treatment Wetlands (FTWs) are ecological interventions that can remove

[2] The average amount of time water stays in a lake or a reservoir

nutrients from Bangalore's lakes reducing the nutrient availability for algal proliferation. The areas with FTW also create shade from the sunlight thereby limiting the availability of light for algal photosynthesis. Since FTWs are controlled plant growth setups, this prevents the possibility of uncontrolled growth of macrophytes. Moreover, FTWs increase the aesthetic value of lakes and have recreational benefits. Also, in-situ deployment of FTWs does not require additional land area which is a significant advance over constructed wetlands.

The aquatic plants growing in Constructed Wetlands (CWs) or Floating Treatment Wetlands (FTWs) can assimilate nutrients, provide habitat for aquatic organisms and also can be used for other purposes when harvested (refer **Table 1**). FTWs have a lower operation and construction cost when compared to CWs due to the absence of solid substrates such as soil. FTWs do not get clogged like the constructed wetlands. It is also easier to remove the assimilated nutrients from FTW systems as compared to CWs. Moreover, FTWs can cope more easily with water level fluctuations, provide physical filtration and surfaces for biofilms, and dampen waves thus avoiding resuspension of settled particles [6].

Lake nutrient management needs to be a gradual, iterative process.

Managing nutrients in lakes through ecologically sound and economically feasible methods should be adopted. Internal measures to manage in-lake limits have physical limits. So, most Indian lakes will need fairly substantial reductions in external loading of nutrients to avoid eutrophication in the long term. Hence, lake restoration is a stage-wise long-term process where the necessity of each stage is dictated by the performance of the preceding stage.

Acknowledgements

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Table 1: List of macrophytes used for bioremediation [7]–[11]

Macrophyte species	Favorable habitat
Phragmites karka (common reed)	Warm swampy and marshy areas. Grows well in sunny areas.
Typha latifolia (cattails)	Grows best in extremely moist environments like freshwater wetlands.
Canna Indica (canna lily)	Moist tropical climate, grows best in sunny position.
Scirpus articulates (bulrushes)	Prefers wet places, grows on floating mat formed by degradation of *Eichhornia crassipes*.
Ludwigia adscendens (water primrose)	Grows in wet places like freshwater pools, ditches, swamps etc… very common, from the lowland up to elevations of around 1,600 m.
Chrysopogon zizanioides (Vetiver grass)	Prefers to grow in areas sunny areas with annual temperatures ranging from 22°C to 35°C (but tolerates from -15°C to 55°C) and absorbs dissolved nutrients from waters.
Cyperus spp. (nut grass) *C. cephalotes, C. platystylis* etc…	Found in moist and warm climate, grows best in flooded area and floating islands. Survives in high temperatures.
Iris spp. (Irises) *I. pseudacorus, I. wilsonii*	Found in nutrient rich (especially N) environments such as wetlands, swamps… Tolerant to anoxic conditions
Lythrum salicaria (purple loosestrife)	Prefers moist to wet, sunny habitats with neutral to slightly acidic pH, grows in wetlands and swamps.
Carex virgata (swamp sedge)	Grows in swampy places, from full sun to partial shade, also in damp sites within lowland forest. Widespread from sea level to about 1000 m.
Juncus effusus (soft rush)	Grows in moist and wet conditions with enough sunlight. It grows scattered mostly in wetland habitats although it can also occur in wet pasture or moorlands.
Sagittaria spp. (arrowhead) *S. latifolia, S. lancifolia*	Thrives in freshwater and has affinity for high levels of phosphates and hard waters. It can withstand turbid conditions, and it does not tolerate severe sediment deposition.