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EFFICACY OF REJUVENATION OF LAKES IN BENGALURU, INDIA

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Abstract

Purpose of the study: The main objective of the present work is to assess the efficacy of the restoration endeavour in Bengaluru lakes, Karnataka, India. Rapid urbanisation coupled with industrialisation in urban areas has greatly stressed the available water resources qualitatively and quantitatively. This has also resulted in the generation of enormous sewage and wastewater after independence.

Method: Environmental monitoring of 40 restored lakes was carried out to identify the key issues and assessed water quality (physical, chemical and biological). Weighted arithmetic water quality index (WQI) and Pearson's correlation coefficient (r) was determined using data of physicochemical parameters of lakes. Principal Component Analysis (PCA) performed using PAST3 software to identify the factors responsible for variations in water quality.

Main Findings: The monitored forty lakes distributed across the three major watersheds namely Koramangala and Challaghatta valley, Vrishabhavathi valley and Hebbal valley were grouped under three different WQI status like good water quality (10%); poor water quality (37%) and very poor water quality (53%). Majority of these restored lakes has become polluted which indicates improper decontamination and poor maintenance of restored lakes.

Application of this study: This study provides vital information for policymakers to understand the gaps which helps in the course correction while implementing further rejuvenation of lakes.

Novelty/Originality of this study: The efficacy of rejuvenation was assessed through integrated cost-effective scientific approaches for the lake monitoring. Monitoring during the pre and post rejuvenation period has aided in assessing the efficacy of rejuvenation, which is done for the first time in India.

Keywords*: *Lake rejuvenation, Water quality, Pollution, WQI, Multivariate analysis

INTRODUCTION

Lakes and water bodies also referred to as wetlands are one of the most productive ecosystems contributing to ecological sustainability thereby providing necessary linkages between land and water resources. The quality and hydrologic regime of these lakes and wetlands are directly dependent on the integrity of its watershed. Urban lakes have been aiding in recharging groundwater resources, microclimate moderation, floods mitigation, supported local livelihood (fish, fodder, etc.), local water (irrigation and domestic) demand apart from recreation facilities. Washing, household activities, vegetable cultivation and fishing are the regular activities in the lake for livelihood. In the last couple of decades, rapid urbanization coupled with unplanned anthropogenic activities has altered the wetland ecosystem severely across the globe. Changes in land use and land cover (LULC) in the wetland catchments influence the water yield and water quality of the lakes.

Reduction of wetlands in Bengaluru and the pollution load has increased over years due to population growth, urbanization, industrialization, land use changes, encroachments, etc. (Ramachandra & Aithal, 2016). This has escalated greenhouse gas (GHG) footprint of about 19796.5 Gg of CO_2 equivalents from various sectors in Bengaluru (Ramachandra & Shwetmala, 2012; Ramachandra et al., 2015a), with significant share from waste sector, domestic wastewater sector emits 759.29 Gg (15.42 and municipal solid waste emits 374.73Gg of CO_2 equivalents (Ramachandra et al., 2015a). The sustained inflow of untreated wastewater has increased the pollution levels which is evident from the nutrient enrichment and consequent profuse growth of macrophytes, impairing the functional abilities of the wetlands. Reduced treatment capabilities of wetlands have led to the decline of native biodiversity. Apart from this, prevailing unhygienic conditions with mosquito menace and contamination of groundwater levels has been affecting the livelihood of wetland dependent population, which necessitated rejuvenation of lakes in Bengaluru.

Lake restoration or rejuvenation endeavour is toward the recovery of lakes that has been degraded or damaged. Lake restoration is very important as the pollutants in lake can cause serious problem for human health and the environment. In Bengaluru, there are many para state agencies connected with the governance like BBMP (Bruhat Bengaluru Mahanagara Palike), BDA (Bengaluru Development Authority), BWSSB (Bengaluru Water Supply and Sewerage Board), PCB (Pollution Control Board) at Central and State Government and various departments including Revenue, Fisheries, Minor Irrigation, Forest, Ecology and Environment Department, Citizens, NGOs etc. Figure 1 illustrates the steps involved in lake rejuvenation and conservation.

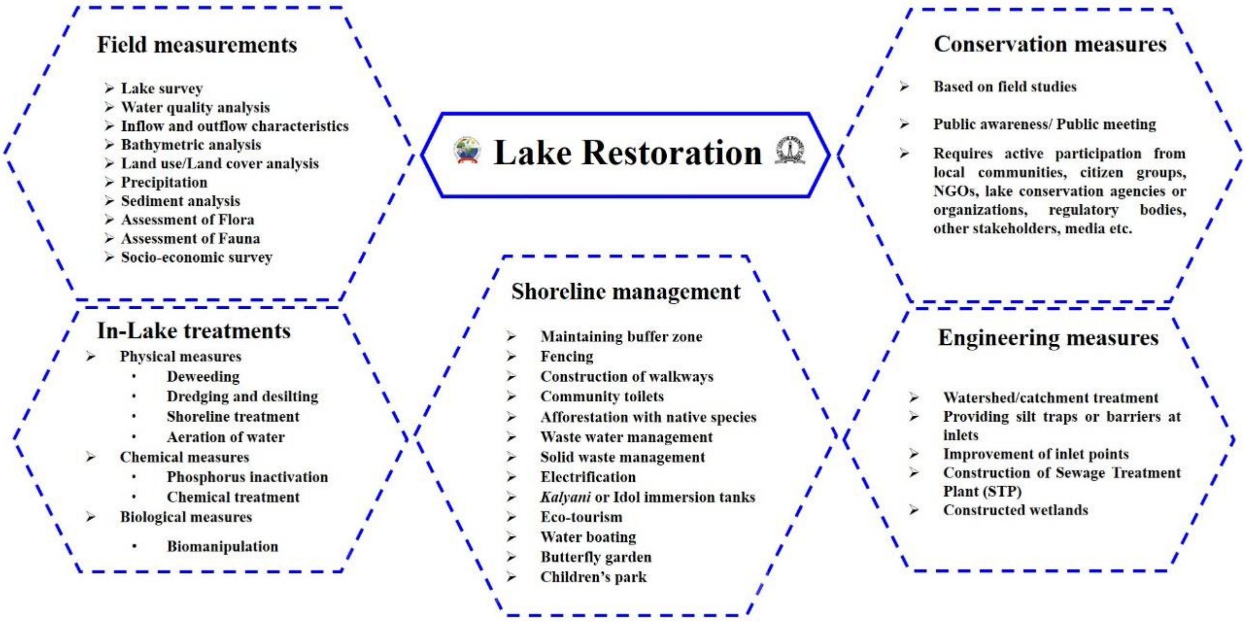


Figure 1: The major steps involved in lake rejuvenation and lake conservation

Different activities involved in lake rejuvenation process are:

a. Fencing around the lake helps to prevent land encroachment (due to construction of roads, infrastructure and residential layouts, and other land uses) and dumping of garbage, loss of wetland area and shrinkage in water spread area.
b. De-weeding which involves regular harvesting/removal of macrophytes in lakes through manual operations/machines that will improve the quality of lakes.
c. Accumulation of silt in lakes and loss of interconnectivity among lakes have been contributing to frequent floods (Ramachandra & Mujumdar, 2009). Thus, dredging (dry/wet dredging) helps in enhancing the water storage capacity of a lake. The removal of contaminated silt and sediments deposited at the lake bottom help in de-contamination. Before initiating dredging in lakes, one need to consider the following points: amount of sediment to be removed, a destined place to dump sediment after removal, feasibility and the associated transportation costs and release of contaminants into lake water during dredging operation.
d. Creating islands for birds for their resting, roosting and nesting activities.
e. Creating walkway/jogging path for visitors, which provides opportunities for recreation and tourism.
f. Afforestation activities, which include planting trees of native species in lake area, provide nectar and fruits, attract butterflies, bees, birds and other biotas. The trees will also provide shade and cool environment to visitors.
g. Construction of idol immersion tank (*Kalyani*) in lakes for the people to offer pooja and immerse idols during festivals. The chemical paints used for idols generally contain heavy metals like lead, copper, cadmium, iron, calcium, manganese, chromium, zinc, mercury, arsenic etc. that can leach into lake water and alter the water quality. Thus, immersing idols at the designated locations like *Kalyani* will prevent the water pollution with heavy metals.
h. The construction of Sewage Treatment Plant (STP) in lakes will help in wastewater treatment and optimal reuse. Raw sewage or industrial effluents should not enter the water bodies. In Bengaluru, sewage is treated to secondary treatment standards and then the treated water may be allowed to flow into the lakes through constructed wetlands to ensure nutrient removal. Construction of artificial wetlands in lakes to enhance their self-purification capacity.
i. Instalment of fountains/aerators in lakes to increase the dissolved oxygen level in water, which helps aquatic organisms to survive.

Water quality refers to various physical, chemical and biological characteristics. Water pollution reduces the availability of freshwater resources and hence, leads to an increase in water demand resulting in water crisis. Water pollution due to anthropogenic and natural factors would result in (a) decrease in water transparency due to the presence of high concentrations of organic matter, nutrients, micro-organisms and suspended matter; (b) change in water quality characteristics; (c) depletion of oxygen due to accumulated organic matter, nutrients and high microbial activities; (d) bacterial contamination that affects public health; (e) destruction to habitats, (f) loss of biodiversity and invasion of exotic as well as pollution tolerant species; (g) obstructs recreational activities and (h) economic consequences ending in negative externalities (Ramachandra et al., 2014; Vincon-Leite & Casenave, 2019; Ho & Michalak, 2017; Carmichael & Boyer, 2016; Watson et al., 2016). Consumption of polluted water causes cholera, typhoid fever, diarrhoea, vomiting, headache, stomach ache, dizziness etc. Industrial waste contains toxins that can cause immune suppression, reproductive failure and acute poisoning (Juneja & Chaudhary, 2013). The heavy metals release from industries pose serious threat to aquatic life due to their toxicity, long persistence, bioaccumulation and biomagnification in the food chain (Ramachandra et al., 2018a). This necessitates the water quality assessments to evaluate trends in water quality, identify the pollutants and their various sources and augmenting certain mitigating measures/solutions.

RESEARCH PROBLEM: Most of the wastewater generated in the city is discharged directly into storm water drains that ultimately link to water bodies. The pollution load on lakes in Bengaluru had increased over years due to population increase with the rapid urbanization and industrialization, which resulted in land use changes, encroachments, loss of interconnectivity among lakes, pollution from point and non-point sources etc. These in turn affected the aquatic biodiversity and contaminates the surface and ground waters posing critical health problems to the citizens. Thus, it is necessary to monitor lakes in order to assess the extent of pollution.

AIM OF THE STUDY: Main objective of the present work is to assess the water quality status and efficiency of restoration endeavor of Bengaluru lakes. This study will help the different stakeholders to implement appropriate remedial measures to enhance the ecosystem services to the society.

LITERATURE REVIEW

Prevalent restoration strategies adopted for lake management

Restoration methods for lakes need to focus on curtailing exogenous and endogenous pollution sources. Multiple restoration approaches will enable to achieve better water quality and habitat conditions. Reduction in flow of nutrients to the lake can reduce deterioration of lake water quality. The restoration methods proposed for Bielsko lake were phosphorus inactivation, reconstruction of the food web, biomanipulation, filtration of treated municipal sewage through a 3-m layer of sand to groundwater and treatment of stormwater in a two-part system consisting of a pond and constructed wetland, which will function as a biofiltration and sedimentation system (Dondajewska et al., 2018a).

The concept of constructed wetlands in nutrient removal is widely accepted. Construction of surface and subsurface flow artificial wetlands is essential to enhance the self-purification capacity of aquatic ecosystems (Wang et al., 2016). Macrophytes have the capability to reduce nutrients in shallow eutrophic lakes (Srivastava et al., 2008; Quilliam et al., 2015). Integration of constructed wetlands and algal ponds as in Jakkur lake, Bengaluru has helped in the removal of nutrients (Ramachandra et al., 2018b). The concept of "wetlaculture" (integration of wetlands and agriculture) has been tried to protect Lake Erie to achieve nutrient removal through restored wetlands and then recycling nutrients to agriculture to minimize the use of additional fertilizers (Mitsch, 2017). Different restoration technologies tried in lakes across the world had successfully achieved pollution abatement and re-established the pristine ecosystem (table 1).

Table 1: Different approaches of lake restoration and their efficiency

Name and location of the Lake	Restoration method adopted	Results achieved due to restoration	Reference
Jakkur Lake, Bengaluru, Karnataka, India	Treated water from STP send through integrated system of constructed wetlands and algal pond	Nutrient removal, increased algal diversity	Ramachandra et al., 2018b
Uzarzewskie Lake, Western Poland	P precipitation from lake water/sediments and nitrate treatment for permanent P binding in sediments	Suppressed internal P loading; concentrations of P, chlorophyll-a content and cyanobacterial biomass reduced	Dondajewska et al., 2018b
Swarzędzkie Lake, West Poland	Aeration of lake water; phosphorus inactivation using small doses of iron sulphate and magnesium chloride; biomanipulation with removal of cyprinids and stocking of pike fry	Increased secchi depth; oxygenation improved; reduction in nutrients; decreased phytoplankton population; eliminated cyanobacteria with increase in number of chlorophytes, chrysophytes, cryptophytes	Rosinska et al., 2018
Varsity Lake, University of Malaya, Kuala Lumpur	Stoppage of wastewater flow to the lake; soil dredging; harvesting of algae and *Najas* sp. and installation of soil retainer	Reduced pollutant concentration; reduction in NO_3^- (95.6%); PO_4^{3-} (96.8%); BOD (99.8%) and TSS (95.6%)	Mood et al., 2017
Sankey Lake, Bengaluru, Karnataka, India	Aeration of lake water using fountain	Reduced cyanobacterial blooms	Ramachandra et al., 2015b

Uzarzewskie Lake, Poland	Supply of nitrates rich water from small tributaries to the hypolimnion of lake	Hydrogen sulfide disappeared; redox potential in the hypolimnion increased; phosphorus in the hypolimnion and internal P loading decreased	Goldyn et al., 2014
Durowskie Lake, Poland	Oxygenation of hypolimnetic waters using wind aerators; iron treatment with small doses of coagulant and biomanipulation	Water quality improved; water transparency and oxygen content increased; chlorophyll-a decreased; dominant cyanobacteria was replaced by diatoms, dinoflagellates and chrysophytes; benthic macroinvertebrate taxa and submerged macrophytes increased	Goldyn et al., 2014
Experiment with water from Xiangjiang River Basin, China.	A restoration-promoting integrated floating bed (RPIFB) was designed to combine the processes of water purification and macrophyte restoration	Best purification capacity; removal efficiencies of RPIFB for TN, TP, NH_4^+-N, NO_3^--N, COD_{Cr}, Chlorophyll-a and turbidity were 74.45%, 98.31%, 74.71%, 88.81%, 71.42%, 90.17% and 85%, respectively	Guo et al., 2014
Lake Yuehu, central Wuhan, China	Sediment dredging	Reduction in phosphorus, organic matter, total suspended solids, chlorophyll-a and secchi depth; reduced internal nutrient load and a shift in zooplankton dominance by less eutrophic species	Zhang et al., 2010
Lake Taihu, China	Enclosure experiment included fish removal, stocking of piscivorous fish, aquatic macrophyte planting, shoreline reconstruction, benthic macro-animal stocking and silver carp cultivation in pens	Enhance water transparency in spring and reduce algal bloom in summer	Chen et al., 2009
Finjasjon Lake, Southern Sweden	Food web manipulations through cyprinid reduction; control of external nutrient loading and construction of 30 ha wetland	Nitrogen and phosphorus reduction; increase in transparency allowed the development of submerged macrophytes; reduction in phosphorus and phytoplankton biomass.	Annadotter et al., 1999

Restoration efforts in some lakes had only resulted in short term improvement in the water quality. For instance, water quality of Lake Geerplas improved initially for four years after restoration. But later, increased internal loading was evident due to an increase in bicarbonate concentration and high P:Fe ratio of the sediment (Van Duin, 1998). This emphasises the need to decontaminate the lake completely by arresting external sources of pollution and the removal of endogenous elements, which entails desilting, which helps in the removal of accumulated contaminants in sediments. Chemical treatment to reduce the productivity of Lake Wolsztynskie water did not bring about permanent improvement of the water quality (Dunalska et al., 2018). Rate and magnitude of recovery of Lake Okeechobee seems to depend on the residence time of lake and the available P in sediments to drive internal loading (James & Pollman, 2011). Dredging can reduce internal P loading but the quantity to be dredged out of the lake and the quality of dredged material influences lake restoration measures. Dredging the top 55 cm sediments would remove 123 g P/m^2 approximately, when compared to 80 and 108 g P/m^2 for 30 and 45 cm dredging, respectively (Reddy et al., 2007). This underlines the fact that we need to choose multiple scientific restoration strategies to achieve better wetland efficiency.

LEGAL FRAMEWORK TO PROTECT WETLANDS IN INDIA

In India, lakes/wetlands are protected by various acts and rules which includes: The Indian Fisheries Act - 1897; The Indian Forest Act - 1927; Wildlife (Protection) Act - 1972; Water (Prevention and Control of Pollution) Act - 1974; Water (Prevention and Control of Pollution) Cess Act - 1977; Forest (Conservation) Act - 1980; The Environment (Protection) Act - 1986; Wildlife (Protection) Amendment Act - 1991; National Conservation Strategy and Policy Statement on Environment and Development - 1992; The Biological Diversity Act - 2002; National Water Policy - 2002; National Environment Policy - 2006; Environment Impact Assessment Notification - 2006; Wetlands (Conservation and Management) Rules - 2010, Government of India; National Water Policy - 2012; Wetlands (Conservation and Management) Rules - 2017, Government of India; Karnataka Lake / Tank Conservation and Development Authority Act, 2014.

Lakes in Bengaluru are protected by Karnataka Tank Conservation and Development Authority Act - 2014. The main functions are to protect, conserve and restore lakes to facilitate recharge of depleting ground water; to prevent and remove encroachment of lakes; to conduct environmental impact assessment studies for lakes; environmental planning and mapping of lakes with the help of geographical information system (GIS) and prepare database and atlas of lakes along with their catchments; to prepare a plan for integrated development of lakes; to improve habitat quality by reducing point and non-point sewage impacts; to promote research pertaining to lakes and conduct public awareness programs for lake conservation, preservation and protection.

The Ministry of Environment, Forest and Climate Change (MoEFCC), India has categorized industrial sectors into Red, Orange, Green and White based on the Pollution Index considering the levels of emissions (air pollutants), discharge of effluents (water pollutants), generation of hazardous wastes and resource consumptions. It should be noted that none of the industries in Red category shall be permitted in an ecologically fragile area or protected area. These rules/acts need to be followed for the protection and conservation of lakes or wetlands.

MATERIALS AND METHODS

Study area

Bengaluru landscape with undulating terrain forms three major watersheds namely Koramangala and Challaghatta Valley, Vrishabhavathi Valley and Hebbal Valley. Bengaluru (Greater Bangalore or Bangalore) lies between the latitude 12°39’00” to 13°13’00” N and longitude 77°22’00” to 77°52’00” E, covering an area of 741 square kilometres and located at an altitude of 920 meters above mean sea level. The study involves monitoring of 40 lakes of Bengaluru spread over the 3 valleys (figure 2). The exploratory field survey was done for determining the location coordinates (longitudes and latitudes) and identifying the key issues in and around the lakes.

Sample collection and water quality analysis

Water samples for determining the physicochemical characteristics were collected from the forty lakes in the clean and sterile polypropylene bottles during the years 2016 - 2019. Various physicochemical analysis like water temperature (WT), dissolved oxygen (DO), pH, total dissolved solids (TDS), electrical conductivity (EC), total alkalinity (TA), chloride (Cl), total hardness (TH), calcium (Ca), magnesium (Mg), nitrate (Nit), ortho-phosphate (OP), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of lake water samples were analyzed using standard methods (APHA, 2005). Some parameters like water temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO) and turbidity (TB) were measured onsite while other chemical and nutrient parameters were estimated in laboratory. Each experiment was carried out in triplicates to determine the overall water quality.

WQI estimation

Weighted arithmetic water quality index (WQI) was computed for the monitored forty lakes using ten key water quality parameters like total dissolved solids, electrical conductivity, dissolved oxygen, pH, calcium, magnesium, total hardness, chloride, total alkalinity and nitrate (Chaurasia et al., 2015; Sincy et al., 2016). Created distribution maps with water quality data using QGIS software.

Data analysis

Pearson’s correlation coefficient (r) was determined using data of physicochemical parameters of lakes. In order to identify the main factors responsible for variations in water quality, multivariate analysis like Principal Component Analysis (PCA) was done using PAST3 software.

RESULTS AND DISCUSSION

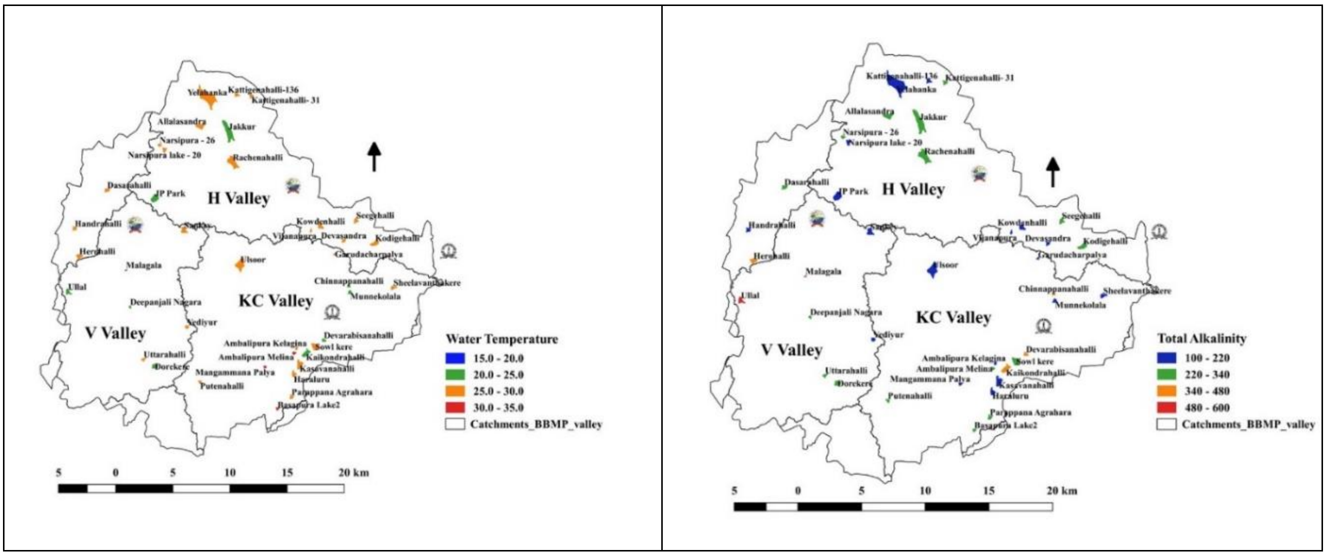
Physicochemical characteristics of restored lakes

The variations in physicochemical characteristics of lakes during the study period are presented in figure 3. Water temperature ranged from 23.6 to 34.2°C, which showed diurnal and seasonal variations. Water temperature affects the physicochemical characteristics of lake water and accelerates the metabolic/biological activities of aquatic organisms. In the present study, total dissolved solids and electrical conductivity ranged from 150.5 - 1230 mg/L and 311 - 2814 µS/cm respectively. Less TDS in water indicates of lower pollutants and can be used for domestic purposes (Bhatia et al., 2018; Ravikumar et al., 2013). pH is an important parameter which influences the availability and release of nutrients like ammonia, phosphate, iron and trace metals into lake water. pH ranged from 7.08 - 9.43 in the monitored lakes. Total alkalinity ranged from 102.6 - 595 mg/L and gives the measure of bicarbonates, carbonates, phosphates and hydroxides etc. in water samples. Dissolved oxygen (DO) which represents the amount of oxygen present in water that supports aquatic life, varied from 0 - 16.53 mg/L. Oxygen enters water from the air and through photosynthesis by algae and aquatic plants. The increase or decrease in DO depends on photosynthesis and decomposition activities in lakes.

Organic pollution in lakes represented by chemical oxygen demand (COD) and biochemical oxygen demand (BOD), which ranged from 8 - 164 mg/L and 4.07 - 99.59 mg/L respectively. Total hardness, calcium and magnesium in monitored lakes ranged from 79 - 738 mg/L, 21.11 - 224.45 mg/L and 5.03 - 49.07 mg/L respectively. Chloride ions exist in natural waters as the salts of sodium, potassium and calcium. In the monitored lakes, chloride ranged from 46.86 - 1586.14 mg/L. Polluted lakes receiving sewage water, industrial effluents and agricultural run-off have higher amount of chloride. Basapura lake - 2 had higher values of water temperature, total dissolved solids, electrical conductivity and BOD, which indicated ionic and organic pollution. Ambalipura Kelagina kere had higher ionic contents with chloride, total hardness and calcium. Lesser ionic pollution was evident in Yediyur lake with lower values of chloride, total hardness, magnesium, electrical conductivity and total dissolved solids. Handrahalli lake had lowest organic pollution compared to others evident from minimum values of BOD and COD. Dorekere lake had high nutrient loadings of ortho-phosphate and nitrate. Domestic wastewater mainly containing detergents, organic wastes, industrial effluents and agricultural run-off contribute to higher levels of phosphates in surface waters (Iscen et al., 2008).

Pearson's correlation coefficient (r) helped to identify the correlation among water quality parameters. In the current study, strong positive correlation was found between EC - TDS (r = 0.95); COD - BOD (r = 0.98); total hardness - chloride (r = 0.81); calcium - chloride (r = 0.80); magnesium - total hardness (r = 0.90) and nitrate - orthophosphate (r = 0.73).

Figure 2: Restored lakes of Bengaluru, Karnataka, India



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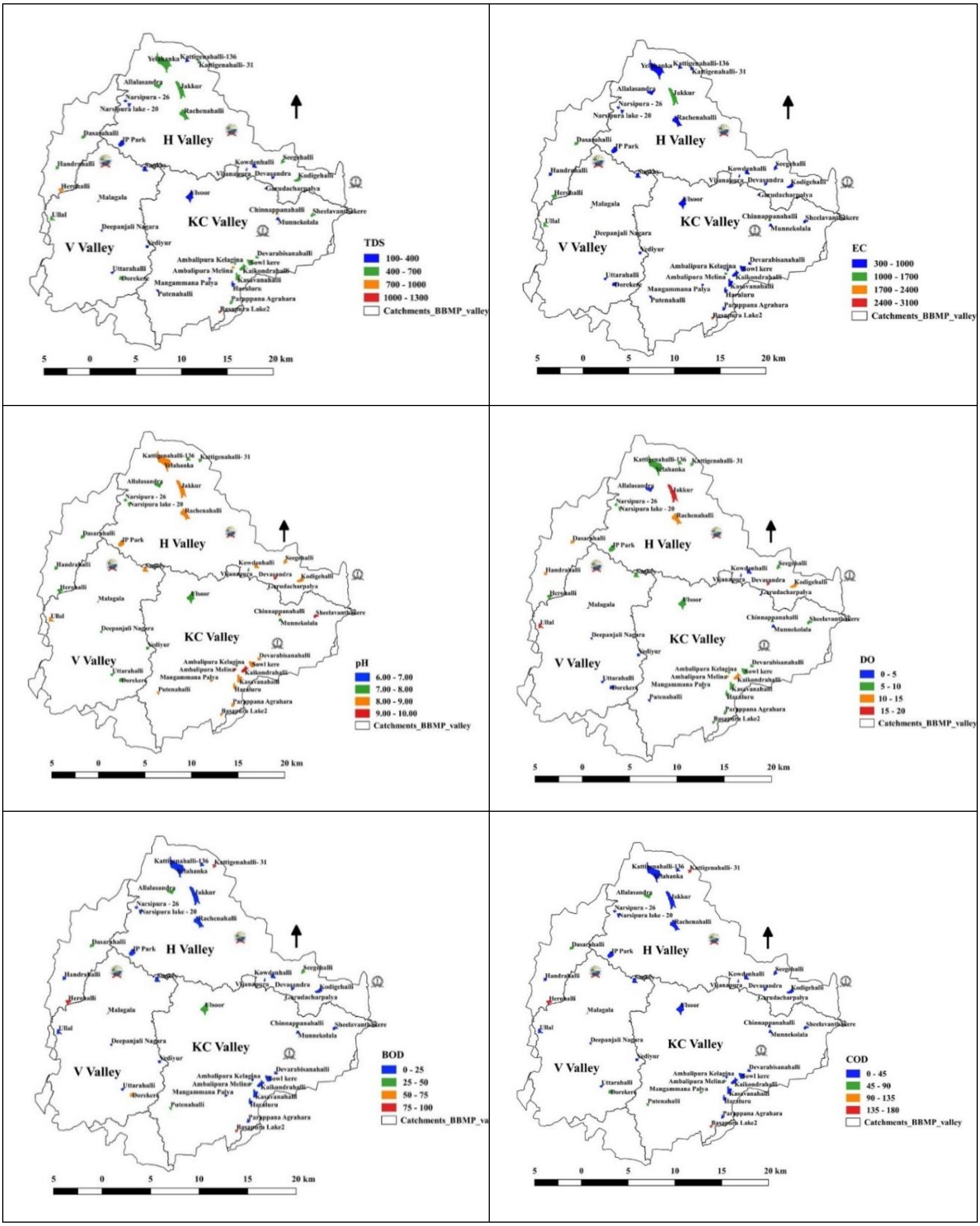

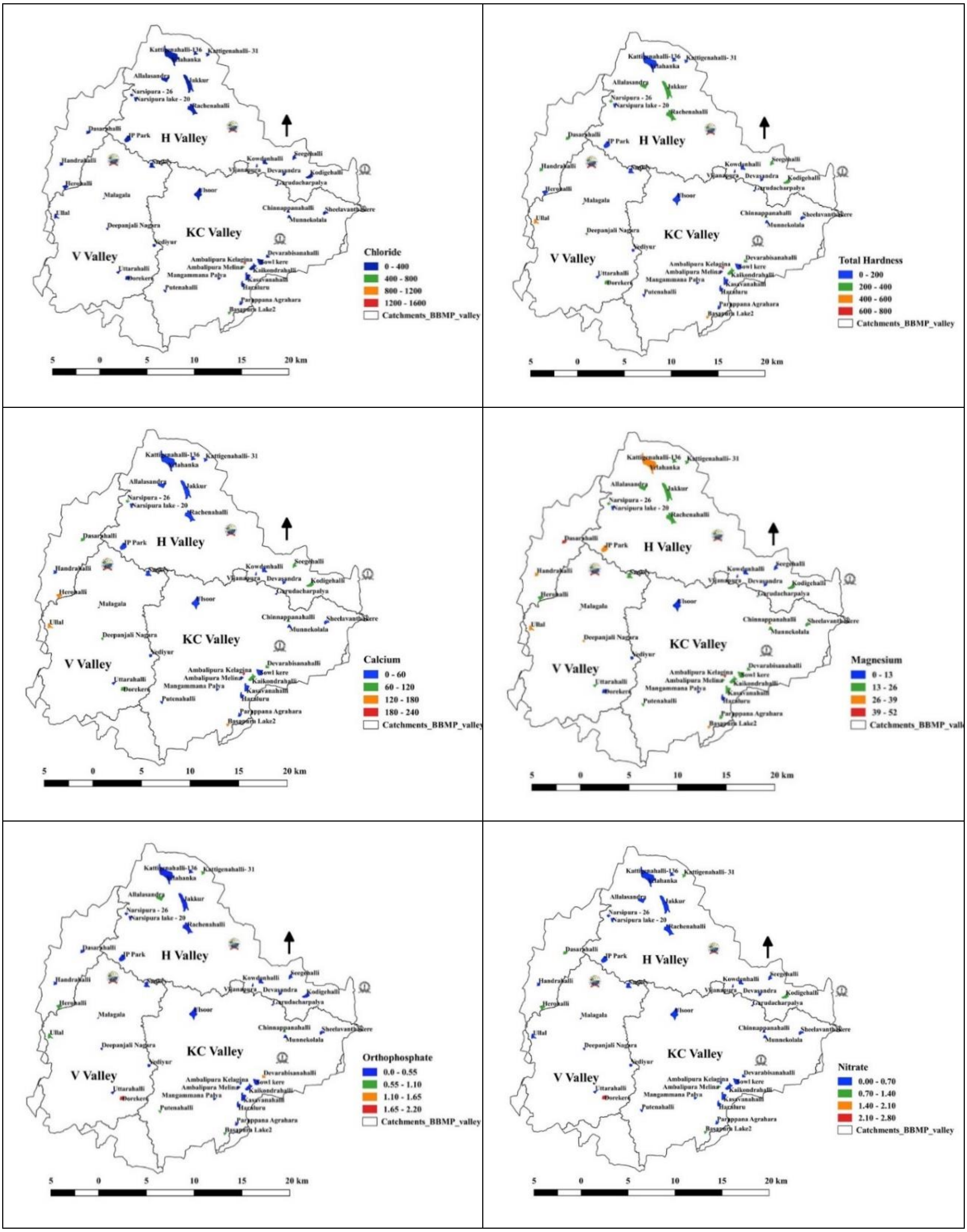

Figure 3: Spatial variation in water quality parameters

ENVIRONMENTAL VARIABLES AFFECTING WATER QUALITY OF LAKES

Principal Component Analysis (PCA) aided in identifying the most important environmental variables that significantly influence the water quality of lakes. PCA performed on normalized water quality data of forty lake samples described by fourteen physical and chemical parameters (14 variables), yielded 4 PCs with eigenvalues >1. The eigenvalues were 5.75, 3.08, 1.60 and 1.49 and the % variance were 41.07, 22.02, 11.41 and 10.67% for PC1, PC2, PC3 and PC4 respectively and these components explained the variability in water quality variables (table 2). PC1 has strong positive loading on pH, dissolved oxygen, orthophosphate and nitrate whereas negative loading on total hardness. PC1 indicates non-point sources of pollution due to the presence of nutrient and organic pollution. PC2 influenced by chloride which indicates pollution in lakes through domestic sources. PC3 influenced by BOD and COD, which indicate domestic as well as industrial pollution of lakes. PC4 influenced by water temperature and TDS, showed the influence of climatic factors. Thus, PCA revealed that the physicochemical parameters like pH, dissolved oxygen, orthophosphate, nitrate, chloride, calcium, BOD, COD, water temperature and TDS played an important role in the present study.

Table 2: Loadings and eigenvalues of water quality parameters on significant principal components

Parameters	**Abbre.**	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Water Temperature	WT	0.36	-0.27	0.03	0.76
TDS	TDS	0.17	-0.29	-0.47	-0.73
EC	EC	0.57	-0.59	-0.36	0.18
pH	pH	0.92	0.21	-0.06	0.30
DO	DO	0.91	0.30	-0.10	0.04
BOD	BOD	0.55	-0.50	0.59	-0.21
COD	COD	0.37	-0.63	0.63	-0.09
Alkalinity	TA	-0.61	-0.51	-0.25	0.28
Chloride	Cl	-0.08	0.76	0.50	-0.17
Total Hardness	TH	-0.74	0.48	-0.15	0.18
Calcium	Ca	-0.45	0.56	0.23	0.18
Magnesium	Mg	0.61	0.44	-0.31	-0.15
Ortho-Phosphate	OP	0.91	0.34	-0.04	0.02
Nitrate	Nit	0.91	0.34	-0.04	0.03
Eigenvalue		5.75	3.08	1.60	1.49
% variance		41.07	22.02	11.41	10.67

WQI STATUS OF RESTORED LAKES

Monitored lakes were grouped under three different WQI status like good water quality (10%); poor water quality (37%) and very poor water quality (53%). WQI results revealed that only 4 lakes such as Jakkur, Devasandra 1, Ullal and Handrahalli had good water quality. About 15 lakes fell under poor water quality i.e., Dasarahalli (Chokkasandra), Kattigenahalli, Narsipura - 20, Kodigehalli, Kattigenahalli kere - 136 (Palanahalli), Narsipura - 26, Sowl kere, Dorekere, Sankey, Yediyur, Rachenahalli, Ulsoor, Vijnanapura, Mangammanapalya kere and Yelahanka. Rest of the lakes such as Ambalipura Melina kere, Kasavanahalli, Haraluru, Chinnappanahalli, Herohalli, Munnekolalu, Parappana Agrahara, Garudacharpalya, J.P. Park, Sheelavanthakere, Kaikondrahalli, Seegehalli, Basapura - 2, Uttarahalli, Allalasandra, Malagala (Ballehannu), Devarabisanahalli, Kowdenhalli (Gangadharkere), Ambalipura Kelagina kere, Deepanjali Nagara kere and Puttenahalli lake had very poor water quality (figure 4).

Most of the restored lakes were polluted as they continue to receive pollutants in the form of untreated or partially treated sewage from the catchment and dumping of industrial effluents. Inflow of sewage and industrial effluents resulted in chemical pollution and microbial contamination of groundwater in Bengaluru city, causing health risks (Sheeba et al., 2017).

Rejuvenation is expected to improve the overall quality of lakes. Comparison of the status of Devarabisanahalli lake before and after restoration activities, it was found that the water quality of Devarabisanahalli lake has not improved, evident from the WQI of very poor water quality during the two scenarios. This shows a lacuna in the current restoration measures. This also underlines an urgent need to maintain these restored lakes before further deterioration. Awareness programs and implementation of environmental norms is required to arrest further deterioration (Ladu et al., 2018).

CONCLUSION

Bengaluru lakes are under stress due to the mismanagement with the uncoordinated and fragmented governance, which is evident from the sustained inflow of untreated or partially treated sewage, untreated industrial effluents, dumping of municipal solid waste including construction and demolition waste, encroachment of storm water drains and lake bed. Despite the attempts to restore degraded lake to the original status has proved to be futile due to the lack of ecological approaches in the restoration. Multivariate analyses showed that the physicochemical parameters like pH, dissolved oxygen, orthophosphate, nitrate, chloride, calcium, BOD, COD, water temperature and TDS played an important role in determining the water quality of these restored lakes. WQI results revealed only 4 lakes such as Jakkur, Devasandra 1, Ullal and

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Handrahalli has good water quality. It was noted that Devarabisanahalli lake has very poor water quality before and after restoration activities which shows a lacuna in the current restoration measures. Proper restoration measures should be practiced to control and prevent pollution due to indiscriminate disposal of liquid and solid wastes from domestic and industrial sources into water bodies for improving and maintaining their quality and there is an urgent need to maintain these restored lakes before further deterioration.

Gaps in the current rejuvenation path are (i) lack of understanding of functional aspects of a lake – ecological, hydrological and remediation aspects in addition to recreation services; (ii) the focus of lake rejuvenation is only to utilize the allocated funds (activities matching the allocated funds have been proposed and implemented) without any scientific evaluation of the lake and the need assessment; (iii) not decontaminating the lake – partial removal of contaminated silt (accumulated over a period); (iv) reuse of contaminated silt – shoreline stabilization, creation of 'islands'. Contaminants in the silt leaches to the lake and maintain the contaminated status of the lake; (v) not arresting fresh pollutants – sustained inflow of partially treated or untreated sewage and industrial effluents; (vi) removal of riparian vegetation and wetlands (which would have removed the nutrients). Riparian vegetation also aids as breeding ground for dependent biota – birds, butterflies, etc.; (vii) emphasis of rejuvenation based on civil works than on ecological restoration; (viii) converting the lake to a 'cement bowl' than restoring the ecology of the lake system; and (ix) the focus of rejuvenation is on creating jogging path and beautification of the lake than ecological restoration.

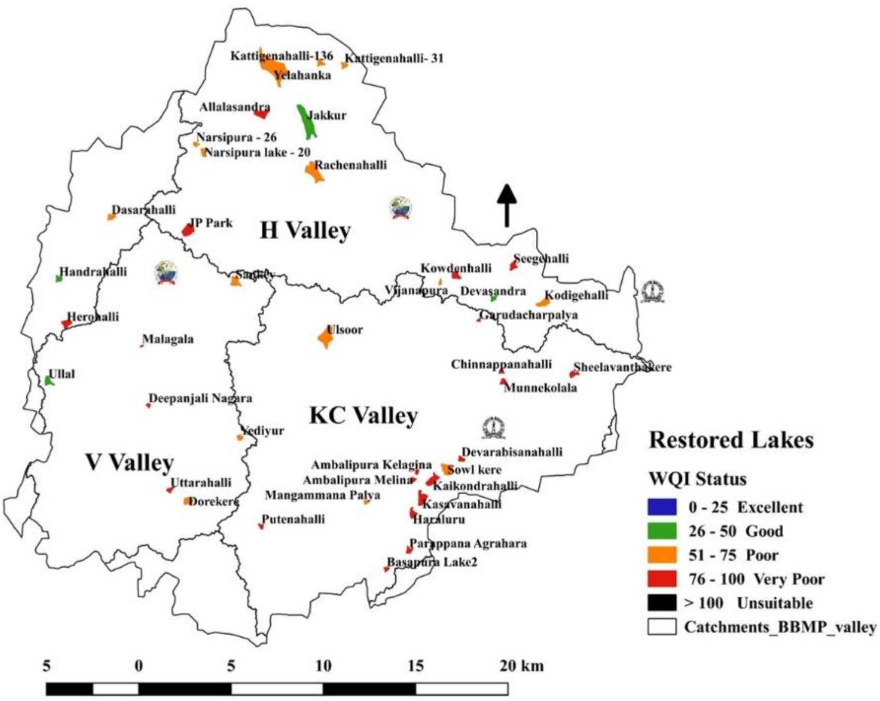

Figure 4: WQI status of restored lakes

RECOMMENDATIONS

Restoration efforts should reduce pollution, improve the lake water quality and provide habitat, which supports maximum aquatic biodiversity. The following measures need to be adopted to save these restored lakes (table 3):

Table 3: Rejuvenation protocol

Rejuvenation Protocol: Restore to enhance ecological integrity and not to fool public
DECONTAMINATE
• **Complete removal** of accumulated contaminated silt in the lake. **Desiltation** not only enhances storage capacity but also aid in removing contamination. Adopt latest state of the art technology - wet dredging to remove deposited sediments; • **Scientific approaches in desilting**; Remove all accumulated silt considering the original topographic contours; • **Do not reuse the silt** (removed from the lake) for shoreline stabilisation or for creating 'islands' as the contaminants get leached to the water, impairing the chemical integrity of an ecosystem; • Ensure the complete removal of silt and verification of the achieved depth through scientific survey (total station survey); • Implementation of '**polluter pays' principle** as per the water act 1974; Zero discharge from industries; • **Stop dumping** of solid waste and Construction & Demolition (C & D) wastes in the lake bed, storm water drain; Treat C & D Waste as per C & D waste management rule 2016, GoI; • **Stop Pollution** – only treated sewage shall enter the lake. Sewage treatment through integrated constructed wetlands (similar to Jakkur Model – Secondary Treatment Plant (STP) + Constructed Wetlands + Algae ponds, will remove nutrients, etc.);

• **No diversion of sewage** from upstream to downstream regions and • **Adopt de-centralized sewage treatment option** (similar to Jakkur lake – removal of chemical ions and nutrients) and reuse of treated sewage in the locality.
EVICT ENCROACHERS
• **Remove all blockades** at outlets as well as inlets– to prevent stagnation of water and enhance aeration in the water body; • **Remove all encroachments** without any considerations or political interventions (lake bed, storm water drains, buffer zone); • **Remove the nexus** of consultants, contractors and engineers.
REGULAR MAINTENANCE
• Minimum 5 years maintenance of the lake by an agency (who implemented rejuvenation); • Remove macrophytes (covered on the water surface) regularly to (i) maintain the water spread area of lakes, (ii) minimise the instances of nutrient re-release to the lake by decay of macrophytes, and (iii) to allow the photosynthesis of algae and improving the trophic level performance. • Install fountains (with music and LED) to enhance surface aeration and recreation value of the ecosystem; • No introduction of exotic species of fauna (fish, etc.); • Identify Local NGO for regular maintenance and management; • Public Participation: Decentralised management of lakes through local lake committees involving all stakeholders - Involve local stakeholders in the regular maintenance and management.
MONITORING AND SURVEILLANCE
• Regular surveillance through vigilant resident groups and a network of local education institutions; • Regular monitoring of treatment plant and lake water quality (physical, chemical and biological) and the dissemination of information to the public through internet; • Online portal for all urban lakes (with the regular updation of information of water quality, photographic evidences, etc.)
SENSIBLE POLICY & IMPLEMENTATION
• Shun the path of rejuvenation to siphon off the public funds; • **Ban on use of phosphates** in the manufacture of detergents; will minimise frothing and eutrophication of water bodies; • **Digitation of land records** (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query based information system to public; • **Implementation of 'polluter pays'** principle as per water act 1974; • Planting native species of macrophytes in the buffer zone (riparian vegetation) as well as in select open spaces of lake catchment area; • Restrictions on the diversion of lake for any other purposes; • NO construction activities in the valley zones.
GOOD GOVERNANCE
• Protect flood plains (buffer zones) to enhance the water retention capability of the lake. Enrich floodplains with riparian vegetation so that water gets treated as it passes through riparian zones; • Maintain a minimum of 75 m buffer zone in urban lake and for larger lakes the buffer zone depends on the topography and shape of the catchment; • Avoid comparisons with the neighbouring regions (who are in the clutches of land mafia) and reduce the buffer zone; • Single agency with the statutory and financial autonomy to be the custodian of natural resources [ownership, regular maintenance and action against polluters (encroachers as well as those who contaminate through untreated sewage and effluents, dumping of solid wastes)]. Effective judicial system for speedy disposal of conflicts related to encroachments; • Autonomous status to the agency to ensure minimal interference by the local politicians; • Legislators to legislate and ensure effective implementation through the executive mechanism; • Efficient decentralised administration through elimination of Land, Water and Waste Mafia. • Make bureaucrats and engineers of the respective para-state agencies accountable for the poor status of urban lakes.

FUTURE SCOPE OF WORK

The present work underlines the gaps in the current restoration of lakes in Bengaluru, which will be helpful for different stakeholders and other government agencies who are involved in lake development and watershed management. Implementation of the recommendations would help in improving the local environment conditions. Development of environment health card for all lakes at regular interval would help in mitigating pollution of vital ecosystems.

CONFLICT OF INTEREST AND ETHICAL STANDRADS: We have no competing interests either financial or non-financial.

RESEARCH ETHICS: The publication is based on the original research and has not been submitted elsewhere for publication or web hosting.

ANIMAL ETHICS: The research does not involve either humans, animals or tissues

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AUTHORS CONTRIBUTION

i. Ramachandra T V: Conceptualization and design of experiments; data analysis and interpretation of data, article revision and final editing.
ii. Sincy V: Field monitoring of lakes, carrying out experiments, data analysis and result interpretation and paper writing.
iii. Asulabha KS: Lake monitoring, water quality analysis, data analysis and interpretation and paper writing.

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