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Title

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Journal

Electronic Green Journal, 1(15)

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Publication Date

2001-12-01

Peer reviewed

Restoration And Management Strategies Of Wetlands In Developing Countries

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Wetlands is the collective term for marshes, swamps, bogs, and similar areas. Wetlands filter sediments and nutrients from surface water and support all life forms through extensive food webs and biodiversity. They are fragile ecosystems that are susceptible to changes even with little change to the composition of their biotic and abiotic factors. In recent years, there has been increasing concern over the continuing degradation of world's wetlands, particularly rivers and lakes. Wetlands sustain all life and perform useful functions in the maintenance of ecological balance. Interfacing between land and water systems, they are highly productive and biologically rich ecosystems, and are also the most endangered.

Indian wetlands are mostly associated with river systems distributed from the cold, arid zone of Ladakh, and the warm, arid zone of Gujarat-Rajasthan to the tropical monsoon of central India and the wet, humid zone of the southern peninsula. Of an estimated 4.1 million hectares (excluding irrigated agricultural lands, rivers, and streams) of wetlands, 1.5 million hectares are natural and 2.6 are man-made, while the coastal wetlands occupy an estimated 6,750 sq km, largely dominated by mangroves. Wetlands in southern peninsular India are mostly man-made. Known as *tanks*, they are constructed in every village and provide water for human needs and nesting sites for a variety of avifauna. It is a well-established fact that development of water resources is the backbone of any economic activity. The results of wetland loss lead to environmental and ecological problems, depreciating the socio-economic benefits. Apart from fishing, wetlands support agriculture, transhumance herding of domestic livestock, and hunting of wild herbivores migrating in response to flooding pattern. In the recent past, commercially sensitive and economically exploitative attitudes of society have subjected these ecosystems to stress, in some cases leading to alteration and hampering of their functions and their ultimate destruction.

Wetlands in Bangalore (waterbodies-lakes, tanks), Karnataka State, India, are threatened due to pressures from unplanned urbanization and land use activities. In order to accommodate the burgeoning populace, many of the city's wetlands have made way to residential layouts, industrial complexes, and so forth. This has also contributed to the deteriorating water quality and significant change in local climate.

The result has been to show that about 80% of the local residents are dependent on the lake, either directly or indirectly, for irrigation, domestic water needs (ground water), fuel, and fodder. The socio-economic survey in the vicinity of lake ecosystem revealed that about 65% of the residents were willing to pay for its restoration, conservation, and efficient management. In this direction, a suitable management program has been developed that addresses these concerns. This paper discusses restoration, post-restoration, and management strategies through a holistic approach based on the findings of pilot studies in Bangalore city, Karnataka State, India. The pilot studies cover spatial-temporal analysis, characterization of water quality through physico-chemical and biological analysis, restoration plans, socio-economic evaluation, a community's perception of lake restoration program, and the roles of the various agencies and departments.

1.0 Introduction

Wetland systems directly and indirectly support millions of people, providing goods and services to them. They contribute to important processes, which include the movement of water through the wetland into streams or the ocean; decay of organic matter; release of nitrogen, sulfur, and carbon into the atmosphere; removal of nutrients, sediment, and organic matter from water moving into the wetland; and the growth and development of all organisms that require wetlands for living. The direct benefits of wetlands are the components/products such as fish, timber, recreation, and water supply, and the indirect benefits arise from the functions occurring within the ecosystem such as flood control, ground water recharge, and storm protection. Wetlands may be of a great significance to indigenous people as part of their cultural heritage.

Wetlands have the capacity to retain excess floodwater during heavy rainfall that would otherwise cause flooding. By retaining flood flows, they maintain a constant flow regime downstream, preserving water quality and increasing biological productivity for both aquatic life as well as human communities of the region. Periodically inundated wetlands are very effective in storing rainwater and are the primary source for recharging ground water supplies. The extent of groundwater recharge depends on the soil and its permeability, vegetation, sediment accumulation in the lakebed, surface area to volume ratio, and water table gradient.

Wetland vegetation plays a major role in erosion control, which in turn contributes to shoreline stabilization and storm protection. Coastal wetlands, in particular mangrove forests, play a role in shoreline

stabilization and storm protection by helping dissipate the force and protect the coast by reducing the damage of wind and wave action. Thus, the mangrove forests manage natural hazards at much lower cost by reducing current velocity through friction, and improve the water quality.

Wetlands retain nutrients by storing eutrophic parameters like nitrogen and phosphorus, flooding waters in vegetation, or accumulating them in the sub-soil, thus decreasing the potential for eutrophication and excess plant growth in receiving waters. They also help in absorbing sewage and in purifying water supplies.

Apart from this, the socio-economic values, through water supply, fisheries, fuel wood, medicinal plants, livestock grazing, agriculture, energy resource, wildlife resource, transport, recreation and tourism, and so forth, are significant. The functional properties of a wetland ecosystem clearly demonstrate its role in maintaining the ecological balance.

1.1 Wetlands Loss and Degradation

Wetlands are estimated to occupy around 8.6 million sq km (6.4 %) of the earth's surface, out of which about 4.8 million sq km are found in the tropics and sub-tropics. This estimation was compared with estimates in the 19th century and it was found that approximately 50% of the world's wetlands have been lost in the past century alone. The major activities responsible for wetlands loss are urbanization, drainage for agriculture, and water system regulation (Shine & de Klemm, 1999). Development activities, like excavation, filling, draining, and so forth, are the major destructive methods resulting in a significant loss of wetland spatial spread throughout the country.

Environmental impacts on wetlands may be grouped into five main categories: loss of wetland area, changes to water regime, changes in water quality, overexploitation of wetland products, and introduction of exotic or alien species.

These quality and quantity declinations, have contributed to the decline in the biological diversity of flora and fauna, migratory birds, and productivity of wetland systems. Simultaneously, several thousand species have become extinct, and fish, timber, medicinal plants, water transport, and water supply are over exploited.

1.2 Global Scenario Of Wetlands

The earth, two-thirds of which is covered by water, looks like a blue

planet-the planet of water-from space (Clarke, 1994). The world's lakes and rivers are probably the planet's most important freshwater resources. But the amount of fresh water covers only 2.53% of the earth's water. On the earth's surface, fresh water is the habitat of a large number of species. These aquatic organisms and the ecosystem in which they live represent a substantial sector of the earth's biological diversity.

It is interesting to know that there are nearly 14×10^8 cubic km of water on the planet, of which more than 97.5% is in the oceans, which covers 71% of the earth's surface. Wetlands are estimated to occupy nearly 6.4% of the earth's surface. Of those wetlands, nearly 30% is made up of bogs, 26% fens, 20% swamps, and 15% flood plains. Of the earth's fresh water, 69.6% is locked up in the continental ice, 30.1% in underground aquifers, and 0.26% in rivers and lakes. In particular, lakes are found to occupy less than 0.007% of world's fresh water (Clarke, 1994).

1.3 Indian Scenario Of Wetlands

India is blessed with numerous rivers and streams. By virtue of its geography, varied terrain, and climate, it supports a rich diversity of inland and coastal wetland habitats. The association of man and wetlands is ancient. It is not surprising that the first sign of civilization is traced to wetland areas. The flood plains of the Indus, the Nile delta, and the Fertile Crescent of the Tigris and Euphrates rivers provided man with all his basic necessities. Water may be required for various purposes like drinking and personal hygiene, fisheries, agriculture, navigation, industrial production, hydropower generation, and recreational activities. The wide variety of wetlands, like marshes, swamps, bogs, peat land, open water bodies like lakes and rivers, mangroves, tidal marshes, and so forth, can be profitably used by humans for various needs and for environmental amelioration. Ever-increasing population and the consequent urbanization and industrialization have mounted serious environmental pressures on these ecosystems and have affected them to such an extent that their benefits have declined significantly.

1.4 Distribution Of Wetlands In India

Major river systems in the north are Ganga, Yamuna, and Brahmaputra (perennial rivers from the Himalayas) and in the south, Krishna, Godavari, and Cauvery (not perennial, as they are mainly rain-fed). The central part of India has the Narmada and the Tapti. The Indo-Gangetic floodplain is the largest wetland regime of India. Most of the natural wetlands of India are connected with the river systems of the North and the South. The lofty Himalayan mountain ranges in northern India

accommodate several well-known lakes, especially the palaeartic lakes of Ladakh and the Vale of Kashmir, which are sources of major rivers. In the northeastern and eastern parts of the country are located the massive floodplains of Ganga and Brahmaputra along with the productive system of swamps, marshes, and oxbow lakes. Apart from this, there exist a number of man-made wetlands for various multipurpose projects. Examples are Harike Barrage at the confluence of the Beas and the Sutlej in Punjab, Bhakra Nagal Dam in Punjab and Himachal Pradesh, and the Cosi Barrage in Bihar-Nepal Border. India's climate ranges from the cold, arid Ladakh to the warm, arid Rajasthan, and India has over 7,500 km of coastline, major river systems, and mountains.

There are 67,429 wetlands in India, covering about 4.1 million hectares. Out of these, 2,175 wetlands are natural, covering about 1.5 million hectares, and 65,254 wetlands are man-made, occupying about 2.6 million hectares.

According to Forest Survey of India, mangroves cover an additional 6,740 sq km. Their major concentrations are Sunderbans, Andaman, and Nicobar Islands, which hold 80% of the country's mangroves. The rest are in Orissa, Andhra Pradesh, Tamilnadu, Karnataka, Maharashtra, Gujarat, and Goa.

Wetlands have been drained and transformed due to anthropogenic activities, like unplanned urban and agricultural development, industries, road construction, impoundments, resource extraction, and dredge disposal, causing substantial economic and ecological losses in the long term. They occupy about 58.2 million hectares, of which 40.9 million hectares are under paddy cultivation. About 3.6 million hectares are suitable for fish culture. Approximately 2.9 million hectares are under capture fisheries (brackish and freshwater). Mangroves, estuaries, and backwaters occupy 0.4, 3.9, and 3.5 million hectares respectively. Man-made impoundments constitute 3 million hectares. Nearly 28,000 km are under rivers, including main tributaries and canals. Canal and irrigation channels constitute another 113,000 km.

Though accurate results on wetland loss in India are not available, the Wildlife Institute of India's survey reveals that 70-80% of individual fresh water marshes and lakes in the Gangetic flood plains have been lost in the last five decades. Indian mangrove areas have decreased by half from 700,000 ha in 1987 to 453,000 ha in 1995.

1.5 Karnataka Scenario Of Wetlands

Karnataka state is situated between 11° 31' and 18° 45' N latitude and 74° 12' and 78° 40' E longitude, and endowed with numerous rivers, lakes, and streams, and has a coastline of about 320 km. Spatial extent of the state is 1,92,204 sq km (5.35% of the country's total geographical area) with a population of 52 million. Mean annual rainfall varies from 3,932 (Dakshina Kannada) to 140 mm (Bijapur).

The wetlands of Karnataka are classified into inland and coastal categories, both natural and man-made. Natural inland wetlands include lakes, ox-bow lakes, and marshes/swamps; man-made inland wetlands include reservoirs and tanks. Natural coastal wetlands include estuaries, creeks, mudflats, mangroves, and marshes; while man-made coastal wetlands includes salt pans. Wetlands cover about 2.72 million hectares, of which inland wetlands cover 2.54 million hectares, and coastal wetlands 0.18 million hectares.

The area of 682 wetlands, scattered throughout the state of Karnataka, is about 2,718 sq km, of which seven are natural inland wetlands (581.25 ha), 615 are man-made inland wetlands (253,433.75 ha), 56 are natural coastal wetlands (16,643.75 ha) and four are man-made coastal wetlands (1,181.75 ha). Inland wetlands cover 93.43% (254,015 ha) of the total wetland area while coastal wetlands cover only 6.57 % (17,825.5 ha). Tanks (561) account for 79,088 ha; followed by reservoirs (53), which cover about 174,290 ha; lakes, which occupy about 438 ha; and mangroves, which account for 550 ha. Karnataka includes the basins of Krishna (58.9%), Cauvery (18.8%), Godavari (2.31%), North Pennar (3.62 %), South Pennar (1.96%), Palar (1.55%), and west flowing rivers (12.8%) with drainage of 191,770 sq km. (Rege, et al., 1996).

The total water spread area during pre-monsoon is about 204,054 ha, and 246,643 ha in post-monsoon. Out of the total wetlands in the state, 71 have shown water spread less than 56.25 ha (Rege, et. al, 1996). Water-spread area of lakes/ponds in post-monsoon is about 437.50 ha, and 368.75 ha in pre-monsoon. Reservoirs have shown considerable variations from post-monsoon (167,268 ha) to pre-monsoon (138,684.25 ha). Tanks also vary from 46,975.25 ha (post-monsoon) to 60,912.25 ha (pre-monsoon). Coastal wetlands, under constant influence from the sea, have no variation in terms of water spread area in all seasons. Most of the tanks dry up during pre-monsoon.

1.6 The Status Of Wetlands At Bangalore

Bangalore district is located in the southeastern corner of Karnataka State (12° 39' to 13° 18' N latitude and 77° 22' and 77° 52' E longitude) with a

geographical area of about 2,191 sq km, at an average elevation of 900 m. It has two rainy seasons, June to September and October to November, coming one after the other but with opposite wind regime, corresponding to southwest and northeast monsoons. The mean annual rainfall is about 900 mm. Many lakes and ponds of Bangalore have been lost due to anthropogenic activities and unplanned urbanization. Surviving lakes have become cesspools due to direct discharge of industrial effluents and unregulated dumping of solid wastes.

Wetlands of Bangalore occupy about 4.8% of the geographical area (640 sq km) covering both urban and non-urban areas. Bangalore has many man-made wetlands but no natural wetlands. They were built for various hydrological purposes and mainly to serve the needs of irrigated agriculture. There were 262 lakes (in 1960) within the Green belt area of the city, which has fallen to 81 at present (Lakshman Rau, et al., 1986).

Status of wetlands in Bangalore is a direct measure of the status of management of anthropogenic activities, management of land, solid waste collection and disposal, disposal of used water, and also the attitudes of people in general. The wetlands of Bangalore are being lost due to anthropogenic stress (Kiran & Ramachandra, 1999). Increasing population and a growing economy, leading to unplanned urban development, put greater pressure on land resources. There is a lack of governmental commitment, necessary expertise, and cohesive academic research centered on wetland in understanding the importance and essence of conservation and management (owing to financial constraints and lack of infrastructure). Deficiency in proper management of non-point source of pollution, like storm water runoff, agricultural runoff and unregulated land use management, has also led to problems of pollution, eutrophication, invasion of exotic species, and toxic contamination by heavy metals, pesticides and organic compounds.

Urbanization and anthropogenic stress in Bangalore city has led to discontinuity of the drainage network due to loss of wetlands. Studies revealed a nearly 35% decrease in the number of bodies of water during 1973 to 1996 (Deepa, Ramachandra, & Kiran, 1998).

Earlier investigations revealed that nearly 30% of the lakes are used for irrigation. Fishing is being carried out in 25% of the lakes surveyed. While 36% of the lakes were used for washing purposes. Only 3% were used for drinking water. Agriculture along drying margins is practiced at 21% of the lakes. Approximately 35% of the lakes were used for grazing by cattle. Mud lifting was recorded in 30% of the lakes, and brick making in

38% of the lakes (Krishna, Chakrapani, & Srinivasa, 1996).

2.0 Objectives

The main objectives of this study were to identify the status of wetlands based on qualitative and quantitative impacts due to urbanization and various anthropogenic activities, and explore suitable restoration, conservation, and management strategies based on pollution level.

3.0 Methodology

A suitable restoration action plan could be devised only if characterization of the type and source of pollutants entering the ecosystem is known. Investigation of the physico-chemical and biological parameters in this regard helps in assessing the status, which is required for evolving appropriate restoration methods towards conservation and management. In order to characterize the water quality of wetlands, sample lakes/tanks were chosen in and around Bangalore for monitoring, depending on the location and type of pollutants getting in to the system. The present study entailed sampling and analyzing the lake water quality, performing a socio-economic survey of the lakes, and investigating spatio-temporal changes.

4.0 Results: Physico, Chemical And Biological Aspects

The color of the polluted lakes was mostly greenish, due to algal blooms and effluents from domestic and industrial sources. Turbidity in the lakes ranged from 1-25 NTU (Nephelometric Turbidity Units) in cleaner waterbodies to 70-362 NTU in polluted lakes, and was mainly due to silt, organic matter, and autochthonous sources (mainly planktons) from both point source (industries and domestic) and non-point source pollution (storm water runoff), which directly influences the light penetration and affects the production efficiencies.

The pH values of most water samples analyzed ranged from alkaline (7.6-9.3) to acidic. Kamakshipalya had values of 6.0-6.6 during the entire study period. Higher alkaline values were noticed at Yediur and Ulsoor tanks. At a given temperature, pH is controlled by the dissolved chemical compounds and the biological processes in the solution (Chapman, 1996). The dissolved solids mainly consist of carbonates, sulphates, chlorides, nitrates, and possibly phosphates of calcium, magnesium, sodium, and potassium. High dissolved solids were noticed in all the studied lakes except Bannergatta and Sankey lakes and ranged from 30-301 mg/L and 430-1024 mg/L in Kamakshipalya and Yediur respectively. The suspended

solids ranged from 52.2 mg/L to a high of 288.3 mg/L as a result of silt and matter in suspension.

The dissolved oxygen levels of the analyzed lakes ranged from 1.2 mg/L (in Kamakshipalya lake) to 11.1 mg/L (in Ulsoor and Yediur lakes) largely due to photosynthetic activity. The recommended dissolved oxygen concentration for a healthy and ideally productive lake water body is 8 mg/L (Wetzel, 1973).

Phosphate content was found to be low, ranging from 0.06 mg/L to a high of 4.2 mg/L in Kamakshipalya lake. The standard is 0.2 mg/L for surface inland water (Chakarapani & Ramakrishna Parama, 1996). This parameter is very crucial and ecologically elusive, as it has the tendency to be precipitated by the many cations and accumulates at the bottom of the lake. The nitrate values ranged from 0.1mg/L to 2.7 mg/L. The standard for inland surface water is 0.1 mg/L (National Environmental Engineering Research Institute, 1988: xv). This parameter is very significant from the point of view of productivity in lakes.

The Chemical Oxygen Demand (COD) measures the oxygen equivalent of the organic and inorganic matter in a water sample that is susceptible to oxidation. COD as a result of pollution is largely determined by the various organic and inorganic materials (calcium, magnesium, potassium, sodium, and so forth). The COD values ranged from 27mg/L in the unpolluted waters to a high of 621 mg/L in Kamakshipalya. Among the analyzed heavy metals, iron and lead were shown to be present in greater concentrations than zinc and chromium.

Results of the study showed that most of the analyzed parameters of five lakes (Ulsoor, Hebbal, Yediur, Kamakshipalya, and Madivala) out of the seven exceeded the limits set by Indian Standard for Industrial and Sewage Effluents Discharge (*Indian Standards: 2490, 1982*).

5.0 Discussion: Wetland Management

Management is the manipulation of an ecosystem to ensure maintenance of all functions and characteristics of the specific wetland type. The loss or impairment of a wetland ecosystem is usually accompanied by irreversible loss in both the valuable environmental functions and amenities important to the society (Zentner, 1988). Appropriate management and restoration mechanisms need to be implemented in order to regain and protect the physical, chemical, and biological integrity of wetland ecosystems. In this context, a detailed study of wetland management and socio-economic implications is required from biological

and hydrological perspectives.

In Bangalore, as in most urban centers, environmental pressures on wetlands are created by human activities (changing land use in the watershed area, pollution from point and non-point sources, soil compaction, loss in interconnectivity, and solid waste dumping, and so forth), which affect their natural functions. Protecting and preserving their functions proves to be incredibly complex, as it involves building a partnership among various agencies, working in co-ordination, and addressing the common goal of minimizing human-induced changes that affect the hydrology, biogeochemical fluxes and the quality of these lakes. The problems of wetlands in Bangalore can be broadly summarized as:

- Hydrologic alterations, which include changes in the hydrologic structure and functioning of a wetland by direct surface drainage, de-watering by consumptive use of surface water inflows, unregulated draw down of unconfined aquifer from either groundwater withdrawal or by stream channelization for various human activities.
- Increased sedimentation, nutrient, organic matter, metals, pathogen, and other water pollutant loading from both storm water runoff (non-point source) and wastewater discharges (point source).
- Atmospheric deposition of pollutants into these lakes mainly by the vehicular and industrial pollution both from within the cities and from the suburban industrial complexes.
- Introduction or change in characteristic wetland flora and fauna (exotic) as a result of change in the adjacent land uses deliberately or naturally changing the water quality, and so forth.

The overexploitation of wetlands in Bangalore is evident, as it is used for disposing untreated sewage, runoff from urban and agricultural areas, changed land use within the watershed, and so forth. All these unplanned short-sighted anthropogenic activities have resulted in rendering the ecosystem integrity in peril. Deteriorating water quality due to pollution has also led to the spawning of mosquitoes in the absence of predators, such as *Gambusia affinis*, and killifishes (*Fundulus spp.*), which prey on mosquito larvae (Buchsbaum, 1994). It has been suggested that an Integrated Pest Management approach involving bio-regulation could possibly control mosquitoes rather than draining wetlands.

5.1 Wetland Management, Conservation, Restoration Strategies And Action Plan

A wetland management program generally involves activities to protect,

restore, manipulate, and provide for functions and values emphasizing both quality and acreage by advocating their sustainable usage (Walters, 1986). Management of wetland ecosystems require intense monitoring and increased interaction and co-operation among various agencies such as state departments concerned with the environment, soil, agriculture, forestry, urban planning and development, natural resource management; public interest groups; citizen's groups; research institutions; and policy makers.

Such management goals should not only involve buffering wetlands from any direct human pressures that could affect their normal functions, but also in maintaining important natural processes operating on them that may be altered by human activities. Wetland management has to be an integrated approach in terms of planning, execution, and monitoring, requiring effective knowledge on a range of subjects from ecology, hydrology, economics, watershed management, and local expertise, people, planners and decision makers. All these would help in understanding wetlands better and evolve a more comprehensive and long-term conservation and management strategies. Some of the suggested strategies in this regard are:

1. The management strategies should involve protection of wetlands by regulating inputs, using water quality standards (WQS) promulgated for wetlands and such inland surface waters to promote their normal functioning from the ecosystem perspective, while still deriving economic benefits by sustainable usage.
2. Urban wetlands provide multiple values for suburban and city dwellers (Castelle, Johnson, & Conolly, 1994). The capacity of a functional urban wetland in flood control, aquatic life support, and as pollution sink implies a greater degree of protection. These wetlands provide a resource base for people dependent on them. When dealing with such common resources, some of the important factors to be considered for developing a management strategy are described below.
 - I. Data relating to the current ecological condition of the lakes in Bangalore is inadequate. This necessitates an immediate need to create a database on the wetland types, morphological, hydrological, and biodiversity data surrounding land use, hydrogeology, surface water quality, and socio-economic dependence. Such a database would highlight the stress these systems are subjected to in the given context.
 - II. Involve institutions, colleges, and regulating bodies in conducting regular water quality monitoring of surface water, groundwater, and biological samples. Such programs help in providing technical support and information, which aid in understanding these systems better and formulating a comprehensive restoration, conservation, and

- management program.
- III. Development of a water quality database, accessible to all users, for analyzing and disseminating information. This can be achieved through:
 - Exchanging data across departments involved in the program to allow easy accessibility to regularly and continuously monitored data;
 - Updating technical guidance and water quality maps at regular intervals and indicating quality determinant parameters;
 - Analyzing and discussing case studies of water quality issues;
 - Providing spatial, temporal, and non-spatial water quality database systems.
 - IV. Correct non-point source pollution problems and administer the Pollution Prevention Program through environmental awareness programs.
 - V. Creating buffer zones for wetland protection, limiting anthropogenic activities around the demarcated corridor of the wetland, could revive their natural functioning. The criteria for determining adequate buffer zone size to protect wetlands and other aquatic resources depend on the following (Castelle, et al. 1994):
 - I. Identifying the functional values by evaluating resources generated by wetlands in terms of their economic costs,
 - II. Identifying the magnitude and the source of disturbance, adjacent land use, and project the possible impact of such stress in the long term,
 - III. Identifying catchment characteristics-vegetation density and structural complexity, soil condition and factors.
 - VI. A fully formed functional *In-buffer* must consider the magnitude of the identified problems, the resource to be protected, and the function it has to perform. Such a buffer zone could consist of diverse vegetation along the perimeter of the water body, preferably an indigenous species, serving as a trap for the sediments, nutrients, metals and other pollutants, and reducing human impacts by limiting easy access and acting as a barrier to invasion of weeds and other stress inducing activities (Stockdale, 1991).
 - VII. Wetlands require collaborated research involving natural, social, and inter-disciplinary study aimed at understanding the various components, such as monitoring of water quality, socio-economic dependency, biodiversity, and other activities, as an indispensable tool for formulating long term conservation strategies (Kiran & Ramachandra, 1999). This requires multidisciplinary-trained professionals who can spread the understanding of wetland importance at local schools, colleges, and research institutions by initiating educational programs aimed at raising the levels of public awareness and comprehension of aquatic ecosystem restoration, goals, and methods.
Actively participating schools and colleges in the vicinity of the

waterbodies may value the opportunity to provide hands-on environmental education which could entail setting up laboratory facilities at the site. Regular monitoring of waterbodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

- VIII. An interagency regulatory body comprising personnel from departments involved in urban planning (Bangalore Development Agency, and Bangalore City Corporation, for example) and resource management (Forest department, Fisheries, Horticulture, Agriculture, and so forth), and from regulatory bodies such as Pollution Control Board, local citizen groups, research organizations, and NGO's, would help in evolving effective wetland programs. These programs would cover significant components of the watershed, and need a coordinated effort from all agencies and organizations involved in activities that affect the health of wetland ecosystems directly or indirectly.

Restoration means reestablishment of pre-disturbance aquatic functions and the related physical, chemical, and biological characteristics (Cairns, 1988; Lewis, 1989) with the objective of emulating a natural and a self regulating/perpetuating system that is integrated ecologically with the landscape and the functions the wetlands perform. The goals for any restoration program should be realistic and tailored to individual regions, specific to the problems of degradation, and based on the level of dependence. The restoration program should mandate all aspects of the ecosystems, including habitat restoration, elimination of undesirable species, and restoration of native species, from the ecosystem perspective with a holistic approach designed at watershed level, rather than isolated manipulation of individual elements. This often requires reconstruction of the physical conditions-chemical adjustment of both the soil and water, biological manipulation, reintroduction of native flora and fauna.

Restoration goals, objectives, performance indicators (indicates the revival or success of restoration project), monitoring, and assessment program should be viably planned so that project designers, planners, biologists, and evaluators have a clear understanding. Monitoring of restoration endeavors should include both structural (state) and functional (process) attributes. Monitoring of attributes at population, community, ecosystem, and landscape level is appropriate in this regard.

Restoration strategy developed in collaboration with the government, researchers, stakeholders at all levels, and NGO's should:

- Set principles for establishing priorities and decision making.

- Prioritize goals, assessment, and monitoring strategies based on specific roles they perform, level of dependency and type of problems faced by them.
- Foster innovative financing and use of land and water programs for better and sustainable usage of wetland resources.

It is important to give priority to repairing those systems that would become extinct without any intervention. Prioritizing systems for repair requires that a framework be developed categorizing the level of interventions (National Research Council, Committee on Restoration of Aquatic Ecosystems, 1992). These categories should be based on:

- Wetlands that could recover without any intervention.
- Wetlands that could be restored close to their former condition to serve their earlier functions, considering cost involved, technical review of the restoration plan, and based on the goals and objectives set.
- Wetlands that are not restorable to any agreeable viably.

6.0 Conclusion

Wetland ecosystems are interconnected and interactive within a watershed. In Bangalore, the environmental pressure of unplanned urbanization and growing population has taken its toll on wetlands. The study revealed about a 35% decline in the number and loss in the interconnectivity among wetlands, disrupting the drainage network and the hydrological regime leading, in some cases, to irreversible changes in wetland quality.

The exploratory survey and physico-chemical and biological characterization of lakes located all over the city shows that lakes are polluted mainly due to sewage from domestic and industrial sectors. Detailed quantitative investigations of seven waterbodies (selected based on location and the type of input source) involving physical and chemical parameters and statistical analysis of selected parameters reveal that Kamakshipalya, Yediur, Hebbal, and Ulsoor lakes each have a higher degree of pollution compared to Sankey and Bannerghatta tanks, which have no major sources of pollution.

The preliminary socio-economic survey carried out in the region surrounding Hebbal lake, through the Contingency Valuation Method, showed high level of dependency on wetlands for groundwater, food, fodder, fish, fuel, and so forth. The high level of dependency on wetlands and the poor quality of those wetlands calls for immediate restoration of

degraded lakes and appropriate measures for their conservation and management in order to maintain ecological balance in the region.

The restoration program with an ecosystem perspective through Best Management Practices helps in correcting point and non-point sources of pollution wherever and whenever possible. This along with regulations and planning for wildlife habitat and fishes helps in arresting the declining water quality and the rate in loss of wetlands. These restoration goals require intensive planning, leadership, and funding, with active involvement from all levels of organization (governmental, NGO's, corporate conglomerates, citizen groups, research organizations, media, and so forth) through interagency and intergovernmental processes instrumental in initiating and implementing the restoration programs. Various measures, including the creation of a Regional Conservation Forum represented by a network of educational institutions, researchers, NGO's, and the local people, are suggested to help restore the already degraded lakes and conserve those at the brink of extinction.

7.0 Acknowledgement

The financial assistance from the Ministry of Environment and Forests and the Ministry of Science and Technology, Government of India is acknowledged. I thank Mrs. Deepa for her assistance in developing GIS database and Mr. Kiran, Ms. Ranjani, Ms. Ahalya and Mr. Rajinikanth in their timely assistance in literature review. I am grateful to Prof. N. V. Joshi, Dr. B. K. Chakarapani, Dr. M. B. Krishna and Prof. Devashish Kar for useful suggestions.

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