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Ecological and Socio-Economic Assessment of Varthur Wetland, Bengaluru (India)

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Wetlands are the most productive ecosystems, recognized globally for their vital role in sustaining a wide array of biodiversity and provide goods and services. But presently increased anthropogenic activities such as intense agriculture practices, indiscriminate disposal of industrial effluents and sewage wastes have altered the physical, chemical as well as biological processes of wetlands, which is evident from the present study carried out to assessVarthur wetland in India. Coastal wetland ecosystem in the world has 14,785/ha US$ annual economic value. An earlier study of relatively pristine wetland in Bengaluru revealed the value of ₹ 10,435/ha/day while the polluted wetland showed the value of ₹ 20/ha/day. On the contrary Varthur, a sewage fed wetland has a value of ₹ 118.9/ha/day. The pollutants and subsequent contamination of the wetland-Varthur has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish), in addition to profuse breeding of disease vectors and pathogens. Water quality analysis revealed high phosphate (4 22-5 76 ppm) level in addition to the enhanced BOD (119-140 ppm) and decreased DO (0-1 06 ppm). The amplified decline of ecosystem goods and services with degradation of water quality necessitates the implementation of sustainable management strategies to recover the lost wetland benefits of Varthur.

Key words : *Urban wetlands, ecosystem services, water quality, urbanization, conservation strategies*

Introduction

Wetlands represent a combination of aquatic and terrestrial environment, in which the soil is seasonally or permanently covered by shallow water and the water table is close to or near the surface[1, 2]. Wetland covers thousands of square kilometers; at spatial scale ranging from a crack in the rock to rain forest or ocean. Being highly productive, in terms of biodiversity and as well ecosystem's benefits; human community derive, directly or indirectly from ecosystem functions. Ecosystem functions refer varyingly to the habitat, physical and biological benefits/processes of the ecosystem[3]. On a larger scale, anthropogenic activities impact physical, chemical and biological processes, which impair the ecosystem functioning[4] causing decline and degradation of ecosystem services and also economic value of the wetland[5]. Wetlands predominantly endure change in wetland hydrology and habitat, loss of catchment area adjacent to urban growth, increasing runoff of nutrients and pollution, introduced species replacing indigenous species, land clearance and over-use of resources by losing its subsistence economies of that region mainly due to urbanization. The benefits which may be lost are not effectively quantified in viable markets and also in terms comparable with economic services, are often specified with too little weight in policy decisions. Hence, quantifying economic values of ecosystem are essential to respite human activities apart from accounting their services in the regional planning.

Valuation entails assigning an economic value in direct market for all the benefits (such as food, fodder, remediation, clean water, biodiversity, groundwater recharge, etc) of wetlands. Nevertheless, the possible way of addressing the economic value is to estimate the value which is exactly the price payable to replicate the natural ecosystem[3] or the price estimated/ paid for the same in direct market by means of economic valuation.

Economic valuation

Economic valuation is an attempt to assign values in terms of market price for the goods and services offered by the ecosystem. In Economic terms, the goods and services are broadly grouped as use and non-use values[6] as indicated in **Table 1**. Valuation technique includes "willingness to pay" reflecting individual's choice for the ecological commodities (aesthetic value, recreational opportunities), wood products and intrinsic values[7,8] and also captures its values in an economic value framework[9]. The commonly used technique for the valuation is the contingent valuation technique based on personal interactions with the local people using questionnaires; information on willing to pay for something they value or willing to receive in compensation for tolerating a cost.

The zero ecosystem benefits imply zero human welfare[3], thus economic value of a wetland varies from a pristine

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Table 1: Classification of total economic value for wetland

Use Values			Non - Use Values
Direct use values	**Indirect use values**	**Option value & Benefits**	**Existence value**
Fish, Agriculture, Fuel wood, Fodder, Recreation,(Boating, Fauna, Walking) Transport, Wildlife, harvesting, Peat/ Energy Education	Nutrient retention, Flood control,Storm protection,Ground water recharge,External ecosystem support, Filtration,Micro-climate, Shoreline stabilization	Potential future use (as per direct and indirect use).Future value of information, e g., pharmaceuticals, education.	Biodiversity,Culture, Heritage,Bequest

Source [14]

(natural benefits) to polluted (degraded ecosystem's benefits) wetland; influenced by a defined set of environmental conditions Wetland value increases with quality of goods and services derived and vice versa.

Numerous studies on economic valuation of wetlands have been carried out around the world; however, most of these studies have focused on wetlands in developed countries[11]. Economic studies for Indian wetland are meager addressing serious threats due to agricultural conversion, hydrological alteration followed by urbanization in recent years owing to 60 % loss

Several studies across countries in the past few decades support the estimation of economic value of a wide variety of goods and services. The annual value of wetland was estimated to be second highest, US$ 14 785/ha based on the assessment of 17 ecosystem services in 16 biomes which emphasize that ecosystem functions provide an important portion to the total contribution to human welfare[3] Other studies include wetlands of Africa[11], China[12], Bangladesh[13] and the European water framework directive of European Union (EU) (2000/60/EC). Assessment of the health of wetlands in China highlights that among all factors, water quality, ecosystem function and structure of waterfront area as the main factors that limit the wetlands value. Study of Mississippi Alluvial Valley focuses on the restoration of wetland ecosystem services in the floodplain area which has profound consequences due to habitat loss, fragmentation, flood storage loss and water quality degradation due to non point source runoff[14]

Many wetlands in India including those in Bengaluru are being degraded due to the apathy of the decision makers and planners. These wetlands, urban as well as rural, paved way to residential layouts, industrial complexes and indiscriminate disposal of urban wastes which has led to the deteriorating water quality and significant changes in local climate. Number of wetlands has dwindled from 250 to 81 (1985) and 33 in 2006[15]. Population of Bengaluru reached 7 million in 2007[16] due to the spurt in unplanned urbanization and consequent land use activities Effect of sustained inflow mainly of sewage, industrial effluents and agricultural runoff is evident from the results of regular monitoring of water quality at Hebbal, Varthur, Madiwala, Rachenahalli and Amruthalli wetlands[17]. A comparative evaluation of Amruthhalli lake with the relatively unpolluted Rachenahalli lake[2] brings out the impact of degrading ecological integrity of wetlands evident from the drastic decline of values from ₹ 10, 435/ha/day (Rachenahalli lake) to ₹ 20/ha/day (Amruthalli lake). Lower value is mainly due to eutrophication and water being unavailable for any use with an excessive nutrient inflow (sewage and industrial effluents) and storm water. Discharge and dumping of waste into catchment area lead to high levels of phosphates, Total Suspended Solids (TSS), Alkalinity, Hardness, Odour, weed infestation and low dissolved oxygen (DO) Study of Hebbal lake also reflects decreased water quality due to excessive sewage and industrial effluents inflow from surrounding area The Contingency valuation technique employed for preliminary socio-economic survey reveal high level of dependency on wetlands for groundwater, food, fodder, fuel and so on. The lake supports irrigation, provides food (fish, etc.) and fodder to the livestock in the surrounding areas The investigation of causes of mass fish mortality in Sankey Lake[18] revealed that the death was due to a sudden and considerable fall in dissolved oxygen (DO) levels in some locations caused by sewage let into the lake resulting in asphyxiation. An incidence of mass-scale fish mortality in Bengaluru reported from Ulsoor Lake[19] supported the above study These studies highlight the significance of maintaining wetland's quality to ensure sustained ecological functions contributing to economic values.

Bengaluru was known for its lush greenery with numerous wetlands, Varthur wetland being one of the largest amongst all. Rapid unplanned urbanization coupled with the increase in population has affected both Bengaluru and its surrounding towns and villages, including Varthur[15]. Varthur lake constructed 1000 years ago by Ganga rulers, today receives almost 40% of Bengaluru sewage to the extent of 450-500 minimum lethal dose per day (MLD/day). Part of city's untreated sewage passes through the network of interconnected lakes such as Bellandur and Ulsoor apart from many households directly in the immediate vicinity in a span of 220 hectares. The quantum of sewage exceeds the wetlands ability to assimilate contaminants and hence water quality has declined and has become unfit for human consumption. The contaminated water from Varthur ultimately flow downstream connecting Dakshina Pinakini River. Considering the dependence and impaired livelihood due to decline in ecological functional ability and capability consequent to sustained inflow of sewage and effluents, necessitates the ecological restoration of the lake. This entails understanding of the physico-chemical aspects with the wetland dynamics and the valuation of ecosystem services and goods. The study was carried out with a hypothesis that accumulation of contaminants has been responsible for degradation of water quality and consequent erosion of ecosystem services and goods. In this backdrop, Varthur wetland was investigated for water quality and valuation of the benefits to understand the drivers responsible for wetland degradation and impairment of economic benefits.

The study objectives were to: 1. assess physicochemical water quality variables and 2. economic valuation of wetlands through contingent valuation technique, focusing on the causes for wetland degradation and appropriate allocation of wetland use.

The study region

The study was carried out in Varthur wetland, one of the largest wetland located to the south of Bengaluru with 12.940699°N and 77.746596°E geographic position and a surface area of 220 sq. km. The wetland water accounts to irrigate 625 hectares of agricultural fields in the command area, for growing crops like rice, ragee, coconut, flowers and a variety of fruits and vegetables. It provides habitat for a wide variety of flora and fauna, including resident and migratory waterfowl. The inlet receives sewage and industrial wastes, contaminating not only wetland water quality but also Pinakini river at the downstream. Decreased water quality in recent years has influenced the economical significance of wetlands. **Fig.1** represents the study area and sampling points.

Methods

Water quality analysis

Water samples (triplicates) were collected from three sites viz. inlet (12°56'35.99"N lat. and 77°44'5.32"E long.), south-outlet (12°56'43.91"N lat. and 77°44'48.21"E long.) and

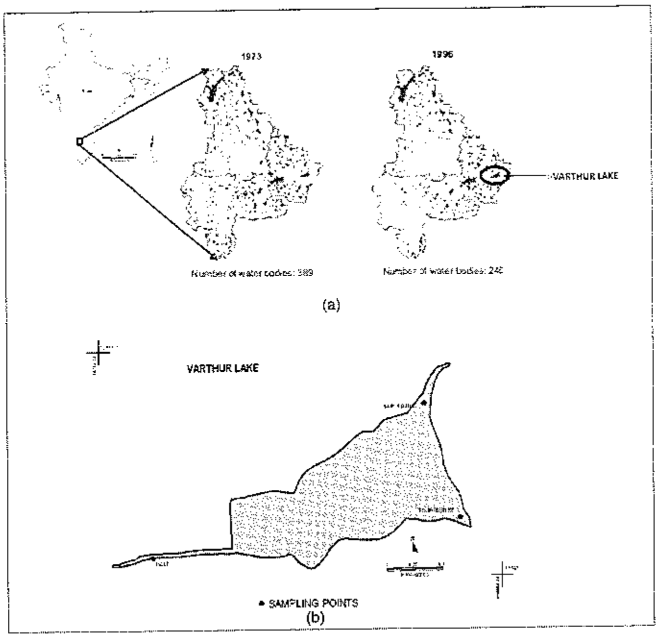

Fig. 1: (a) No. of water bodies in Bengaluru in 1973 and 1996 and (b) Varthur Lake with samplig points (inlet, north outlet and south outlet)

north outlet (12°57'22.86"N lat. and 77°44'40.56"E long.) in Varthur wetland during February 2009. Samples were stored in polythene bottles and were carried to laboratory for further analysis. Dissolved Oxygen was analyzed on-site using 125mL BOD bottles. Physical variables like pH, temperature (°C); total dissolved solids (mgL^{-1}); salinity (mgL^{-1}) and electric conductivity (μScm^{-1}) were measured using EXTECH EC500 Probe immediately after collection. Other water chemistry variables like chloride, hardness, magnesium, calcium, sodium, potassium, nitrates and phosphates were analyzed in laboratory and analyses were carried out as per the standard methods for the examination of water quality as mentioned[20].

Socio-economic survey

A contingency valuation technique was applied for the economic survey of wetland through a participatory approach involving local school students. 235 people from 43 randomly selected households from Varthur and nearby villages were interrogated using a standard questionnaire by KK High School students (VIII to X grade), Bengaluru. The questionnaire was made to quantify use-values of the lake including demographic information, domestic water usage, irrigation, fishing and aquaculture, water usage for livestock, livestock fodder, groundwater recharge, health effects and family history. Valuation of resources through the survey was aimed to evaluate the economic status and dependency of residents. Demographic information included total number of persons/houses, occupation and income per annum which relate to the dependency of residents on lake domestic water usage, irrigation, fishing and aquaculture, water usage for livestock and livestock fodder in turn the dependency of residents on lake water, aquatic plants and organisms The use of groundwater resources highlights the indirect association with the Varthur lake, responsible for recharging local aquifers.

Results

Water quality analysis

Characteristics of water collected from various sampling sites are mentioned in **Table 2**. pH ranged from 7.5-7.7 across sampling sites Conductivity was found to be high in inlet (1420 µS) compared to outlet sampling sites (South outlet, 1075 and North outlet, 1224 µS) Higher conductivity value at inlet was mainly due to the sustained sewage inflow and dissociation of minerals from soil Total Dissolved Solids which account for the amount of sedimentation did not show much variation (749-994 ppm) in lake Dissolved Oxygen (DO) was 0 ppm and 1.06 ppm as observed in inlet and north outlet respectively while at south outlet 8 16 ppm was recorded. Biological Oxygen Demand (BOD) was higher (119-140 ppm) at the inlet which confirms the inflow of higher amount of nutrients into the lake Chemical Oxygen Demand (COD) range (124-188 ppm) indicated the presence of increased oxidizable load. This highlights the anoxic conditions prevailing at inlets. Total hardness and alkalinity were found in the range of 236-288 ppm and 400-420 ppm respectively. The sodium and potassium values were174-180 ppm and 19-21 ppm respectively. Nitrates and phosphates varied from 0.31-0 55 ppm and 4.22-5 76 ppm respectively. Phosphate concentrations were found above the permissible limits.

Socio-economic survey

235 people from 43 houses were surveyed for evaluating the level of dependence for goods and services of Varthur Lake, which are listed in **Table 3**.

Domestic use: Few residents in the catchment area depend on lake for domestic usage due to its poor quality. Among all, 15 houses rely on bore wells Groundwater or bore well water usages are categorized as indirect use value as wetlands play significant role in recharging the groundwater sources in and around catchment area. On an average 5 individuals in a house utilize 200 liters of water per day. The dependency value is ₹ 25, 000 per house per year. For drinking water the amount spend on bottled water accounts to ₹ 30,000 per house per year.

Agriculture: Among 43 households surveyed, 35 houses depend on agriculture for livelihood. Wetland water is utilized for irrigating a total land area of 24.28 ha for growing mainly paddy, radish, carrot, tomato, chilly, coconut, beetle leaf and floriculture and the area under each crop is listed in **Table 3**. Apart from this, many paddy, coconut and beetle fields are cultivated nearby which are not included in this survey. The dependency for water for agriculture amounts to ₹ 12, 24,000 every year.

Table 2: Water quality analysis

Variables	Inlet	South outlet	North outlet	Surface Water Standards (permissible limit)
pH	7.70	7.50	7.50	6.5-8.5
Water Temperature (°C)	29.00	30.00	26.00	—
Air Temperature (°C)	28.00	31.00	29.00	
Salinity (ppm)	710.00	532.00	605.00	<400
TDS (ppm)	994.00	749.00	849.00	<500 ppm
Electric Conductivity (µS)	1420.00	1075.00	1224.00	<1200 µS
Total Alkalinity (ppm)	420.00	400.00	420.00	<600 mgL^{-1}
Dissolved Oxygen (mgL^{-1})	1.06	8.16	0.00	>5 mgL^{-1}
Chlorides (ppm)	167.56	173.24	191.70	<200 mgL^{-1}
Total Hardness (ppm)	252.00	236.00	288.00	<300 mgL^{-1}
Calcium Hardness (ppm)	108.00	128.00	135.00	<80 mgL^{-1}
Biological Oxygen Demand (mgL^{-1})	122.40	119.50	140.80	<3 mgL^{-1}
Chemical Oxygen Demand (mgL^{-1})	128.00	124.00	188.00	<250 mgL^{-1}
Nitrates (ppm)	0.31	0.47	0.55	20 mgL^{-1}
Phosphates (ppm)	5.76	4.22	5.00	—
Sodium (ppm)	177.00	174.00	180.00	—
Potassium (ppm)	21.00	19.00	19.00	—

Table 3: List of resources and their economic values

Use values	Quantity of Resource	Wetland Value in Rupees (₹)
Domestic use (bathing, cooking)	25-50 litres/person/day	25,00,000/year
Agriculture (income)	4,080/house/month	12,24,000/year
Household	2,500/month	30,000/house/year
Fisheries	5 kg fish/person/yr	25,00,000 /year
Domestic animals	6 animals/house	10,000/year
Fodder for Domestic animals	720 kg/year	57,60,000/year
Fire wood	10,000/month	12,24,000/year
Total		Rs. 95,54,000/220 ha/year

Livestock : On an average 5 animals viz cows, buffaloes, sheep and goats were reared in each house. Water hyacinth and other aquatic weeds (*Eichornia crassipes.*, *Typha* sp., *Alternanthera* sp etc) are utilized as feed for cattles. Farms rely on the sale of dairy products for part of their income. The dependency for livestock (fodder) and for washing purposes amounts to ₹ 57, 60,000 and ₹ 10,000 per 6 cows every year respectively.

Fisheries : 5 residents depend on aquaculture for occupation. Fishing is the major source for people nearby. As per the survey consumption of fish is 5 kg/person/year and the value from fisheries amounts to ₹ 25,00,000/year.

Fire wood (Energy): The dependency of people for the fire wood on the wetland amounts to ₹ 10,000 per year.

Discussion

Residents are residing in the catchment of Varthur lake for nearly 30 years to more than 200 years and at least 60% of the families persist for over 100 years[2]. It plays a significant role in providing daily requirements for the local inhabitants such as for domestic use of water, irrigation, fuel and fodder for livestock; while undergoing the stress sequentially due to anthropogenic activities. Higher values of BOD, COD, Nitrates and Phosphates reveal that lake water is severely contaminated. DO of lake was quite low (1.06 ppm) in inlet mainly due to increased inflow of organic material through untreated sewage. DO decreases due to presence of inorganic reducing agents such as Hydrogen Sulphide (H_2S), ammonia, nitrites and certain oxidizable substances[21]. Profuse growth of macrophytes mainly water hyacinth, limits air water interface, light penetration and consequently there is a drop in the penetration of atmospheric oxygen as well as algal photosynthetic activities. This maximizes the probability of hypoxic and anoxic conditions in the lake making difficult for survival of aquatic organisms in the water. Higher values of alkalinity show the presence of more carbonates, bicarbonates and hydroxyl ions. Water quality analysis of Varthur during 2002 also reported similar conditions of low dissolved oxygen, alkaline pH and high nutrient inputs (Nitrates, Phosphates and Ammonia) Varthur contains significant amounts of the macronutrients in large quantities in order to grow and survive aquatic plants under higher concentrations of nitrates and phosphate. Elevated amount of nutrients mainly fortify the contamination of water with sewage and non-point sources - fertilizers[2]. Amplified water quality degradation observed when current status was compared with that of past study (**Table 5**), explaining due to the sustained and enhanced inflow of contaminants over time.

Table 4: Livelihood details

Livelihood	Hectares
Floriculture	11.74
Vegetables	10.32
Paddy	2.02

Calculation : ₹ 9554000/220 ha /year

= ₹ 43427.28/ha/year

= ₹ 118.978/ha/day

Water pollution

Varthur Wetland receives 450-500 MLD of sewage from households and industrial wastewater directly into wetland from Bellandur and surrounding localities. These contribute enriched nutrients and increased amount of toxic substances (heavy metals). Enhanced land cover changes have contributed to siltation and consequent sedimentation decreasing lake's depth. The degree of soil saturation of the wetland depends on the consistency of its freshwater flow. Effluents loading has gone beyond the ability to assimilate contaminants, further degrading the water quality. Along with effluents from households and industrial waste, household garbage, plastics and solid waste from commercial places are being dumped in lake bed.

Valuation of ecosystem highlights that due to the severe contamination of water the wetland's goods and services have declined impinging livelihood of dependent population and also local economy. Even though residing

Table 5: Comparison of major water quality parameters of Varthur (2003 and 2009)

General parameters	2003 (Outlet)			2009	
	October	November	January	Inlet	Outlet
pH	7.61	7.55	7.68	7.7	7.50
Temperature (°C)	27	27	23	29	26
Electric conductivity (µS)	460	474	1420	1420	1224
Dissolved oxygen (mgL^{-1})	2	3	2.9	1.06	0
Chlorides (ppm)	-	100	170	167.56	191.7
Total hardness(ppm)	213.6	209.3	232.5	252.0	288
Calcium hardness(ppm)	132	124	158.1	108	135
Biological oxygen demand(ppm)	-	-	74.2	122.4	140.8
Chemical oxygen demand(ppm)	-	-	82.2	128.00	188
Phosphates(ppm)	-	>1	15.54	5.76	5.00

(Source: Ramachandra *et al.* 2003 and current survey)

community is dependent on lake for manifold use as mentioned in **Table 3** many problems are faced by the wetland for being beneficial. The total economic value of Varthur resources accounts to ₹ 95, 54,000/220 ha/year (ie ₹ 118.98/ha/day), which is much lower compared to a relatively unpolluted lake (₹10,450/ha/day)[3]. The dependency value on wetland water for domestic and agricultural use is maximum compared to other use-values.

Causes of depreciation in lake values

Dumping of garbage and other non-degradable waste materials, inflow of untreated sewage from the residential areas and open defecation are the problems accountable for water quality. Such substances liberate toxic in to the water body; remains suspended; gets dissolved in water or set down on the water bed contributing to groundwater pollution. This majorly deteriorates water quality impinging on aquatic ecosystems. Few effects of these environments are :

- Utilization of contaminated lake water for irrigation purposes has a negative effect on the quality as well as the quantity of crops and this has influenced the major source of income for farmers reliant on agriculture.
- Possibility of contaminants especially heavy metals getting to food chain through fish (which accumulates higher concentrations of heavy metals- bioaccumulation[22]).
- Dumping of municipal solid waste in the lake catchment and letting untreated sewage and effluents into lake has affected the health of the local population due to increase of disease vectors and pathogens (mosquito -*Plasmodium* sp. causing Malaria) and flies population around Varthur region. Current survey also reports health problems like fever, dysentery and skin diseases (dermatitis) in most of the houses. Due to mosquito problem and health hazards, residents spend more than ₹ 30,000 per year in purchase of mosquito repellants (according to survey). Presence of *Eschericia coli* in water sample indicates the fecal matter contamination[3]. Fecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage and survives for a prolonged period in turbid, warm temperature, mildly alkaline pH, and low oxygen levels in lake water.
- Profuse growth of exotic plant species such as water hyacinth (*Eichornia crassipes*) and exotic fish culture have also contributed to extinction of native species of fauna. Prolific macrophytes growth has roofed water surface completely lessening dissolved oxygen level and hindering photosynthesis process. Algal communities depending on photosynthetic activity have declined together with mortality of sensitive life stages inside water. Disturbance in food chain may also lead to changes in algal community and its metabolism.
- Poaching of waterfowl such as Purple Moorhen (*Gallinula chloropus*), Spot Billed Pelican (*Pelecanus philippensis*), Common Coot (*Fulica atra*) and White Breasted Waterhen (*Amaurornis phoenicurus*) by poachers were observed, resulting in its decline.

Dominant fish species reported in 1962, 1998 and 2009 are listed in **Table 6**. *Clarias batrachus, Heteropneustes fosslis, Mystus dittatus* and so on which once contributed substantially to fish community in earlier years has dwindled in their representation in the catches now. The invasive species currently harboring water body are *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal), *Clarias gariepinus* (African catfish), *Oreochromis mossambica* (Tilapia) and medium sized carps. Enhanced sewage and effluents inflow coupled with the overexploitation of wetland goods are prime reasons for the decline in indigenous fish species and consequent prevalence of invasive species during the last two decades.

Table 6: List of major fish species in Varthur wetland during 1962, 1998 and 2009

Species name	1962	1998	2009
Catla catla (Catla)	-	+	-
Labeo rohita (Rohu)	-	+	-
Cirrhinus mrigala (Mrigal)	-	+	-
Clarias gariepinus (African catfish)	-	+	+
Oreochromis mossambica (Tilapia)	-	+	-
Clarias batrachus	+	-	-
Heteropneustes fosslis	+	-	-
Mystus dittatus	+	-	-
Minor carps	-	+	-

(Source: current survey + indicates presence and - indicates absence of fish species.)

Comparative analysis of polluted and unpolluted wetlands reveals difference in fish composition and associated economic value. Varthur lake harbors only *Clarias gariepinus* (African catfish), whereas *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal) and *Oreochromis mossambica* (Tilapia) were found in Rachenahalli while another eutrophic lake at Amruthahalli did not have any species. Varthur and Amruthahalli being eutrophicated with heavy sewage contamination and Rachenahalli is relatively unpolluted. Invasive exotic species, African catfish in Varthur water body has predated native fish and survives under eutrophic condition with the macrophytes covering the entire lake. Subsequently, huge amount of waste along with metals and ions (toxic substances) are accumulated inside fish gut due to bioaccumulation[23]. Consumption of fish rich in heavy metals has carcinogenic influence on humans. According to fishermen, Varthur provides 200-300 kg/day of catfish costing ₹ 50-60 /kg/day due to absence of fish variety while Rachenahalli accounts for ₹ 75 /kg/day specified by varieties of fishes mentioned above[9]. Economic value of fish in Varthur is less than in Rachenahhali mainly because of exotic species and decline of native species, water accomplished with sewage and prolific macrophytes growth in Varthur.

The socio-economic studies on Rachenahalli and Amruthalli lakes showed that the economic dependency in the case of Rachenahalli lake (₹ 10,435/ha/day) is more than that of polluted Amruthalli lake (₹ 20/ha/day). This is mainly because of better water quality in former lake while water quality with severe pollution by phosphates, weed infestations and oxygen deficiency in later case. Although in Varthur, Sorahumase and Valepura village, the land irrigated by utilizing the wetland water amounts to 4211.6/day with water quality indicating eutrophic lake containing high concentrations of organic wastes and phosphorus[2].

Management of wetlands to sustain goods and services

This study highlights the need to manage the wetlands to enhance the use-value of an ecosystem. The strategies include : 1. Restoration of wetlands – removal of contaminants; 2. Letting only treated sewage to the wetlands; 3. Letting the treated water through series of wetlands further improves the water quality; 4. Maintaining food chain in the ecosystem – involves removal of excess growth of macrophytes (if any) and exotic fish species, African cat fish, etc ; and 5. Regular water quality monitoring involving local schools. This would also help in functioning as watchdog to prevent any contamination (solid waste dump, direct inflow of sewage, etc.)

Conclusion

The socio-economic survey and water quality analysis show a decline of ecosystem goods and services with the decline of water quality. This has influenced the livelihood of the local population who are dependent on the goods and services provided by the wetland. The persistent hyper eutrophic condition is due to the sewage from Bellandur lake and also from the surrounding residential apartments. Water treatment plant for Varthur wetland benefits the local environment with better water and impassive sludge that can be utilized for agricultural fields as fertilizer instead of commercial inorganic fertilizers. With the improved water quality, introduction of indigenous and herbivorous fish species into water body along with the removal of African catfish will enhance the food availability. To retain existing reserve and bring back the lost resource, efforts such as restoration process should include wastewater treatment system, removal of over growth of invasive macrophytes and awareness among community and enhanced co-operation among government agencies to manage wetland. Management priorities should mainly include evolving sustainable managing strategies for maintaining water quality, control of invasive species, encroachment, drastic land cover changes in the catchment and identification of buffer zone, providing aquatic resources with adequate water quality and limiting the spread of exotic biota in a sustainable manner evolving managing strategies.

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