Journal of Hydrology: Regional Studies 2 (2014) 1–19

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Review

Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies

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ARTICLE INFO

Article history:
Received 29 April 2014
Received in revised form 7 July 2014
Accepted 12 July 2014
Available online 13 August 2014

Keywords:
India
Wetlands
Ecosystem benefits
Anthropogenic threats
Institutional strategies

ABSTRACT

Study region: India.
Study focus: India has a wealth of wetland ecosystems that support diverse and unique habitats. These wetlands provide numerous ecological goods and services but are under tremendous stress due to rapid urbanization, industrialization and agricultural intensification, manifested by the shrinkage in their areal extent, and decline in the hydrological, economic and ecological functions they perform. This paper reviews the wetland wealth of India in terms of their geographic distribution and extent, ecosystem benefits they provide, and the various stresses they are exposed to. The paper also discusses the efforts at management of these fragile ecosystems, identifies the institutional vacuum and suggests priority area where immediate attention is required in order to formulate better conservation strategies for these productive systems.
New hydrological insights for the region: It has been found that management of wetlands has received inadequate attention in the national water sector agenda. As a result, many of the wetlands are subject to anthropogenic pressures, including land use changes in the catchment; pollution from industry and households; encroachments; tourism; and over exploitation of their natural resources. Further, majority of research on wetland management in India relates to the limnological aspects and ecological/environmental economics of wetland management. But, the physical (such as hydrological and land use changes in the catchment) and socio-economic processes leading to limnological changes have not been explored substantially.

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http://dx.doi.org/10.1016/j.ejrh.2014.07.001

Contents

1. Introduction

Wetlands are amongst the most productive ecosystems on the Earth (Ghermandi et al., 2008), and provide many important services to human society (ten Brink et al., 2012). However, they are also ecologically sensitive and adaptive systems (Turner et al., 2000). Wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, dominant species, and soil and sediment characteristics (Space Applications Centre, 2011). Globally, the areal extent of wetland ecosystems ranges from 917 million hectares (m ha) (Lehner and Döll, 2004) to more than 1275 m ha (Finlayson and Spiers, 1999) with an estimated economic value of about US$15 trillion a year (MEA, 2005).

One of the first widely used wetland classifications systems (devised by Cowardin et al., 1979) categorized wetlands into marine (coastal wetlands), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustarine (lakes), riverine (along rivers and streams), and palustarine ('marshy' – marshes, swamps and bogs) based on their hydrological, ecological and geological characteristics. However, Ramsar Convention on Wetlands, which is an international treaty signed in 1971 for national action and international cooperation for the conservation and wise use of wetlands and their resources, defines wetlands (Article 1.1) as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". Overall, 1052 sites in Europe; 289 sites in Asia; 359 sites in Africa; 175 sites in South America; 211 sites in North America; and 79 sites in Oceania region have been identified as Ramsar sites or wetlands of International importance (Ramsar Secretariat, 2013).

As per the Ramsar Convention definition most of the natural water bodies (such as rivers, lakes, coastal lagoons, mangroves, peat land, coral reefs) and man made wetlands (such as ponds, farm ponds, irrigated fields, sacred groves, salt pans, reservoirs, gravel pits, sewage farms and canals) in India constitute the wetland ecosystem. Only 26 of these numerous wetlands have been designated as Ramsar Sites (Ramsar, 2013). However, many other wetlands which perform potentially valuable functions are continued to be ignored in the policy process. As a result many freshwater wetlands ecosystems are threatened and many are already degraded and lost due to urbanization, population growth, and increased economic activities (Central Pollution Control Board, 2008).

Table 1
Number and size of wetlands as per the various wetland inventories of India.

Inventory	Year	Total number of wetlands		Total area of wetlands (m ha)	
		Natural	Man-made	Natural	Man-made
Directory of Asian Wetlands and Directory of Indian Wetlands (WWF and AWB)	1989 and 1993	Not specified		58.3	
Directory of Indian Wetlands (MoEF, GoI)	1990	2167	65,253	1.45	2.59
Wetlands of India (Space Applications Centre)	1998	18,154	9249	5.31	2.27

Source: Adapted from Garg et al. (1998), Woistencroft et al. (1989) and WWF and AWB (1993).

The negative economic, social, and environmental consequences of declining water quality in wetlands are also an issue of concern for India. The problem of deteriorating water quality is particularly more alarming in the case of small water bodies such as lakes, tanks and ponds. In the past, these water sources performed several economic (fisheries, livestock and forestry), social (water supply), and ecological functions (groundwater recharge, nutrient recycling, and biodiversity maintenance). Despite all these benefits, many decision-makers and even many of the 'primary stakeholders' think of them as 'wastelands'. Every one claims a stake in them, as they are in the open access regime, but rarely are willing to pay for this extractive use (Verma, 2001).

These freshwater bodies are often subject to changes in land use in their catchments leading to reduction in inflows and deteriorating quality of the "runoff" traversing through agricultural fields and urban areas. On the other hand, many of them act as the "sink" for untreated effluents from urban centres and industries. Encroachment of reservoir area for urban development, excessive diversion of water for agriculture is yet another major problem (Verma, 2001). Lack of conformity among government policies in the areas of economics, environment, nature conservation, development planning is one reason for the deterioration of these water bodies (Turner et al., 2000). Lack of good governance and management are also major reasons (Kumar et al., 2013a).

Given this background, the objective of this paper is to review the status of wetlands in India, in terms of their geographic distribution and areal extent; the ecosystem goods and services they provide; various stresses they are being subject to; and the various legal and policy approaches adopted in India for their conservation and management.

2. Distribution and extent of wetlands in India

India, with its varying topography and climatic regimes, supports diverse and unique wetland habitats (Prasad et al., 2002). The available estimates about the areal extent of wetlands in India vary widely from a lowest of 1% to a highest of 5% of geographical area, but do support nearly fifth of the known biodiversity (Space Applications Centre, 2011). These wetlands are distributed in different geographical regions ranging from Himalayas to Deccan plateau.

Initial attempts to prepare wetland inventory of India were made between 1980s and early 1990s (Table 1). As per the: Country report of Directory of Asian Wetlands (Woistencroft et al., 1989); and the Directory of Indian Wetlands 1993 (WWF and AWB, 1993), the areal spread of wetlands in India was around 58.3 m ha. But, Paddy fields accounted for nearly 71% of this wetland area. However, as per the Ministry of Environment and Forests (1990) estimates, wetlands occupy an area of about 4.1 m ha, but it excludes mangroves. The first scientific mapping of wetlands of the country was carried out using satellite data of 1992–1993 by Space Applications Centre (SAC), Ahmedabad. The exercise classified wetlands based on the Ramsar Convention definition. This inventory estimated the areal extent of wetlands to be about 7.6 m ha (Garg et al., 1998). The estimates did not include paddy fields, rivers, canals and irrigation channels. Thus, all these early assessments were marred by problem of inadequate understanding of the definition and characteristics of wetlands (Gopal and Sah, 1995).

Fig. 1. Map showing State-wise number of wetlands in India. (*Note*: Figure in parenthesis represents total number of wetlands in respective State.)

2.1. India's wetland extent as per the latest wetland inventory

National Wetland Atlas 2011, prepared by SAC, is the latest inventory on Indian wetlands. Entire Country was considered for assessment and a total of 201,503 wetlands were identified and mapped on 1:50,000 scale (SAC, 2011). In addition, 555,557 wetlands (area <2.25 ha, which is smaller than minimum measurable unit) were identified as point features. Area estimates of various wetland categories have been carried out using GIS layers of wetland boundary, water-spread, and aquatic vegetation. As per the estimates, India has about 757.06 thousand wetlands with a total wetland area[4] of 15.3 m ha, accounting for nearly 4.7% of the total geographical area of the country (Fig. 1). Out of this, area under

[4] Total wetland area includes area encompassing open water, aquatic vegetation (submerged, floating and emergent) and surrounding hydric soils.

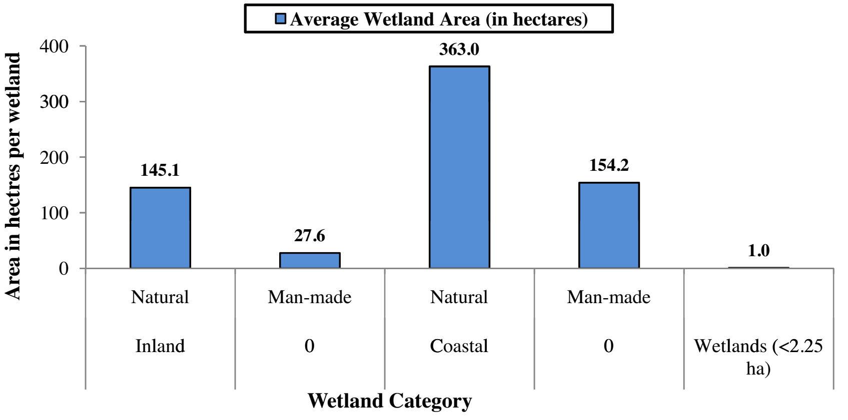

Fig. 2. Average area under different wetlands, India.
Source: Authors' analysis using data from SAC (2011).

inland wetlands accounts for 69%, coastal wetlands 27%, and other wetlands (smaller than 2.25 ha) 4% (SAC, 2011). In terms of average area under each type of wetland,[5] natural coastal wetlands have the largest area (Fig. 2).

The water spread area[6] of wetlands varies greatly. Overall, inland wetlands have a water spread area of 7.4 m ha in post monsoon and 4.8 m ha in pre-monsoon; and coastal wetlands have 1.2 m ha and 1 m ha in post monsoon and pre monsoon, respectively (SAC, 2011). Across all categories of wetlands, the water spread area from post monsoon to the peak of summer reduces significantly indicating the uses and losses the wetlands go through. This has major implications for the total water availability of these wetlands and the various functions that they can perform in different seasons. Overall, reduction in water spread area of inland wetlands is highest (35%) followed by that of coastal wetlands (16%). Within inland wetlands, reduction is significantly higher in man-made types (49.5%), such as surface reservoirs and tanks, in comparison to natural types (24%), such as lakes and ponds, as they are under pressure to meet various irrigational and non-irrigational needs and are also subjected to higher evaporation losses. In terms of average water spread area for each category of wetland, man-made coastal wetlands have the highest area (Fig. 3). The aquatic vegetation in all the wetlands put together, account for 1.32 m ha (9% of total wetland area) in post monsoon and 2.06 m ha (14% of total wetland area) in pre monsoon (SAC, 2011). Major wetlands types in which aquatic vegetation occur include lakes, riverine wetlands, ox-bow lakes, tanks and reservoirs.

2.2. Regional extent of wetlands in India as per the National Wetland Atlas 2011

In terms of the proportion of the geographical area, Gujarat has the highest proportion (17.5%) and Mizoram has the lowest proportion (0.66%) of the area under wetlands. Among Union Territories in India, Lakshadweep has the highest proportion (around 96%) and Chandigarh has the least proportion (3%) of geographical area under wetlands.

Gujarat has the highest proportion (22.8%) and UT of Chandigarh has nearly negligible part of the total wetland area in the country. Water-spread area of wetlands changes over seasons. The States of Sikkim, Nagaland, Mizoram, Meghalaya, and Jharkhand have more than 90% of the total wetland area as water spread area during post monsoon. Significant reduction in water spread area of wetlands

[5] Natural inland wetlands include: lakes, ponds, cut-off meander, high altitude wetlands, riverine wetlands, waterlogged areas, rivers and streams. Man-made inland wetlands include: surface reservoirs, tanks, water logged areas, and salt pans. Natural coastal wetlands include: lagoons, creeks, sand beach, mud flats, salt marsh, mangroves, and coral reefs. Man-made coastal wetlands include: salt pan and aquaculture ponds.

[6] Water spread area of a wetland is the total area encompassing the open water.

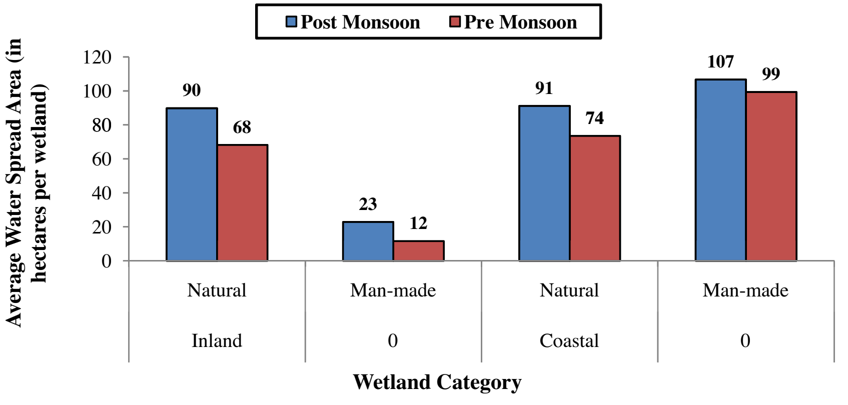

Fig. 3. Average water spread area under different wetlands, India.
Source: Authors' analysis using data from SAC (2011).

from post monsoon to pre monsoon was found in the States of Uttar Pradesh (28%), Chhattisgarh (29%), Himachal Pradesh (29%), Tripura (29%), Sikkim (30%), Andhra Pradesh (31%), Jharkhand (32.5%), Punjab (33%), Bihar (34%), Gujarat (36%), Karnataka (38.5%), Maharashtra (53.5%), Tamil Nadu (55%), Madhya Pradesh (57%), and Rajasthan (57%).

In terms of contribution of the total water spread area in the country, highest during post monsoon was observed in the State of Gujarat (13.5%) and lowest in Sikkim and Tripura (0.1% each). During pre-monsoon, highest was again in Gujarat (12.6%) and lowest was in Sikkim and Tripura (0.1% each).

As regards percentage area under aquatic vegetation, Andhra Pradesh, Delhi, Karnataka, Manipur, Orissa, Punjab, Tamil Nadu, Tripura, and West Bengal have 15–59% of the wetland area under aquatic vegetation (Fig. 4). Further, Andhra Pradesh, Gujarat, Karnataka, Orissa, Tamil Nadu, Uttar Pradesh, and West Bengal account for nearly 3/4th of the total area under aquatic vegetation. In Andhra Pradesh, maximum amount of aquatic vegetation is found in reservoirs, aquaculture ponds and irrigation tanks. In Gujarat, it is found in rivers, reservoirs and creeks. In Karnataka, it is in irrigation tanks, ponds and reservoirs. In Orissa, aquatic vegetation was more in rivers, reservoirs, lagoons, irrigation tanks and ponds. In Tamil Nadu, it is in lakes and irrigation tanks. In Uttar Pradesh, most of the aquatic vegetation is found in rivers, lakes and riverine wetlands, whereas in West Bengal, most of it is in Mangroves.

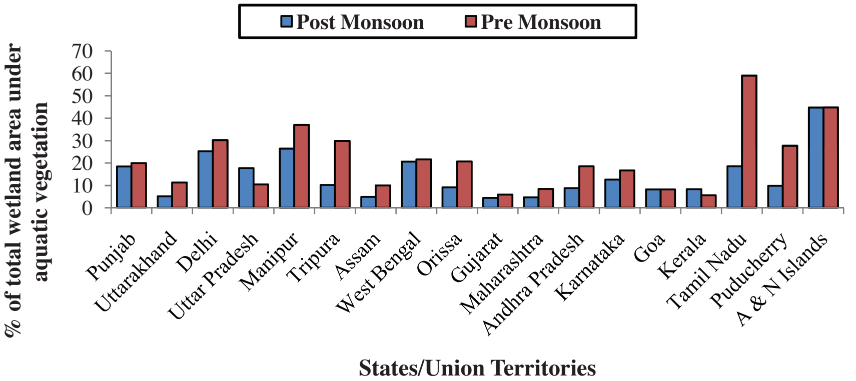

Fig. 4. Proportion of total wetland area under aquatic vegetation in selected States and Union territories of India.
Source: Authors' analysis using data from SAC, 2011.

3. Importance of wetlands

Wetlands are considered to have unique ecological features which provide numerous products and services to humanity (Prasad et al., 2002). Ecosystem goods provided by the wetlands mainly include: water for irrigation; fisheries; non-timber forest products; water supply; and recreation. Major services include: carbon sequestration, flood control, groundwater recharge, nutrient removal, toxics retention and biodiversity maintenance (Turner et al., 2000).

3.1. Multiple-use water services

Wetlands such as tanks, ponds, lakes, and reservoirs have long been providing multiple-use water services which include water for irrigation, domestic needs, fisheries and recreational uses; groundwater recharge; flood control and silt capture.

The southern States of Andhra Pradesh, Karnataka and Tamil Nadu have the largest concentration of irrigation tanks, numbering 0.12 million (Palanisami et al., 2010), and account for nearly 60% of India's tank-irrigated area. Similarly, there are traditional tank systems in the States of Bihar, Orissa, Uttar Pradesh and West Bengal, accounting for nearly 25% of net tank irrigated area (Pant and Verma, 2010). Tanks play a vital role of harvesting surface runoff during monsoon and then allowing it to be used later. Apart from irrigation, these tanks are also used for fisheries, as a source of water for domestic needs and nutrient rich soils, fodder grass collection, and brick making. These uses have high value in terms of household income, nutrition and health for the poorest of the poor (Kumar et al., 2013a).

Tanks are also very important from the ecological perspective as they help conserve soil, water and bio-diversity (Balasubramanian and Selvaraj, 2003). In addition, tanks contribute to groundwater recharge, flood control and silt capture (Mosse, 1999). Water from tanks has also been used for domestic and livestock consumption. Over the years, the multiple-use dependence on tanks has only increased (Kumar et al., 2013a). Similarly, ponds in north-eastern States of India are used for fisheries (Sarkar and Ponniah, 2005) and irrigating homesteads (Central Ground Water Board, 2011; Das et al., 2012).

Lakes, such as, Carambolim (Goa); Chilka (Orissa); Dal Jheel (Jammu and Kashmir); Deepor Beel (Assam); Khabartal (Bihar); Kolleru (Andhra Pradesh); Loktak (Manipur); Nainital (Uttarakhand); Nalsarovar (Gujarat); and Vembanad (Kerala), have long been providing recreational, tourism, fisheries, irrigation and domestic water supply services (Jain et al., 2007a,b). These lakes also contribute to groundwater recharge and support a rich and diverse variety of aquatic flora and fauna.

Further, surface reservoirs have also played an important role in providing irrigation and domestic water security in both rural and urban areas. Approximately 4700 large reservoirs (capacity of not less than 1 million cubic metre) have been built in India so far for municipal, industrial, hydropower, agricultural, and recreational water supply; and for flood control (Central Water Commission, 2009). As per the recent estimates, total live water storage capacity of completed reservoir projects is about 225 billion cubic metres (BCM) and the area covered by reservoirs is around 2.91 m ha (Central Water Commission, 2010). These reservoirs also support a wide variety of wildlife. Many of the reservoirs such as Govind Sagar Lake formed by diverting river Satluj (Bhakra Dam, Punjab) and Hirakud reservoir (Sambalpur, Orissa) are a major tourist attraction.

As per official estimates, tourism contribution to India's GDP and employment in 2007–2008 was 5.92% and 9.24% respectively (Government of India, 2012). These are very important numbers as wetlands (such as coral reefs, beaches, reservoirs, lakes and rivers) are considered to be a significant part of the tourism experience and are likely to be a key part of the expansion in demand for tourism locations (MEA, 2005; Ramsar Convention on Wetlands and WTO, 2012). Every year, on an average nearly seven million tourist visit Kerala's backwaters, beaches and wildlife sanctuaries; three million visit Uttarakhand's lakes and other natural wetlands; one million visit Dal lake; and 20,000 visit lake Tsomoriri.

In terms of growth in fish production in India, wetlands play a significant role. At the moment, majority of fish production in the country is from inland water bodies (61% of total production), i.e. rivers; canals; reservoirs; tanks; ponds; and lakes (Table 2). It increased from 0.2 million tonne in 1950–1951 to about 5.1 million tonne in 2010–2011. Carp constitute about 80% of the total inland

Table 2
Total fish production in India during the last decade.

Year	Total (million tonne)	Marine contribution (%)	In-land contribution (%)
2001–2002	5.96	47.7	52.3
2002–2003	6.20	48.2	51.8
2003–2004	6.40	45.9	54.1
2004–2005	6.30	44.1	55.9
2005–2006	6.57	42.9	57.1
2006–2007	6.87	44.1	55.9
2007–2008	7.13	41.0	59.0
2008–2009	7.62	39.1	60.9
2009–2010	7.91	39.2	60.8
2010–2011	8.29	38.8	61.2

Source: Ministry of Agriculture (2012).

aquaculture production. Presently, the State of West Bengal occupies the topmost position (30% of total inland fish production) followed by Andhra Pradesh, Uttar Pradesh, Bihar and Orissa (Ministry of Agriculture, 2012). Overall, fisheries accounts for 1.2% of India's total Gross Domestic Product (GDP) and 5.4% of total agricultural GDP.

3.2. *Carbon sequestration*

Swamps, mangroves, peat lands, mires and marshes play an important role in carbon cycle. While wetland sediments are the long-term stores of carbon, short-term stores are in wetland existing biomass (plants, animals, bacteria and fungi) and dissolved components in the surface and groundwater (Wylynko, 1999). Though wetlands contribute about 40% of the global methane (CH_4) emissions, they have the highest carbon (C) density among terrestrial ecosystems and relatively greater capacities to sequester additional carbon dioxide (CO_2) (Pant et al., 2003).

Wetlands sequester C through high rates of organic matter inputs and reduced rates of decompositions (Pant et al., 2003). Wetland soils may contain as much as 200 times more C than its vegetation. However, drainage of large areas of wetlands and their subsequent cultivation at many places had made them a net source of CO_2. Restoration of wetlands can reverse them to a sink of atmospheric CO_2 (Lal, 2008). As per the estimations, carbon sequestration potential of restored wetlands (over 50 year period) comes out to be about 0.4 tonnes C/ha/year (IPCC, 2000).

In India, coastal wetlands are playing a major role in carbon sequestration. The total extent of coastal ecosystems (including mangroves) in India is around 43,000 km^2 (Kathiresan and Thakur, 2008). As carbon sink, mangrove wetlands in eastern India are more important than those on the west coast, as they are larger in size, higher in diversity and more complicated due to tidal creeks and canal network. Overall, mangroves are able to sequester about 1.5 metric tonne of carbon per hectare per year, and the upper layers of mangrove sediments have high carbon content, with conservative estimates indicating the levels of 10% (Kathiresan and Thakur, 2008). However, mangroves were also found to be emitting methane (CH_4), one of the primary greenhouse gases, which was around 19% of their carbon sequestration potential. Similarly, tropical coastal wetlands such as the Vembanad Lake, a lagoon along the West Coast of India, were found to be releasing up to 193.2 $mg/m^2/h$ of CH_4 (Verma et al., 2002). Wetlands function as net sequesters or producers of greenhouse gases depending on their bio-geo-chemical processes and hydrology. Thus more research is required to ascertain whether wetlands can be managed as net carbon sinks over time and their potential role in climate change mitigation and international carbon trading system.

3.3. *Pollution abatement*

Wetlands act as a sink for contaminants in many agricultural and urban landscapes. From an economic perspective too, wetlands have been suggested as a low cost measure to reduce point and non-point pollution (Bystrom et al., 2000). Natural wetlands, such as riparian wetlands, reduce the nutrient load of through-flowing water by removing nitrate and phosphorus from surface and subsurface runoff (Verhoeven et al., 2006). Maximum potential rate of nitrogen and phosphorous removal by wetlands in the temperate regions ranges from 1000 to 3000 kg N/ha/year and from 60 to 100 kg P/ha/year (Groffman and Crawford, 2003; Kadlec and Reddy, 2001).

However, natural wetlands should not be used to reduce rural non-point source (NPS) problems as they are already at risk from regional drainage (altering their hydrology) and significant inputs of agricultural runoff. Further, these natural wetlands may degrade due to increase in pollution load (leading to eutrophication) affecting wildlife habitat and its recreational use. Nevertheless, properly designed restored or created wetlands can be used as pollution sinks (van der Valk and Jolly, 1992) but abatement costs must be sufficiently low to motivate restoration or construction of wetlands as a part of a cost-effective pollution reduction programme (Bystrom et al., 2000). It should also be noted that a wetland designed to improve nutrient retention may not necessarily increase biodiversity and vice versa (Hansson et al., 2005).

In India too, wetlands are polluted through agricultural runoff and discharge of untreated sewage and other waste from urban areas. Under normal conditions, wetlands do retain pollutants from surface and sub-surface runoff from the catchment and prevent them from entering into streams and rivers. However, because of increased urbanization and land use changes, the nutrient loading in wetlands far exceed their capacity to retain pollutants and remove them through nitrification, sedimentation, adsorption, and uptake by aquatic plants. This adversely affects the wetland water quality and its biodiversity. Such wetlands show drastic changes in nutrient cycling rates and species lose (Verhoeven et al., 2006).

Various scholars in India have mainly focused on the usefulness and potential of constructed wetlands in pollution abatement on experimental scale (Billore et al., 1999; Juwarkar et al., 1995; Kaur et al., 2012). Also, role of wetland plants in ameliorating heavy metal pollution both in a microcosm and natural condition is well established (Dhir et al., 2009). *Typha*, *Phragmites*, *Eichhornia*, *Azolla*, and *Lemna* are some of identified potent wetland plants for heavy metal removal (Rai, 2008).

Constructed wetlands are considered to be a viable option for treatment of municipal wastewater. A well designed constructed wetland should be able to maintain the wetland hydraulics, namely the hydraulic loading rates (HLR) and the hydraulic retention time (HRT), as it affects the treatment performance of a wetland (Kadlec and Wallace, 2009). However, one of the major constraints to field-scale constructed wetland systems in India is the requirement of a relatively large land area that is not readily available. Thus, for Indian conditions, batch-fed vertical sub-surface flow wetlands that require just about 1/100th of land area and 1/3rd HRT than the surface flow systems have been suggested (Kaur et al., 2012).

3.4. Flood control

Wetlands play an important role in flood control. Wetlands help to lessen the impacts of flooding by absorbing water and reducing the speed at which flood water flows. Further, during periods of flooding, they trap suspended solids and nutrient load. Thus, streams flowing into rivers through wetlands will transport fewer suspended solids and nutrients to the rivers than if they flow directly into the rivers. In view of their effectiveness associated with flood damage avoidance, wetlands are considered to be a natural capital substitute for conventional flood control investments such as dykes, dams, and embankments (Boyd and Banzhaf, 2007).

Based on the study in Rat River Watershed (Canada), it is estimated that with 10% increase in wetland area, there was a reduction of 11.1–18.6% in the total flood volume (Juliano and Simonovic, 1999). The flood protection value of human-made wetlands along the Nar and Ancholme rivers in the UK was estimated to be around 8201 USD/ha/year and 8331 USD/ha/year (Ghermandi et al., 2010). In India too, researchers have worked on estimating the value of flood protection function of the wetlands. One such study on the Bhitarkanika mangrove ecosystem in Orissa (second largest mangrove forest of India mainland), estimated that the cyclone damage avoided (taking cyclone of 1999 as a reference point) was highest in the village that was protected by mangrove forests. The loss incurred per household was greatest (US$ 153.74) in the village that was not sheltered by mangroves and lowest (US$ 33.31) in the village that was protected by mangrove forests (Badola and Hussain, 2005).

Huge loss of life and damage to economic outputs are reported every year from the Indo-Gangetic flood plains (largest wetland system in India) due to increased occurrence of floods. During 2010, in Bihar (one of the 11 States of Ganga basin) alone, a total of 0.72 million population and 3.24 m ha of cropped area in 8 out of 32 districts were affected by floods. Further, about four thousand houses were damaged. These recurrent floods also put pressure on the State and Central government budget as about INR 13.50 billion has been released till 2010–2011 for flood management programme in Ganga river basin alone (Ganga Flood Control Commission, 2012). One of the main reasons for flood induced catastrophe is decrease in areal extent of wetland area on account of conversion to agricultural uses, such as for rice farming and fish pond aquaculture (Prasad et al., 2002). Further, increased groundwater pumping for agriculture in eastern India (mainly West Bengal) might have had adverse impact on wetlands as they receive inflows also from shallow aquifers. Lowering of water table of shallow aquifers during winter–summer seasons, when agricultural water demand actually picks up, can result in the temporary drying up of the shallow wetlands (Kumar et al., 2013b). This will have a huge impact on poor families who depend on these water bodies for domestic water supplies, irrigation and fisheries.

3.5. *Biodiversity hotspots*

As with any other natural habitat, wetlands are important in supporting species diversity. Some vertebrates and invertebrates depend on wetlands for their entire life cycle while others only associate with these areas during particular stages of their life. Because wetlands provide an environment where photosynthesis can occur and where the recycling of nutrients can take place, they play a significant role in the support of food chains (Adams, 1988 cited in Juliano and Simonovic, 1999, p. 7). In India, lakes, rivers and other freshwater bodies support a large diversity of biota representing almost all taxonomic groups. The total numbers of aquatic plant species exceed 1200 and they provide a valuable source of food, especially for waterfowl (Prasad et al., 2002). The freshwater ecosystems of Western Ghats, a biogeographic region in southern India which runs along the west coast covering a total area of 136,800 km^2, alone has about 290 species of fish; 77 species of Mollusc; 171 species of Odonates; 608 species of aquatic plants; and 137 species of amphibians. Out of these, almost 53% of freshwater fish, 36% of freshwater Mollusc, and 24% of aquatic plants species are endemic to this region (Molur et al., 2011). Similarly, Loktak lake in Manipur, which is the largest natural water body in North-eastern India, supports a rich biological diversity. The lake is famous for its floating mats of vegetation locally called as *phumdi* (a unique ecosystem consisting of heterogeneous mass of soil, vegetation and organic matter at various stages of decomposition) and for being the only refuge of the endangered *Sangai* (Manipur brow-antlered deer) (Sharma, 2009a). 75 species of phytoplankton (Sharma, 2009a) and 120 species of rotifers have also been documented from the Loktak lake (Sharma, 2009b).

Wetlands are important breeding areas for wildlife and provide a refuge for migratory birds. In many such wetland areas of India, like Bharatpur wild life sanctuary in Rajasthan, and little Rann of Kutch and coastal areas of Saurashtra in Gujarat, many migratory species of birds from western and European countries come during winter. According to certain estimates, the approximate number of species of migratory birds recorded from India is between 1200 and 1300, which is about 24% of India's total bird species (Agarwal, 2011). In Delhi alone, more than 450 species of birds are sighted every year, which boasts of having the largest number of birds that can be seen in a capital city after Nairobi. Due to its diverse ecological features, Delhi and surrounding areas make it possible for large number of migratory birds to come and flock here, especially during winter. Some of these migratory birds are Red Crested Pochards, Brooks Leaf Warbler; White Tailed Lapwing; Orphean Warbler; Sind Sparrow; Rock Eagle Owl; and Great White Pelicans (Lalchandani, 2012).

Attempts have also been made to value the wetland biodiversity. The value of biodiversity enhancement through constructed wetlands at various locations along the Elbe River in Germany is estimated to be around USD 1942 per hectare per year (Ghermandi et al., 2010). Similarly, value of tropical river and inland fisheries alone has been estimated at USD 5.58 billion per year (Neiland and Bene, 2008). In 2011–2012, fisheries (both marine and inland) contributed about USD 10.9 billion to India's GDP (at current prices) (Ministry of Agriculture, 2012). This translates into huge opportunity for India, where close to 6 million people are dependent on inland fisheries for their subsistence and livelihood.

4. Growing threat to wetland ecosystem

Freshwater wetland ecosystems are among the mostly heavily used, depended upon and exploited ecosystems for sustainability and well-being (Molur et al., 2011). More than 50% of specific types of wetlands in parts of North America, Europe, Australia, and New Zealand were converted during the twentieth century (MEA, 2005). In Asia alone, about 5000 km^2 of wetland area are lost annually to agriculture, dam construction, and other uses (McAllister et al., 2001). Further, dependence on water and other resources in this environment has placed enormous pressures on the ecosystem worldwide resulting in direct impacts to species diversity and populations (Molur et al., 2011). As a result many wetland dependent species including 21% of bird species; 37% of mammal species; and 20% of freshwater fish species are either extinct or globally threatened (MEA, 2005).

Loss in wetland area results in adverse impact on the key functions (ecosystem goods and services) performed by wetlands (Zedler and Kercher, 2005). Worldwide, the main causes of wetland loss have been: urbanization; land use changes; drainage to agricultural use; infrastructure development; pollution from industrial effluent and agricultural runoff; climate change and variability. Some of these factors which led to significant alterations in India's wetland ecosystems have been discussed in the subsequent sub-sections.

4.1. Urbanization and land use changes

Between 1951 and 2011, total population in India increased from 0.4 billion to 1.2 billion with an average decadal growth rate of around 22%. During the 90 year period from 1901 to 1991, the number of urban centres doubled while urban population has increased eightfold (Bassi and Kumar, 2012). This magnitude of growth exerted tremendous pressure on wetlands and flood plain areas for meeting water and food demand of growing population. Between 1950–1951 and 2008–2009, total cultivated land in India increased from about 129 to 156 m ha. Also, area under non-agricultural uses (commercial or residential use) increased from 9 to 26 m ha (Data Source: Indiastat). In most of the major river basins of India, the increase in area for both agricultural and non-agricultural use was at the cost of conversion of flood plain areas, primary forests, grasslands and associated freshwater ecosystems to meet demands of growing population (Zhao et al., 2006). For instance, about 34,000 ha of the water spread area of the Kolleru lake (Andhra Pradesh) have been reclaimed for agriculture in recent years (MoEF, n.d.).

Further, there was a large scale development of irrigation and water supply infrastructure in the country which altered the inflows and water spread areas of many water bodies. Till 2007, about 276 major and 1000 medium irrigation projects were completed in India (Central Water Commission, 2010), with an estimated total water storage capacity of about 225 BCM (12% of total water resources potential of India). Though, the large reservoir projects have played a critical role in water supply; flood control; irrigation; and hydroelectric power production, the rapid proliferation of artificial water impounding structures without proper hydrological and economic planning (such as construction of small dams in semi-arid and arid regions where runoff potential is limited) has caused widespread loss and fragmentation of freshwater habitats (Kumar et al., 2008; Zhao et al., 2006); and reduction in environmental flows (due to over allocation of water mainly for meeting agricultural and industrial water demands). Already, most of the river basins in southern and western India are experiencing environmental water scarcity, which means the discharge in these basins has already been reduced by water withdrawals to such levels that the amount of water left in the basin is less than that required by the freshwater dependent ecosystems (Smakhtin et al., 2004).

Urbanization exerts significant influences on the structure and function of wetlands, mainly through modifying the hydrological and sedimentation regimes, and the dynamics of nutrients and chemical pollutants. Impact of urbanization is equally alarming on natural water bodies in the cities. A study found that out of 629 water bodies identified in the National Capital Territory (NCT) of Delhi, as many as 232 cannot be revived on account of large scale encroachments (Khandekar, 2011). Similarly, between 1973 and 2007, Greater Bengaluru Region lost 66 wetlands with a water spread area of around 1100 ha due to urban sprawl (Ramachandra and Kumar, 2008). Further, poor management of water bodies, lack of concrete conservation plans, rising pollution, and rapid increase in localized

Table 3
Status of sewage generation and treatment capacity in Indian urban centres.

Sr. no.	Urban centre	Total no. of cities/towns	Sewage generation (2008)	Sewage treatment capacity (2008)
			In million litres per day (MLD)	
1	Metropolitan cities	35	15,644	8040
2	Class I cities (other than metropolitan cities)	463	19,914	3514
3	Class II towns	410	2697	234
	Total	908	38,255	11,788

Source: Adapted from Central Pollution Control Board (2009).

demands for water are pushing these precious eco-balancers to extinction (Indian National Trust for Art and Cultural Heritage, 1998).

4.2. Agricultural, municipal and industrial pollution

Water in most Asian rivers, lakes, streams and wetlands has been heavily degraded, mainly due to agricultural runoff of pesticides and fertilizers, and industrial and municipal wastewater discharges, all of which cause widespread eutrophication (Liu and Diamond, 2005; Prasad et al., 2002).

As a result of intensification of agricultural activities over the past four decades, fertilizer consumption in India has increased from about 2.8 million tonne in 1973–1974 to 28.3 million tonne in 2010–2011 (Data Source: Indiastat). As per estimates, 10–15% of the nutrients added to the soils through fertilizers eventually find their way to the surface water system (Indian Institute of Technology, 2011). High nutrient contents stimulate algal growth, leading to eutrophication of surface water bodies. Studies indicate that 0.5 mg/l of inorganic Nitrogen and 0.01 mg/1 of organic Phosphorus in water usually stimulates undesirable algal growth in the surface water. Runoff from agricultural fields is the major source of non-point pollution for the Indian rivers flowing through Indo-Gangetic plains (Jain et al., 2007a,b). Water from lakes that experience algal blooms is more expensive to purify for drinking or other industrial uses. Eutrophication can reduce or eliminate fish populations (Verhoeven et al., 2006) and can also result in loss of many of the cultural services provided by lakes.

Along with runoff from agricultural fields, untreated wastewater also contributes significantly to pollution of water bodies. Less than 31% of the domestic wastewater from Indian urban centres is treated, compared to 80% in the developed world. In total of 35 metropolitan cities, treatment capacity exists for only 51% of the sewage generated. Conditions in smaller urban centres are even worse as treatment capacity exist for only about 18% of the sewage generated in Class I cities (population size of 100,000 or more but other than metropolitan cities) and 9% of the sewage generated in Class II towns (population between 50,000 and 100,000) (Table 3). Actual sewage treatment will be further low due to inadequacy of the sewage collection system and non-functional treatment plants. Thus, there is a huge gap in generation and treatment of wastewater in Indian urban centres and most of sewage is discharged without treatment in the natural water bodies such as streams and rivers (Central Pollution Control Board, 2009).

Results from monitoring of Indian aquatic resources also show that water bodies, such as rivers and lakes, near to urban centres are becoming increasingly saprobic and eutrophicated due to the discharge of partly treated or untreated wastewater (Central Pollution Control Board, 2010). River Yamuna, which passes through 6 Indian States, receives about 1789 MLD of untreated wastewater from the capital city of Delhi alone. This is about 78% of the total pollution load that flows in to the river every day. As a result the water quality and hydrological character in the Delhi segment of the river is the most polluted as compared to other stretches in terms dissolved oxygen (DO) and biological oxygen demand (BOD). The DO level had decreased to 1.41 from 8.05 in the Himalayan segment and the BOD level has risen to 17.2 from 2.8. This is quite significant as National Capital Territory of Delhi extract about 2500 million cubic metres of water per annum from river Yamuna for domestic, industrial and irrigation purposes (Study Group on Environment, n.d.).

4.3. Other threats

Global climate change is expected to become an important driver of loss and change in wetland ecosystem (MEA, 2005; UNESCO, 2007). These findings are important for Indian subcontinent where the mean atmospheric temperature and frequency of occurrence of intense rainfall events has increased, while the number of rainy days and total annual amount of precipitation have decreased due to increase in the concentration of greenhouse gases such as CO_2, CH_4 and N_2O in the atmosphere (Bates et al., 2008).

Limited analysis on the impact of climate change on wetlands in India suggests that high altitude wetlands and coastal wetlands (including mangroves and coral reefs) are some of the most sensitive classes that will be affected by climate change (Patel et al., 2009). For instance, climate change induced rising level of glacial fed high altitude lakes, such as Tsomoriri in Ladakh, has submerged important breeding islands in the lake where endangered migratory birds like the Black-necked Crane and Bar-headed Goose would breed (Chandan et al., 2008). In case of the coastal wetlands such as Indian part of Sunderbans mangrove, rising sea surface temperature and sea level rise due to thermal expansion, could affect the fish distribution and lead to the destruction of significant portion of mangrove ecosystem. Further destruction of the Sundarbans mangroves would diminish their critical role as natural buffers against tropical cyclones resulting in loss of lives and livelihoods (Centre for Science and Environment, 2012; UNESCO, 2007).

The limited analysis also seems to suggest that the inland natural wetlands, especially those in arid and semi-arid regions, will be impacted through alteration in its hydrological regime due to changes in precipitation, runoff, temperature and evapo-transpiration (Patel et al., 2009). Climate change induced rising temperature and declining rainfall pattern presents a potential danger to the already disappearing lakes in the Gangetic plains (Sinha, 2011). Decreased precipitation will exacerbate problems associated with already growing demands for water and hence alter the freshwater inflows to wetland ecosystems (Bates et al., 2008; Erwin, 2009), whereas, rise in temperature can aggravate the problem of eutrophication, leading to algal blooms, fish kills, and dead zones in the surface water (Gopal et al., 2010). Also, seasonality of runoff in river basins (such as Ganges) will increase along with global warming, that is, wet seasons will become wetter and dry seasons will become drier (World Bank, 2012). This would have severe adverse impact on affected populations, especially if the seasonality of runoff change would be out of phase with that of demand.

As per estimates, India will lose about 84% of coastal wetlands and 13% of saline wetlands with climate change induced sea water rise of 1 m (Blankespoor et al., 2012). As a result there will be adverse consequences on wetland species, especially those that cannot relocate to suitable habitats, as well as migratory species that rely on a variety of wetland types throughout their life cycle. However, it must be noted that projections about the extent of loss and degradation or decline of wetlands are not yet well established as climate models used for such predictions are not robust. It is not clear how the regions' temporal and spatial variability in rainfall gets captured by these models. Further, there is tendency to attribute hydrological regime changes in wetlands to climate change, rather than trying to find the real physical and socio-economic processes responsible for such changes (Kumar, 2013).

5. Institutional strategies adopted for wetland management in India

In India, wetlands continue to be seen in isolation and hardly figure in water resources management and development plans. The primary responsibility for the management of these ecologically sensitive ecosystems is in the hands of the Ministry of Environment and Forests (MoEF), Government of India. Though India is signatory to both Ramsar Convention on Wetlands and the Convention of Biological Diversity, there seem to be no clear cut regulatory framework for conservation of wetlands. In the subsequent sub-sections wetland management strategies including the legal framework and policy support for wetland conservation will be discussed.

5.1. Legal framework

Though there is no separate legal provision for wetland conservation in India, it is indirectly influenced by number of other legal instruments. These include: Indian Fisheries Act 1857, Indian Forest Act 1927, Wildlife (Protection) Act 1972, Water (Prevention and Control of Pollution) Act 1974, Territorial Water, Continental Shelf, Exclusive Economic Zone and other Marine Zones Act 1976, Water Cess Act 1977, Maritime Zone of India (Regulation and fishing by foreign vessels) Act 1980, Forest (Conservation) Act 1980, Environmental (Protection) Act 1986, Wildlife (Protection) Amendment Act 1991, Biodiversity Act 2002, and Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006 (MoEF, 2007; Prasad et al., 2002).

Provisions under these acts range from protection of water quality and notification of ecologically sensitive areas to contributing towards conserving, maintaining, and augmenting the floral, faunal and avifaunal biodiversity of the country's aquatic bodies. However, the term wetland was not used specifically in any of these legal instruments.

5.2. Policy support

Until the early part of 2000, the policy support for wetland conservation in India was virtually non-existent. The action on wetland management was primarily influenced by the international commitments made under Ramsar Convention and indirectly through array of other policy measures, such as, National Conservation Strategy and Policy Statement on Environment and Development, 1992; Coastal Zone Regulation Notification, 1991; National Policy and Macro level Action Strategy on Biodiversity, 1999; and National Water Policy, 2002 (MoEF, 2007; Prasad et al., 2002).

As a signatory to Ramsar Convention on Wetlands and recognizing the importance of protecting such water bodies, the Government of India identified two sites, i.e. Chilika lake (Orissa) and Keoladeo National Park (Rajasthan), as Ramsar Wetlands of International Importance in 1981 (MoEF, 2012). Thereafter in 1985–1986, National Wetland Conservation Programme (NWCP) was launched in close collaboration with concerned State Governments. Initially, only designated Ramsar Sites were identified for conservation and management under the Programme (MoEF, 2007). Several measures were taken to arrest further degradation and shrinkage of the identified water bodies due to encroachment, siltation, weed infestation, catchment erosion, agricultural run-off carrying pesticides and fertilizers, and wastewater discharge. Subsequently in 1993, National Lake Conservation Plan (NLCP) was carved out of NWCP to focus on lakes particularly those located in urban and peri-urban areas which are subjected to anthropogenic pressures. Initially, only 10 lakes were identified for conservation and management under the plan (MoEF, 2007). There is also a National River Conservation Plan (NRCP), operational since 1995, with an objective to improve the water quality of the major Indian rivers through the implementation of pollution abatement works, to the level of designated best use. The new draft National Water Policy, 2012 which is cleared recently by the National Water Resources Council also recognizes the need for conservation of river corridors and water bodies (including wetlands) in a scientifically planned manner. Further, the policy emphasizes that the environmental needs of aquatic eco-system, wetlands and embanked flood plains should be recognized and taken into consideration while planning for water resources conservation (Ministry of Water Resources, 2012).

Over the years, number of designated Ramsar Sites has increased to 26 (Ramsar Convention on Wetlands, 2012), number of rivers under NRCP has increased to 39 and number of wetlands covered by the NWCP and NLCP has increased to 115 and 61 respectively (MoEF, 2012). However these initiatives proved to be too little considering the extent of ecologically sensitive wetland ecosystems in the country and the fact that only a selected few wetlands were taken up for conservation and management purpose (Dandekar et al., 2011) (Table 4).

Lately, the National Environmental Policy 2006 recognized the importance of wetlands in providing numerous ecological services (MoEF, 2006). The policy, for the first time, accepted that there is no formal system of wetland regulation in the country outside the international commitments made in respect of Ramsar sites and thus there is a need of legally enforceable regulatory mechanism for identified valuable wetlands, to prevent their degradation and enhance their conservation (Dandekar et al., 2011; MoEF, 2006). Further, the policy advocated, developing of National inventory of such

Table 4
Status of wetland conservation in India.

Sr. no.	Particulars	Status
1	Total number of natural wetlands in the country as per the latest National Wetland Atlas	55,862
2	Number of natural wetlands under conservation:	
	a) Wetlands designated as Ramsar Sites and under NWCP	119
	b) Wetlands under NLCP	61
	c) Wetlands under NRCP	39
	d) Overall number of natural wetlands under conservation	219
3	% under conservation to total number of natural wetlands in the country	0.4

Source: Data compiled from MoEF (2007, 2012), Ramsar Convention on Wetlands (2012) and SAC (2011).

wetlands (MoEF, 2006, 2007). A report by National Forest Commission (2006) among other suggestions also emphasized on: framing of a National Wetland Conservation Act; and establishment of a National Wetland Inventory and Monitoring Programme in order to develop a sustained and serious programme for monitoring wetlands.

Based on the directives of National Environment Policy, 2006 and recommendations made by National Forest Commission, Central Government notified the Wetlands (Conservation and Management) Rules, 2010. As per the provision under Rule 5 of the wetlands rules, Central Wetlands Regulatory Authority (CWRA) has been constituted under the chairmanship of Secretary, Environment and Forest. The Expert Group on Wetlands (EGOW) has also been constituted for examining management action plans of newly identified wetlands (MoEF, 2012). The rules put restrictions on the activities such as reclamation, setting up industries in vicinity, solid waste dumping, manufacture or storage of hazardous substances, discharge of untreated effluents, any permanent construction, etc. within the wetlands. It also regulates activities (which will not be permitted without the consent of the State government) such as hydraulic alterations, unsustainable grazing, harvesting of resources, releasing treated effluents, aquaculture, agriculture and dredging.

However, only selected wetlands based on the significance of the functions performed by them for overall well-being of the people are being regulated under these rules. These include: (1) wetlands selected under Ramsar Convention; (2) wetlands in ecologically sensitive and important areas; (3) wetlands recognized as UNESCO World Heritage site; (4) high altitude wetlands (at or above an elevation of 2500 m with an area equal to or greater than five hectares); (5) wetland complexes below an elevation of 2500 m with an area equal to or greater than 500 ha; and (6) any other wetland identified by the Authority (Wetlands Rules, 2010). Lack of regulations, especially of wetlands below 2500 m, totally neglects the management and conservation of some of the crucial smaller wetlands in urban and rural areas which perform important socio-ecological functions and are under severe threat by land-filling and reclamation. Further river channels (included as wetlands under Ramsar Convention definition) and irrigation tanks are excluded from protection status under the Wetland Rules (Dandekar et al., 2011).

Thus, despite the recent national legislation on wetland regulation, a majority of the wetlands continue to be ignored in the policy process. However, it should be noted that the latest National Wetland Atlas, which is prepared by SAC, ISRO with support from Ministry of Environment and Forest, does include tanks in the wetland database. Hence, there seems to be a disagreement among the national agencies on the kind of water bodies that can be considered as a wetland. Some scholars have emphasized that the rules do not recognize the traditional rights over the wetlands for livelihoods even as they seeks to regulate such activities. Such regulation can in effect become prohibitive for livelihood activities. Also, the rules limit the involvement of community and local stakeholder groups in the management of the wetlands. This goes against the recommendation 6.3 of Ramsar Convention (relating to encouraging active and informed participation of local and indigenous people at Ramsar listed sites and other wetlands and their catchments), made during the Sixth Conference of Parties in 1996 (ATREE, 2010).

Given that only a small fraction of total wetlands have been taken up for conservation and growing threat to their ecosystem, it is essential that other ecologically important wetlands be identified and protected. Further, it is important to regulate large scale land use changes in the catchment area of wetlands and also prevent them from getting polluted in order to maintain their hydrological and ecological integrity. For achieving the second objective, an effective and proper water quality monitoring plan needs to be devised.

6. Conclusion

In India, wetland ecosystems support diverse and unique habitats and are distributed across various topographic and climatic regimes. They are considered to be a vital part of hydrological cycle and are highly productive systems in their natural forms. Wetlands not only support large biological diversity but also provide a wide array of ecosystem goods and services (Wetlands Rules, 2010). In India, wetlands provide multiple services, including irrigation, domestic water supply, freshwater fisheries and water for recreation. They are also playing important role in groundwater recharge, flood control, carbon sequestration and pollution abatement. However, management of wetlands has received inadequate attention in the national water sector agenda. As a result, many of the wetlands in urban and rural areas are subject to anthropogenic pressures, including land use changes in the catchment; pollution from industry and households; encroachments; tourism; and over exploitation of their natural resources.

India is signatory to Ramsar Convention on Wetlands and has drafted Wetland (Conversation and Management) Rules in 2010 but still no significant progress has been made on the conservation and wise use of wetlands. The main reason is that only selected number of wetlands has received significant attention (by way of financial and technical assistance from the central government) under the wetland conservation programmes (like NWCP and NLCP) while the remaining ones continue to be in neglected state.

Majority of research work on wetland management in India relates to the limnological aspects and ecological/environmental economics of wetland management. But, the physical (such as hydrological and land-use changes in the catchment) and socio-economic (such as population growth and changes in economic activities) processes leading to limnological changes have not been explored substantially. Further, the institutional aspects (policies, rules, regulation and organizations) of wetland management have received limited attention and attracted the imagination of research scholars only recently. Thus more research emphasis on the physical, socio-economic and institutional factors influencing condition of wetlands and their use is required in order to arrive at better and comprehensive management strategies for wetlands that are facing growing stress from a variety of anthropogenic and climatic factors.

Conflict of interest

We declare that there is no conflict of interest associated with this manuscript.

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