Wetlands and Water Management: Finding a Common Ground

Ritesh Kumar, Harsh Ganapathi and Santosh Palmate

Abstract Wetlands, ecosystems at the interface of land and water, have a significant role in ensuring water and climate security of India given their role in the water cycle and multiple hydrological functions. The rapid loss of natural wetlands as has been experienced lately is as much a threat to water and climate security, as is an environmental crisis. The supply-side hydrology which characterized water sector for long has tended to overlook this role of wetlands, and at several instances, in an attempt to 'develop' these ecosystems, created several adverse ecological and socio-economic impacts. With broadening of thinking on water resources management from run-off to precipitation-based management incorporating land use, the role of ecosystems such as wetlands in building water system resilience becomes highly significant in Indian context. Forging 'natural infrastructure' of wetlands with the conventional 'physical infrastructure' of water resources can bring multiple advantages to the water sector and provide the required flexibility to address climate change-induced uncertainties and risks. Using catchment as a planning unit and a harmonized understanding of wetlands and their hydrological functions is the foundation step for collaboration between water and wetlands sectors. Communication between the two sectors can be bridged by wetlands managers articulating water needs and hydrological functions of wetlands in terms useful to water sector, and the latter, incorporating wetlands as nature-based solutions for meeting water management objectives.

Keywords Wetlands · Trend index · Nature-based solutions · Ecosystem services · Resilience

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1 Introduction

Water challenges in India are deepening with intensifying impacts of climate change, reducing per capita water availability, equity concerns and growing water conflicts (World Bank 2005; Cronin et al. 2014; Jain 2019). The Government of India, of late, has rightly accorded high priority to water in its development agenda and has taken strategic steps such as consolidation of institutional landscape for water by creating Jal Shakti Ministry in 2019 (merging the erstwhile Ministry of Water Resources, River Development and Ganga Rejuvenation and Ministry of Drinking Water and Sanitation) and adopting a mission of 'water for all' (GoI 2020).

Wetlands, which form an integral part of water cycle and perform multiple hydrological functions, have a significant role in ensuring water and climate security of the country. Forging 'natural infrastructure' of wetlands (da Silva and Wheeler 2017) with the conventional 'physical infrastructure' of water resources can bring multiple advantages to the water sector, provided the role these ecosystems play in the hydrology of a landscape is systematically taken into account in policy and programming decisions.

This chapter looks into the interconnections between wetlands and water management and builds a case for integration of wetlands into water sector policies and programmes. It is argued that the rapid loss of natural wetlands is not just a crisis for environment, but also for water and climate security.

By transforming the available science on the role of wetlands into practical actions, the two sectors of wetlands and water which have historically pursued disparate trajectories can capitalize on mutually supportive outcomes towards building resilience. The arguments are presented in seven sections. The section following introduction looks into the scientific basis for integrating wetlands into water management and the enabling mechanisms thereof. The next two sections contain discussions on trajectories of water resources development and wetlands management and the extent to which sectoral coordination opportunities have been taken into account. Joined-up policy and programming opportunities, as well as science, policy and practice barriers limiting integration of wetlands in water resources management, are discussed in sections five and six. Section seven concludes with recommendations for the two sectors to collaborate for building water resilience. Throughout the discussions, the reference to water sector encompasses institutions, groups, agencies and organizations responsible for regulatory, operational and institutional aspects of water policy, programmes and regulation. Similarly, the reference to wetlands sector is to institutions, organizations, groups and agencies responsible for regulatory, operational and institutional aspects of wetlands policy, programmes and regulation.

2 The Need for Integrating Wetlands in Water Management

Wetland is a generic term used for aquatic ecosystems located at the interface of land and water and combining attributes of terrestrial as well as aquatic ecosystems (Keddy 2010). The Ramsar Convention (a multilateral environmental agreement on wetlands ratified by 171 countries, including India, which ratified the Convention in 1982) uses a broad definition of wetlands 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’ (Ramsar 2016).

To ensure connectivity between different habitats, Article 2.1 of the Convention provides that riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands may also be included within the boundary (Ramsar 2016). This broad-ranging definition thus covers a large category of inland aquatic systems (such as ponds, lakes, marshes, swamps and peatlands); coastal and nearshore marine ecosystems (such as coral reefs, mangroves, seagrass beds and estuaries); and human-made wetlands (such as rice–paddies, fish ponds and water storage areas as tanks, reservoirs and dams).

The term ‘water bodies’ is commonly used in the Indian water sector to distinguish water storage areas from flowing systems such as rivers (GoI 2018a). Wetlands are diverse, ranging from open-water-dominated systems (such as lakes, ponds or tanks), wherein evapotranspiration is not constrained by water availability, to those wherein water is at or frequently below the surface (such as swamps and marshes), and evapotranspiration is regulated by plant physiology (McCartney and Acreman 2009). Thus, all water bodies are wetlands, but not all wetlands are ‘water storage’ areas, in the sense used by the water sector.

India has a diverse wetland regime ranging from high-altitude lakes of the Himalayas, floodplains and marshes of the Gangetic–Brahmaputra alluvial plains, saline flats of Great Indian Desert, tank-studded Deccan Peninsula to extensive mangroves and coral reef areas bordering the country’s east and the west coastline (Kumar et al. 2017). As per the National Wetlands Atlas (SAC 2011), India has 15.26 million ha under wetlands, accounting for nearly 4.6% of her geographical area (Fig. 1). In terms of biogeographic zones, the coasts and the Deccan region have the maximum wetlands areas, the proportion of natural wetlands being higher in the former and human-made in the latter.

Wetlands, in their various occurrences, forms and characteristics, play an important role in functioning of the water cycle (Bullock and Acreman 2003). As water moves through the surface or underground, it passes through wetlands, which in turn regulate the quantity, quality and reliability of water. Wetlands provide vital water-related ecosystem services at different scales (e.g. clean water provision, wastewater treatment, groundwater replenishment) and, thereby, offer significant opportunities to address water management objectives with sustainable and, in

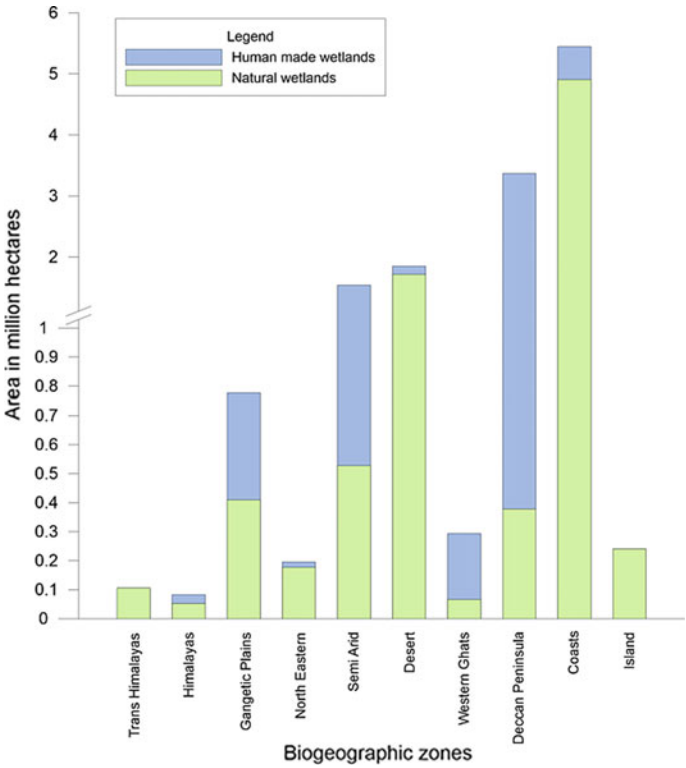

Fig. 1 Distribution of wetlands in different biogeographic zones of India. *Source* Authors, estimated from the data of National Wetlands Atlas (SAC 2011)

several instances, cost-effective solutions (UNEP 2014). The ecosystem services of wetlands can also complement human-made infrastructure to deliver water supply, sewage treatment and energy, thereby aptly being referred to as 'natural' or 'green infrastructure' or 'nature-based solutions' for water managers (UNEP 2014; Nesshöver et al. 2017).

The hydrological functions of wetlands can be elucidated by several examples. The high-altitude wetlands of Himalayas serve as headwaters of the 10 largest rivers of Asia, the basins of which support nearly one-fifth of the global population (Trisal and Kumar 2008). For several cities, wetlands were the primary source of water and continue to be so, as reflected in the moniker 'city of lakes' given to Bangalore (Nagendra 2010), Udaipur (Singh et al. 2018), Bhopal (Verma and Negandhi 2011) and many others. In some instances this water store can be highly significant, such as the water storage in Yamuna floodplains has been estimated to be equivalent to three-fourths of Delhi's water supply (Soni et al. 2009).

Wetlands have traditionally been the backbone of agriculture practised in the Ganga–Brahmaputra floodplains. The waste treatment capability of wetlands has been effectively used by the city of Kolkata which depends upon the East Kolkata Wetlands to treat nearly 65% of its wastewater, saving nearly Rs. 4600 million annually in terms of avoided treatment cost (WISA 2020). Wetlands act as major flood defence systems for cities such as Srinagar (Jammu and Kashmir) and Guwahati (Assam) (Kumar et al. 2017). In the hard rock Deccan Plains and arid regions of the country, there has been an age-old tradition of constructing tanks to store rainwater for use in irrigation and domestic water supply (Bhattacharya 2015). The value of coastal wetlands as a buffer against tropical storms has been brought out by several researchers (Das and Vincent 2009; Kathiresan 2010). Wetlands are also intricately interwoven with the rich cultural and religious tapestry of the country, and several wetlands are considered sacred (Singh 2013).

India's total annual utilizable water resources have been assessed to be 1123 km^3, of which 39% is accounted for by groundwater (MoWR 2010). The surface storage capacity of inland wetlands (projected from the wetland extent data from National Wetlands Atlas and assuming an average depth of 1 m) comes roughly to 60 km^3. The contribution of inland wetlands to groundwater recharge [estimated by the authors using National Wetlands Atlas data and recharge factors of Central Ground Water Board] comes to 51 km^3, of which 21 km^3 is from natural inland wetlands. While the contribution of wetlands to available water resources may appear small (for want of a more systematic assessment), their value lies in their availability as a diffuse resource in virtually all landscapes. Unlike large water storage structures, these systems do not require massive investments into infrastructure for accessing and distributing water, rather can be accessed with very nominal technology. The ability to support diverse life forms while also playing a crucial role in food and climate security makes them an incredible water resource.

Notwithstanding the high value of ecosystem services wetlands provide to society, they continue to be degraded, polluted, encroached upon and converted for alternate uses. A wetland area trend index constructed by the authors for Indian wetlands based on 237 published data points for 1980–2014 using wetland extent trends index method (Dixon et al. 2016) indicates an average decline in natural wetlands area by 41% and a near commensurate increase in area under human-made wetlands by 44% (Fig. 2). These trends are similar to those reported globally, wherein the natural wetlands have been on a decline, and the human-made wetlands are increasing (Gardner and Finlayson 2018). Such trends are worrying because natural wetlands are difficult to restore, and their functions cannot be totally replaced by human-made ones (Gardner and Finlayson 2018).

There is a considerable body of research that highlights the increasing vulnerability of landscapes, wherein natural wetlands have been degraded or lost (Dewan and Yamaguchi 2008; Acreman and Holden 2013; Marois and Mitsch 2015). This is especially true for major urban areas in India, wherein large swathes of wetlands have been converted to give way for housing and other infrastructure needs (Kumar and Kaul 2018). As a matter of fact, a positive relationship between an increase in the built-up area, increasing run-off, loss of wetlands and enhanced flood vulnerability has been observed for several cities, such as Mumbai (Zope et al. 2016), Bangalore (Ramachandra et al. 2019) and Chennai (Gupta and Nair 2011).

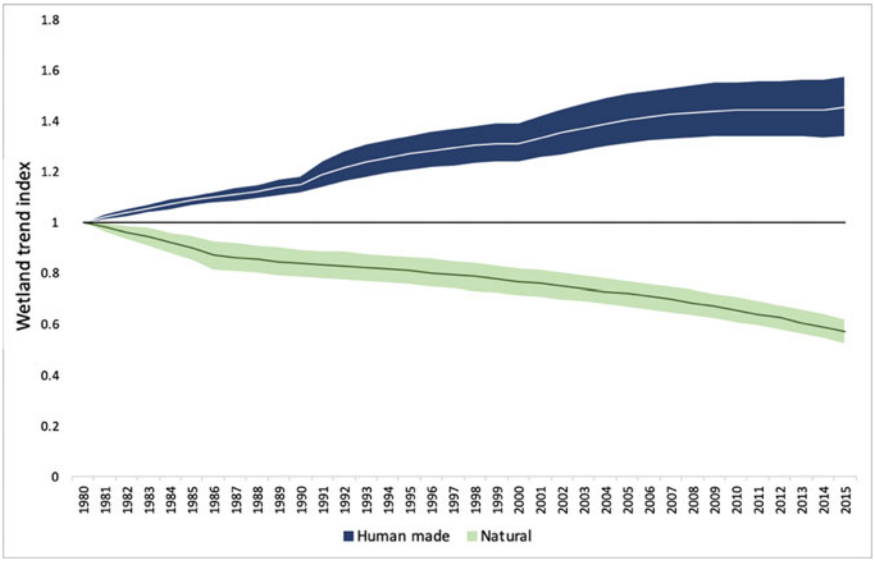

Fig. 2 Wetland area trend index for natural and human-made wetlands of India. *Source* Authors

Extensive urbanization of floodplains and conversion of wetlands were identified as critical anthropogenic drivers of extensive damage due to 2014 extreme flooding in Kashmir (Romshoo et al. 2018). With the capacity of treating sewage limited to only 31% of total generation (ENVIS 2019), pollution of wetlands is rampant. Wetlands are also degraded due to fragmentation of hydrological regimes, excessive siltation, encroachment, invasive species, unregulated tourism and overharvesting of wetland resources (MoEFCC 2019), although the intensity of drivers of change varies in different biogeographic zones.

Wetlands are managed for their wise use—sustainable utilization for the benefit of humankind in a way compatible with the maintenance of natural properties of the ecosystem (Finlayson et al. 2011). Wetlands evolve and function within physical templates set by water regimes and sediments (Ramsar 2010a). Treating water as a commodity and resource delivered through physical infrastructure as dams, pumps and pipes for various human usages (domestic, industrial or agricultural) obfuscates the fact that water is a component of healthy, functional ecosystems such as wetlands. Several water resource development projects have, thereby, led to degradation of wetlands by altering flow patterns, reducing water availability and deteriorating water quality, ultimately rendering the entire water management goal unsustainable. The delivery of hydrological functions is contingent on the availability of water of right quantity and quality and at the right time, thus necessitating that wetland functioning is integrated into water resources planning and decision-making processes (McCartney and Acreman 2009). Similarly, wetland managers need to articulate the water needs of wetlands to water managers and ways wetlands can help meet overall water resources management objectives.

The most significant body of work on wetlands and water is available within the Ramsar Convention. A number of resolutions have been adopted by Contracting Parties which have been summarized in four handbooks (Ramsar 2010a, b, c, d). A common element in all these guidelines is recognition of two important facts: (a) water resources management is dependent to a large degree on the hydrological functions of wetlands, and (b) wetland ecosystems need a certain amount of water allocated for maintenance of ecological character, in order to maintain these hydrological functions. The Ramsar guidelines on integration of wetlands in river basin management are structured around eight principles (sustainability such as a goal, clarity of process, equity in participation and decision-making, credibility of science, transparency in implementation, flexibility in management, accountability for decisions and cross-sectoral cooperation in policy development and implementation) and recommend a critical path approach to achieve the integration (Ramsar 2010d; Rebelo et al. 2013). The guidelines on allocation of water for wetlands stress upon an enabling policy environment, supported by appropriate legal arrangements and a framework for assessing the merits of different allocation options (Ramsar 2010a). Similarly, the guidelines for integrated management planning encourage site managers to take into account the role of wetlands in wider catchments while defining wise use strategies (Ramsar 2010e).

3 Water Resources Development Trajectories and Consequences for Wetlands

The centrality of water resources development in shaping up of Indian state is well recognized (Whitcombe 2005). Wetlands were accorded special status (referred as ‘anupa’, or incomparable lands) in religious texts (Rangarajan 2005), many wetlands species such as fish and lotus were considered sacred, and these ecosystems formed an essential source of water for domestic use and irrigation (Agrawal and Narain 1997; Bhattacharya 2015). With high temporal and spatial variability and heterogeneity in rainfall and availability of water resources, Indian society has adapted to the situation, by either living along the banks of rivers and wetlands, and carefully husbanding water resources (World Bank 2005). The agrarian society was mostly dependent on surface water storages within natural as well as human-made wetlands, and gravity flow irrigation to water crops. In the alluvial plains of the north, monsoon floodwaters were diverted and managed to enable riverine agriculture. The Deccan Plateau of peninsular India, which did not have an abundance of perennial rivers, had a long tradition of constructing tanks to conserve rainwater (Raju and Shah 2000; Van Meter et al. 2014). The cascading tank systems of southern India are an important reference point as multi-functional systems providing seasonal water storage, along with being centres of settlements and as providing social and cultural identity to the communities (Mosse 1997; Van Meter et al. 2014).

The beginning of the nineteenth century, however, marked colonial reconfiguration of irrigation regime by undertaking large canal projects driven by an ambition to commodify water and generate revenue (D'Souza 2002, 2006). Colonial water technologies such as weirs, dams and barrages were directed at providing perennial irrigation for settled agriculture, which was needed to address the food and development needs of a burgeoning population (World Bank 2005), but gradually led to reduced relevance of traditional water systems (D'Souza 2006). The water technologies were also directed at draining and reclaiming marshes and swamps for more productive and revenue-generating usages such as agriculture (Richards et al. 1985). Attempts to tame floods through embankments scarred the alluvial floodplains and the deltas (D'Souza 2003; Singh 2008), which when done counter to natural fluvial regimes, prevented the spread of fertile sediments into the floodplains and ultimately led to extended periods of water logging and converting landscapes from being flood-dependant to flood vulnerable (D'Souza 2003).

Post-independence, taming rivers and floods formed the cornerstone of water resources development. Colonial technologies were perpetuated in the form of dams and embankments. Large-scale water resources development projects backed by powerful state hydraulic bureaucracies stood robustly behind the construction of what the first Indian Prime Minister referred to as 'temples of modern India' (Morrison 2010; Swayamprakash 2014). Increased control over water resources entrenched the prominence of human-made wetlands, the reservoirs and barrages. In contrast, the natural wetlands were seen as unproductive wastelands, reclamation of which was incentivized by state, by means such as drainage programmes, especially in response to the great famines that the country faced in the 1950s.

The approach of 'developing' water resources was also applied to several wetlands. In the north-eastern state of Manipur, the solution to devastating floods of 1966 and the region's deprivation of power was seen in the form of regulating the Loktak, the largest floodplain wetland of the state (Meitei 2020) and converting it into a reservoir. The Ithai Barrage was constructed at the outflow to prevent depletion of water level in dry winters and water from the wetland diverted to produce 105 MW of hydropower through the Ithai multipurpose project of the National Hydroelectric Power Corporation. The vision to green the deserts of Rajasthan by diverting waters from River Sutlej and Beas through Indira Gandhi Canal was realized by constructing a diversion barrage at Harike over a large riverine marsh (Maitra 1987). The Quilon water supply scheme involved embanking the Sasthamcotta, a freshwater wetland linked with Kallada River, to supply water to Kollam City, an important centre of spices trade in Kerala (WISA 2017a). The planners of Kolkata saw the vast saline marshes on the eastern margins of the city as a safe place to discharge sewage and in the process laid the basis of world's most extensive sewage-fed fishery system (WISA 2020). The famed backwaters of Kerala, the Vembanad, were split by Thaneermukkom, a barrier to retain freshwater and enable its availability to Kuttanad, the rice bowl of Kerala. Kuttanad itself emerged out of polderization of floodplains (James et al. 1997).

The impact of water resources development projects, coupled with linked developmental changes in the catchments, has been highly adverse in many cases.

Harike has emerged as a large silt trap and, coupled with continued discharge of pollutants from upstream townships brought into Harike by Rivers Sutlej and Beas, has been perennially infested with water hyacinth (Singh et al. 2020). Regulation of water for hydropower in Loktak has converted a naturally pulsating wetland into a reservoir, causing loss of migratory fisheries and severe degradation of the habitat of globally endangered deer species, *Rucervus eldii*, which inhabits the wetland (Trisal and Manihar 2004; Tuboi et al. 2018). In Vembanad, the changes in hydrological regimes have led to a loss of migratory fish species, concentration of pollutants and reduced flood buffering capacity of the estuary (James et al. 1997; Kumar et al. 2013). As water abstraction has exceeded the availability in Sasthamcotta, the wetland has faced bouts of prolonged drying (WISA 2017a).

In the last six decades, India has become the largest groundwater user in the world, accounting for nearly 65% of the country's gross irrigated area, abstracted collectively from $\sim$30 million wells, bore wells and tube wells (Kulkarni et al. 2015; Smilovic et al. 2015). This trend emerged in the sixties, wherein the use of mechanized pumping technologies made groundwater extraction in large quantities possible, also matching the advent of Green Revolution, which created a high water demand for irrigating the high yielding variety crops (Shah et al. 2012). Rapid expansion in groundwater use for irrigation and drinking water purposes has been encouraged by several factors such as flexibility and timeliness of water supply, the poor service delivery of public water supply systems, newer pump technologies increasing affordability of sinking and operating a tube well, and government electricity subsidies, which shielded farmers from full cost of pumping (The World Bank 2010; Shah et al. 2012). The current situation of groundwater is alarming, with falling water levels and reduced well yields in several parts of the country (Tiwari et al. 2009; GoI 2019a), mobilization of heavy metals from deep aquifers (Kulkarni et al. 2015), inequity of endowments and an invidious nexus of mutual dependence between water, food and energy (Shah et al. 2012; Kulkarni et al. 2015). The creation of a 'water-scavenging' irrigation economy (Narayanamoorthy 2007; Shah 2009) has also meant reduced relevance of gravity flow irrigation from surface storages such as wetlands (Shah 2012). For groundwater-dependent wetlands such as those prevalent in northern India, lowered water levels and fragmentation of river connectivity led to shrinkage in natural inundation regimes. The declining significance of tanks meant they were allowed to decay, silted and at many instances constructed upon (Narayanamoorthy 2007).

Water resources development efforts have singularly focused on freshwater, and thereby water and sediment regime needs of coastal ecosystems have been comprehensively compromised. In several mangrove areas, reduction in freshwater inflow has been identified as a significant causative factor for an increase in salinity resulting in reduced habitats of salinity-sensitive species and dominance of high salt-tolerant ones (Kathiresan 2010; Giri et al. 2014; Gnanappazham and Selvam 2014; Sathyanathan et al. 2014). Estuaries such as Ashtamudi (Kerala) are gradually progressing towards hypersaline conditions, with reduced productivity and a high degree of transformation in species assemblages (WISA 2017b). Shrinkage of deltas due to sediment deprivation has been observed as a significant challenge in almost all parts of the globe (Syvitski et al. 2009), such trends having been noted in the deltas of Ganga (Ramesh et al. 2019), Mahanadi (Bastia and Equeenuddin 2016), Godavari and Krishna (Nageswara Rao et al. 2010). The resulting shoreline erosion is one of the factors inducing investment into concrete shoreline protection measures, which have their adverse impacts on the coastal environment.

There has been a renewed interest in revitalizing tank systems to support local water security. In June 2005, a pilot scheme for the restoration of water bodies was initiated by the Ministry of Water Resources, which has since been upscaled into a full-fledged scheme by the title ‘Repair, Renovation and Restoration (RRR) of Water Bodies’ since the 12th National Plan period to create 2.1 million ha irrigation potential (GoI 2017). As per data retrieved on RRR dashboard at the time of writing this chapter, the programme had covered nearly 2300 water bodies in 12 states, restoring 1.09 km^3 water storage capacity at a total cost of Rs. 19.6 billion. A midterm analysis of Mission Kakatiya, a programme of Government of Telangana to restore over 40,000 derelict tanks in the states, has indicated a positive impact on water availability, groundwater recharge and farm economics (Shah et al. 2017), and also recognized as good practice by India’s national policy think tank—NITI Aayog. Similar programmes have also been launched in several other Indian states.

In summary, the supply-side hydrology, which characterized water sector for a large part of the nineteenth and twentieth century, has tended to overlook the role of wetlands and, at several instances, in an attempt to ‘develop’ these ecosystems on the lines of other water resources projects, created several adverse ecological and socio-economic consequences. Growing neglect of wetlands is reflected in their extensive conversion, physical modification and pollution. However, the value of some wetlands such as tanks as freshwater stores is increasingly being realized in recent times, and efforts are underway for their revival. Some assessments even indicate the positive impacts on groundwater conditions in southern parts of the country in response to such measures (Bhanja et al. 2017), when implemented as a part of broader management measures.

4 Inclusion of Water Management Dimensions in Wetlands Management

Unlike the water sector, wetlands management is of recent vintage, emerging globally around the 1950s over concern for the declining population of water birds in Europe and North America (Gopal 2003). Designating wetlands of high ornithological values as protected areas under colonial laws, and post-independence, under Indian Wildlife Protection Act, 1972, was the primary approach for, as can be discerned from the closure of Vedanthangal, Keoladeo, Khijadiya and Ranganathittu bird sanctuaries or wilderness areas (Kumar 2019).

India’s ratification of Ramsar Convention in 1982 and creation of the Ministry of Environment and Forest in 1985 (from a Federal Department of Environment in

1980) provided the necessary backdrop for the establishment of a national programme on wetlands, which was launched in 1986 for assisting state governments for implementing management plans for prioritized wetlands (MoEF 1992). Subsequently, separate programmes for urban wetlands and mangroves and coral reefs were carved out from the national programme to focus on the issues of urban pollution and increasing vulnerability of coastal wetlands (DasGupta and Shaw 2013). The national wetlands programme is currently known as the National Programme for Conservation of Aquatic Ecosystems (NPCA) and has subsumed the programme on urban wetlands (MoEFCC 2019). As of December 2019, over 250 wetlands have been covered under these national programmes, majority being protected areas, designated for biodiversity values, primarily water birds.

The science base on wetlands, as in Europe, emerged from surveys on wetlands biota. Bird-ringing programmes were initiated as early as the 1920s, highlighting the ornithological value of wetlands (Balachandran 1998). Towards the 1940s, ecologists deepened the science into examining the role of sediments and hydrological regimes in influencing vegetation and other biota (Michael 1980; Gopal 1998). Post-independence, with establishment of CIFRI and launch of International Biological Programme, more focus on ecosystem processes such as primary production and energy dynamics came in, and pollution garnered interests of researchers in the 1970s, concurrently with Government of India enacting the Water (Prevention and Control of Pollution) Act in 1974 and Central and State Pollution Control Boards being established. Long-term ecological studies in Keoladeo National Park (Bharatpur, Rajasthan) were perhaps one of the early ones to start quantitatively defining water regime requirement of wetlands, though the assessments were only based on habitats of select water bird species (Vijayan 1991).

Towards the 1990s, as the MoEFCC's national wetlands programme started gaining strength and increased emphasis was placed on integrated management plans taking into account their catchments, water balance studies began to be taken up (NIH 1999, 2000). This was also the period when the impact of water resources development projects and land use changes on wetlands started garnering the attention of researchers. In Keoladeo National Park, one of the prime water bird habitats in eastern Rajasthan, construction of Panchana Dam over Gambhir River upstream of the park, increasing demand of water for irrigation in the upstream reaches and increasing variability of rainfall exposed the wetland to risks of prolonged drying and depleting water bird population leading to an intense water conflict between allocation for wetland versus irrigation needs (Chauhan 2006). In Loktak, construction of Ithai Barrage was identified as a causative factor for wetland degradation, particularly habitat of globally endangered ungulate species, *Rucervus eldii* (Trisal and Manihar 2004). In Chilika, Odisha, changing hydrology due to reduced connection with the Bay of Bengal was pitted as a significant causative factor for the decline in fisheries and progression of the estuary towards a freshwater-dominated state (Kumar et al. 2020). Impact of freshwater flow reduction on mangrove species diversity in Sunderbans, West Bengal (Gopal and Chauhan 2006), and Pichavaram, Tamil Nadu (Sathyanathan et al. 2014), was also brought to fore. Elsewhere, the impacts of the transformation of wetlands by altering natural hydrological regimes were highlighted, for example, in Kolleru (Andhra Pradesh), wherein the natural flood buffering function was lost to aquaculture (Sellamuttu et al. 2012). During the late 1990s, projects on Chilika, Bhoj and several other urban wetlands were framed on Integrated Lake Basin Management Framework, which was also adopted as an implementation framework for restoration of urban lakes (Nakamura et al. 2007; MoEF 2008a).

Despite the emerging evidence base on the adverse impacts of hydrological transformation on wetlands, integration of wetlands into water resources planning and decision-making has hit several roadblocks. The assessment of environmental flows for Chilika stands out possibly as the only positive example, wherein operational rules of Naraj Barrage at the head of Chilika catchment were formulated considering freshwater needs of the lagoon, and a river basin-level monitoring of hydrological regimes has formed as part of wetland management strategies since 2000 (The World Bank 2005; Kumar and Pattnaik 2012). In the case of Loktak, despite over a decade of assessments and identification of a framework for revising operations of Ithai Barrage to secure Loktak ecosystem, implementation is yet to take place (WISA 2011). For Vembanad, many assessments have indicated options for revision of Thaneermukkom to benefit the wetland environment, as well as address needs of farmers and fishers, and actual change of barrage operation is yet to take place (Kumar et al. 2013).

The network of wetlands prioritized by states for conservation has often included hydraulic structures, as over time their biodiversity values were recognized beyond their role as a water resource. For example, the water bird diversity and numbers in Hirakud Reservoir at present are next only to Chilika (WISA and CDA 2015). Bird surveys in Pong Reservoir indicated that species diversity had considerably increased after the construction of the reservoir (Pandey 1993). The list of 37 wetlands designated by India as Wetlands of International Importance includes 17 reservoirs and barrages. The management arrangements of such hydraulic structures have had to make necessarily incorporation of ecosystem requirements (such as water needs for maintaining water bird habitats), which is an indication that cooperation between the two sectors is indeed possible.

In summary, wetlands conservation in India has been structured around a network of sites. Over time, the narrative has shifted from a concern for species, mainly water birds, to a role in maintaining water and food security and buffering extreme events such as floods. There has been considerable progress in recognizing the role of hydrology in wetland functioning and incorporating hydrological descriptions within wetland management plans. However, translating information on flows to achieving desired changes in water use and allocation practices within the river basin has been very difficult and, more often than not, highly contested.

5 Policy and Programming Synergies Between Wetlands and Water Management

Despite water and wetlands sectors having adopted different development trajectories, there also exist several policy and programming complementarities. The National Environment Policy of 2006 makes explicit recognition of wetlands as 'freshwater resources' and emphasizes integration of conservation and wise use of wetlands into river basin management involving all relevant stakeholders (MoEF 2006). India's National Wildlife Action Plan (2017–2031) identifies conservation of inland aquatic ecosystems as one of the 17 priority areas and envisages development of a national wetlands mission and a national wetlands biodiversity register (MoEFCC 2019). Mainstreaming the full range of wetlands ecosystem services into developmental planning is listed as the objective of the National Wetlands Programme (MoEFCC 2019). In 2017, the MoEFCC notified the Wetlands (Conservation and Management) Rules, 2017, under the Environment (Protection) Act, 1986, wherein state wetlands authorities have been constituted as nodal policy-making, programming and regulatory institutions for wetlands in the state. The structure of the authority includes representation from all sectors, including water resources, thus providing a platform for balancing diverse sectoral interests related to wetlands.

Likewise, integration of wetlands in river basin management has been identified as a strategy for the management of river systems (MoWR 2012). The National Water Policy recommends adoption of a basin approach for water resources management and identifies conservation of river corridors, water bodies and associated ecosystems as an essential action area (MoWR 2012). The guidelines on Integrated Water Resources Management issued in 2016 by the Central Water Commission recommend using water balance as a basis for planning at basin level and ensuring that upstream and downstream impacts are taken into account (GoI 2016). The National Action Plan for Climate Change includes wetland conservation and sustainable management in the National Water Mission and the Green India Mission (MoEF 2008b). The National Disaster Management Plan takes into account several non-structural measures for flood and cyclone risk reduction measures and makes direct reference to wetlands (NDMA 2019). The national indicator framework for monitoring implementation of Sustainable Development Goals provides a mapping of various sectoral programmes towards assessing country's progress on sustainable development goals (MoSPI 2015) and makes several references to integrated management of wetlands and water resources.

The nature of water sector challenges that India currently faces is complex—water demand outstrips supply in several basins, rampant aquifer depletion prevails, economic development driven by urbanization and industrialization is altering water use and efficiency by several proportions while creating water quality issues, and water conflicts have become more endemic (World Bank 2005, 2010; Molle et al. 2010; Cronin et al. 2014). Future climate change projections for the country indicate increasing variability of precipitation, run-off and extreme events, and several other changes further exacerbating water risks (GoI 2018b). The stationarity view that serves as the foundation of much of water resources planning, using assumption that hydrological variables can be described based on time-invariant probability distribution functions, is being increasingly challenged in the context of climate change-induced uncertainties and risks (Milly et al. 2008). A business-as-usual approach to water management, based on only conventional grey infrastructure solutions, will be highly insufficient in the current contexts.

The discourse on water has greatly matured, from a recognition as a vital resource and economic good as per Dublin Principles in 1992 to being the 'bloodstream of the biosphere' determining the sustainability of living systems (Ripl 2003). The water resources thinking has gradually broadened in the last four decades from run-off-based management to precipitation-based water management incorporating land use, focusing on multiple scales and integrating role of ecosystems in water resources management (Falkenmark and Rockström 2010). A widened green–blue approach to planning (partitioning rainfall into a green water resource as moisture in the unsaturated zone and a blue water resource in aquifers, wetlands and water impoundments such as dams, which subsequently generate flows, as green water flow from evaporation and transpiration and blue water flow including river and groundwater flows) and understanding their functions in the water cycle (regulation, production, carrier, maintaining ecosystem state) has been posited providing system view to build resilience against state shifts and tipping points which can be triggered through salinization, terrestrialization of aquatic habitats, desertification, basin closure, aquifer depletion, waterlogging and ecosystem collapse (Falkenmark and Rockström 2006; Falkenmark et al. 2019). In an era of increasing water variability and extreme events, it is argued that stationarity-based water allocation approaches may need to graduate to one that focuses on building resilience, especially preventing breaching of thresholds, which can shift water systems and society to alternate and often undesirable states (Boltz et al. 2019; Falkenmark et al. 2019; Rockström et al. 2014).

A major emphasis on water management in India has been on harnessing blue water, the run-off, using inflexible infrastructure managed often on rules determined on historical hydrological observations—which are found wanting in the face of extreme events and uncertainties imposed by climate change. A widened focus on building water system resilience considering the entire blue–green water interactions allows for addressing the inherent inflexibility of hard engineering infrastructure by bringing in the role of green infrastructure solutions which use natural or semi-natural systems to provide water resources management options (UNEP 2014). Nature-based solutions, which are inspired by nature, and use or even mimic natural processes to contribute to improved water management are at the heart of green infrastructure solutions (Nesshöver et al. 2017). These solutions include wetlands conservation and rejuvenation, and wetlands-based technologies such as constructed wetlands to address various water management issues. A preliminary mapping of suitability of wetlands solutions for different biogeographic zones of India is presented in Table 1.

Table 1 Potential for wetlands rejuvenation and conservation as green infrastructure solutions for water management issues in different biogeographic zones

Biogeographic zones	Water management issues					
	Water supply	Water purification	Erosion control	Flood control—riverine	Urban stormwater run-off	Coastal storm surges
Trans-Himalayas	+++					
Himalayas	+++	+	+		+	
Gangetic plains	+++	+++	+++	+++	+++	
Semi-arid	+++	+++	++	+++	+++	
Desert	+	++	+	+	+	
Western Ghats	+++	++	+	++	+	
Deccan Peninsula	+++	+++	+	++	+++	
Coasts	++	++	+++	+++	++	+++
Islands	+	+	++			+++

(+++ = highly relevant, ++ = relevant, + = somewhat relevant: the degree of relevance is based on the available knowledge on wetlands extent and wetlands function with respect to specific water management objective)

6 Some Integration Bottlenecks and Challenges

Integration of wetlands in water management plans cannot be treated as an additive process, wherein the policies and programmes of wetlands and water sector are simply joined together, but require a more sophisticated and nuanced, collaborative and beyond sectoral disciplinary approaches (Bracken and Oughton 2006). The issue at hand is not just about connecting two different policy areas at a single hydrological (catchment) or administrative (district) scale. Given the pervasive uncertainty (such as the manifestation of climate change on wetlands functioning as well as on extreme hydrological events, such as floods and droughts) and contested knowledge claims (such as increased need for hydrological regulation is required to address variability), the difficulty of joined-up management of wetlands and water cannot be overcome by policy and programme actors acting in isolation. The role of collaborative governance solutions is crucial for addressing challenges associated with building coherent conceptual and methodological narratives (such as wetlands degradation not just seen as tantamount to loss of critical ecosystem services, but reduced landscape resiliency to increasing water risks), and developing approaches for joint working that have potential to transform, rather than simply reaffirming segmented ways of research on natural systems and landscapes. We discuss in this section the science, policy and practice bottlenecks that hinder adoption of integration of wetlands in water management.

6.1 Multiplicity of Wetland Definitions and Management Approaches

There is a multiplicity of definition and interpretation of wetlands used by different ministries of the Government of India. The MoEFCC subscribes to the wider definition of wetlands as agreed to in the text of Ramsar Convention, yet operates multiple schemes to fund conservation of different wetland types. While the NPCA guidelines call for catchment scale planning for wetlands (MoEFCC 2019), the guidelines for management planning for protected area (Sawarkar 2005) used as a reference for wetlands designated as of location within the protected area network underplay the role of hydrological regimes and catchment scale processes. The Ministry of Jal Shakti on the other hand distinguishes between wetlands and water bodies. The National Water Policy of 2012 mentions wetlands only once, together with water bodies, with restoration efforts recommended to be directed to the latter (MoWR 2012). The manual prepared for census of water bodies uses a diffuse definition and indicates these entities to be any area of water, salty or fresh, large and small, distinct from one another in various ways (GoI 2018a). The minor irrigation census includes only those water bodies which are used for storing water or other purposes, and excludes lagoons, mangroves and other coastal systems (GoI 2018a). The Water Resources Information System of the MoWR includes information on water bodies and does not use the term wetlands at all. The Department of Land Resources of the Ministry of Rural Development in their inventory of wastelands includes several wetland categories (such as waterlogged and marshy land, land affected by salinity, sands coastal and snow glacier-dominated areas), but excludes water bodies (GoI 2019b).

6.2 Limited Effort to Translate Information on Wetlands Structure to Wetland Functions

For wetlands to be considered within water resources planning and decision-making, an inventory which renders an understanding of how wetlands function and deliver their hydrological functions may be more relevant, using approaches, such as hydro-geomorphic classification of wetlands (Brinson 1993). The classification used in wetlands inventories prepared by the MoEFCC is based on a mix of parameters, key being morphology, vegetation and inundation (Panigrahy et al. 2012; Garg 2015). This information is useful to give a broad understanding of wetlands structure and key influencing ecosystem processes. The inventory of water bodies under the irrigation census or water resources information system does not dwell much on types and instead looks at their use and water source. Inventory of water bodies prepared for use in water resources planning such as the minor irrigation census or river basin atlases tends to obfuscate wetlands types clubbing them into ecologically meaningless categories.

6.3 Simplistic Extrapolation of Wetland Functioning

The hydrological functions of wetlands are often communicated in generic terms based on simplistic extrapolation of site and wetlands-specific evidence into more generalized statements which give an impression that all wetlands perform similar hydrological functions in all landscape settings (this issue has been aptly highlighted in McCartney and Finlayson 2017). The ability of wetlands to moderate flow regimes is closely linked with soil condition, in particular, the extent of saturation and relative location within a landscape (Bullock and Acreman 2003). Wetlands located in highly saturated headwaters may become a source of floods, rather than acting as a sponge, as is widely believed (Acreman and Holden 2013). In similar lines, there are nonlinearities in storm surge buffering capacity of mangroves, and extreme events with very high water levels and wind speed may actually end up damaging and even destroying mangroves, thus rendering their coastal protection value less effective (Narayan et al. 2016). Knowledge of how wetlands function within a landscape and deliver their hydrological buffering services is crucial for managers and policy planners to pursue integrated approaches (Thorslund et al. 2017).

6.4 Wetlands as 'Water Users'

Evapotranspiration usually forms a significant component of water budget of wetlands, and from the water resource perspective, it is often considered as a 'water loss'. The subcommittee on surface water management in its report for formulation of National Water Mission places water use in wetlands to be amongst the highest amongst all options, compared with irrigated agriculture (GoI 2008). Such a fragmented view of water misses the point that water flowing through wetlands provides the wide-ranging ecosystem services such as food production and climate regulation, and thereby the disjunct between run-off and evapotranspiration is actually about the role of water in meeting human needs through built infrastructure and natural infrastructure. It is the complementarity and coupled nature of water whether it is available as a run-off, or moves through ecosystems in an evaporated form that enables delivery of different functions of the water system.

6.5 Capacity Gaps

Cooperation between water and wetland management sectors is often limited due to inability to describe, quantify and communicate interests, objectives and operational requirements. Wetland managers need a sufficient understanding of the technical and operational aspects of water resources management to understand the methods of articulating and quantifying the requirements of wetland ecosystems in metrics and parameters used by water managers. Further, they also need to know the mechanism of working with water managers to be able to define operating rules and flow regimes that represent the optimal allocation of water between multiple uses, including ecosystem maintenance. Similarly, water managers require a quantitative understanding of the hydrological services of wetlands and the water regime required to maintain these services. The training systems and institutions for water and wetlands hardly overlap, and thereby, siloed thinking on water and ecosystems prevails and is frequently contested upon in policy and programming decisions. With climate change as a pervasive issue across several sectors, conventional training may be insufficient. For wetlands managers, water allocation decisions for restoration determined using historical hydrological regimes may be rendered unfeasible objectives under climate change, and the emphasis on species-focused water allocation may need to include ecosystem functions and services (Capon et al. 2018).

6.6 From Balancing Water Uses Across Sectors to Addressing Water Risks

While the practice guidelines within wetlands are built around the assumption that integrated water resources management provides the necessary policy and programming platform, its realization in India has been contested given the wholesale reforms needed, especially demand management in informal arrangements (Shah and Koppen 2006). While the emphasis on integrated water resources management has been continued in water sector policies and programmes, full-scale realization may be distant, also given the complexities induced by climate change (Moomaw et al. 2018). Increasing variability in water availability and extreme events may need focusing on water risks and water system resilience building, rather than focusing on water allocation challenges.

7 In Conclusion

India's quest for sustainable development is closely hinged on achieving water system resilience. The historical divide between water and wetland sectors, if it has to be paraphrased, is one of viewing water more narrowly from where it can be used, against a fuller understanding on how water moves in a landscape and performs various developmental and ecological functions shaping resilience. Water resource challenges that India presently faces are not limited just to water allocation for various uses but are also about balancing water for food, development, nature and society. The current paradigms of managing water from where it is sourced (surface water or groundwater), where it is used (agriculture, water supply, hydropower and others), technology (dams, reservoirs, canals and tanks) and social equity (the share of accessible water to a particular societal group and geography), preclude a unified vision of water. Given the coupling between land use and water use decisions, the need to widen the scope of integrated water resources management to include land management aspects is pertinent. With wholesale reforms as required to realize integrated water resources management being a difficult terrain, a beginning can be made by thinking on specific issues and challenges, such as managing floods and droughts, or improving water use efficiency in food production.

Integration of wetlands in water management plans is also not about pitting grey and green infrastructure, but achieving complementarities and synergies. While making water infrastructure decisions, a beginning can be made by examining whether green infrastructure solutions such as wetlands can deliver the desired water resource outcome, and then filling the gap that may still exist by a grey-green combination. A harmonized understanding of wetlands and their hydrological functions in a landscape is the foundation step. The science base on wetlands will need to graduate from being dominated by describing ecosystem structures and processes to providing quantitative assessments of hydrological functions, in usable forms and terms suited to water sector policy-makers. Wetlands managers will also need to have the capacity to describe water regime requirements of wetlands to perform these functions while acknowledging that climate change may render historical regime information insufficient to inform about the future course of actions. For water managers, the role of wetlands will need to evolve beyond just an allocation decision, to understanding water as it moves in a landscape, and the role wetlands play in influencing this movement. A natural convergence point is to plan at a catchment scale, wherein the landscape and water interactions can be assessed and planned for meaningfully.

With water sector going through a significant reorganization, an important question to ask is whether wetland management will be better off if brought within administrative frame of the former? The answer, unfortunately, is not a black-and-white one. In case water sector continues its focus on water storages, such a move may be highly retrograde, as only few wetlands and a narrow set of ecosystem functions of wetlands are likely to be considered. On the other hand, when located within the stable of MoEFCC's programmes, wetlands become a silo of their own and get relegated to one of the several sectors that water planners need to consider and provide for in allocation decisions. The answer, perhaps, lies somewhere in between; placing wetlands in either sector does not matter, till the full ranges of ecosystem services and biodiversity values of wetlands are considered and secured in developmental planning and decision-making.

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