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Environmental Perspectives of Pond Ecosystems: Global Issues, Services and Indian Scenarios

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ABSTRACT

Ponds are an integral component of the hydrological system; and perform diverse roles in the biosphere. Studies on pond ecosystems are, however, often neglected, probably, due to their little size. There is no doubt that little things perform many important activities in our lives. The literature survey on pond environment studies shows very little investigative works in India; and there is no review publication on pond environment reports. In Europe, pond conservation initiative has, however, resulted in many studies on the subject. In Indian perspectives, when there is a dearth of studies on ponds, it is futile to say that there is any concrete institutional initiative on pond conservation. The 2010-2011 report of the Central Pollution Control Board (CPCB) shows that there are only 60 CPCB pond water quality monitoring stations in the country. In these scenarios, an attempt has been made in this manuscript to compile the reports on pond environment in India. The problems faced by ponds in India, mostly from pollution and encroachment, have been discussed in the text. Based on outcomes of different pond reports, some suggestions have been discussed in the end of the manuscript for an effective pond conservation initiative, and their sustainable management in India.

Key words: Pondscape Biodiversity; Pond Conservation; Pond Environment Monitoring; Pond Water Pollution; Wetlands**.**

INTRODUCTION

It is misleading to label small water bodies as unimportant and insignificant, because it is our common experience that little things carry more importance in our lives. However, it is not undeniable that small aquatic systems are taken as irrelevant to global problems and are ignored in nearly all globally important views and processes such as carbon processing and transport. Small water bodies are inherent part of the biosphere and the interconnected network of global metabolically active sites[1]. As quoted by Céréghino *et al.*[2] from the published literature of Downing *et al.*[3] — the number of ponds with size less than 1 hectare is around 277,400,000; and the number of water bodies in the range of 1 to 10 hectares is around 24,120,000. The estimate suggests that these water bodies represent over 90% of the planet's 304 million standing water bodies, which accounts for roughly 30% of the earth's standing water by surface area.

The global ecological roles of ponds and small lakes were reasonably explored by Downing[1]. The author precisely put forward the concept that little water bodies mean a lot to our global ecological system. The product of the amount of biosphere (areal extent across the earth) constituted by the ecosystem and the intensity of the process of interest within it, determine the global importance of that ecosystem. Ecosystem having a small areal extent can also play a major role in global ecological processes. The areal extent of continental waters is dominated by ponds and small lakes. These small aquatic ecosystem types disproportionately show large intensity of many ecological processes and

cycles. The intense activities and their dimensions make small aquatic ecosystems more dynamic in time when compared to large water bodies. Understanding of pattern of nutrients in pond water bodies, and other phenomena such as fluxes and conversions of important gases (for examples, N_2O and NH_x), and metal distributions improve understanding about the roles small water bodies play in global budgets in relation to nutrient, gas and toxins. This dynamic feature is unique component of the limnology of ponds which makes the understanding of their function, succession and origination indispensable.

Céréghino *et al.*[2] in their paper on "*the ecological role of ponds in a changing world*" discuss that the ponds provide sustainable solutions to major issues of water management and also environmental problems of climate change, such as, nutrient retention, rainfall interception, and carbon sequestration. Although ponds are small wetland features their ecological roles and landscape values are substantial. Ponds are an important freshwater habitat which, at landscape level, play critical role in maintaining biodiversity. However, they are also vulnerable to degradation[4]. With proper planning ponds can bring major benefits in terms of biodiversity, pollution alleviation, flood relief and climate change. At micro level they are remarkably cheap, and easy to make, manage and protect. Moreover, the pond's ecosystem connects directly with the community people. Ponds, which maintain cultural and economic resources, are increasingly becoming threatened freshwater habitat[5]. Proper pond water management can mitigate climate change impact; provide water for recreation, irrigation, and livestock watering; alleviate flooding; reduce diffuse pollution from intensive agriculture and urban run-off, recharge aquifers, and capture heavy rainfall event[5]. Processes that are most active in small water bodies have global significance and therefore their role and contribution in global ecosystem processes should be emphasised[3]. Ponds with better water quality are economically desirable[6].

In recent years, the scientific reports on large water bodies, especially rivers, have increasingly gained momentum in India (see recent review work of Manoj and Padhy[7]). Literature survey, however, reveals very little investigative reports on environment quality, and also disappearance, of ponds in India. In the absence of any review work on pond environments it is hard to arrive scientifically at their current status in India. Through this communication, we have made a preliminary attempt to compile the fragmented reports on ponds to explain their present state of affairs in India. In the beginning the manuscript deals with some important global services performed by the ponds to emphasise on their research significance; and then various environmental issues which impact pond environment. Recent National Water Policy emphasis on ponds in India has also been analysed in the text, followed by discussion on position of pond environment in India and their conservation and management options.

Safeguarding global water ecosystems

To achieve the United Nations Sustainable Development Goals (SDGs) it is essential to safeguard the planet's water resources. Water is the 'critical thread' through each of the 17 SDGs as water is central to our lives and livelihoods which include food, health, and productive economy. In fact, the water is central to all those species that depend on it. To secure our future economy and wellbeing it is critical to have a reliable, consistent and uninterrupted supply of water. By the year 2030 AD our need for water is expected to increase by 30%. It should be noted that water doesn't only supply, in fact, it also performs. A healthy aquatic ecosystem functions as a natural infrastructure (for example, wetlands act as natural filters for toxins). The water ecosystems provide water infrastructure services for free, and, therefore, it has been estimated that the global economy could save US$ 29 trillion by safeguarding these ecosystems[8]. It is crucial to realise that ecological/ ecosystem security is an essential prerequisite for human and water security. Demands for water have accelerated in recent decades because of escalating population size and unsustainable consumptions and production patterns. In the competition for water, the biggest losers are ecosystems and biodiversity. The degradation of ecosystems and biodiversity causes decline in their ability to provide resilience to the biosphere. This leads to biotic communities and human health to suffer[9].

Definitions of pond in literature

The word 'pond' has its origin from the word 'pound' which means a confining enclosure. This denotes that water is enclosed in a pond[10]. There are many definitions of ponds based on criteria such as presence of wave action, occurrence of rooted macrophytes, or light penetration[11]. However, none of these are satisfactory in the context of its reliability and ease of measurement. Biggs *et al.*[11] describe ponds as water bodies with an area between 1 square metre and 2 hectares (20,000 square metres), which may be seasonal or permanent, including both natural and man-made water bodies. Dubey[10] in a published literature entitled "*the biodiversity of the ponds*" explains many existing criteria to describe ponds — for examples, International Ramsar Wetlands Convention sets 8 hectares as the upper limit of the water body to classify as a pond; some regions of the United States classify pond as a surface water body having surface area less than 10 acres (≈ 40,000 square metres); and many European Biologists adopt upper limit of pond as 5 hectares. Thus, there exists no universal agreement on the definition of the term pond[5]. In simplest terms, ponds can be defined as a body of standing surface water either natural or man-made (artificial) which is quite smaller than a lake[10].

Ponds as instruments for water security

Ponds are a major asset which provides enormous opportunities in water security sector[5]. Climate change is likely to amplify rainfall variability in many places, even in those places where the total amount of rainfall increases[12]. Even high rainfall areas encounter water scarcity problems during non-rainy months[6]. The change in rainfall pattern will affect all important water sources. For example, increase in variability in recharge of groundwater. To deal with this variability, water storage, even on relatively small volume scales, provides a suitable mechanism to strengthen water security, agricultural production, other economic growth and adaptive capacity. To safeguard livelihoods and to reduce poverty level, especially in rural areas, water storage can make substantial contribution. During dry periods small volumes of stored water can safeguard domestic supplies and provide support to crops and/or livestock. Ponds are one of the possible water storage options. They store relatively small volumes of water but are often vitally important. Interventions employing small scale water storage options, with proper planning, can contribute significantly to both food security and rise in economic prosperity of the community at the local level[12]. Protection and creation of ponds should be a part of the important policy decisions for the management of the agricultural landscapes[13]. These small water resources are being increasingly appreciated as a significant contributor to the development of local communities, especially lower income households, even in urban and peri-urban areas. Because ponds are special components of urban water resources, their proper sustainable management is absolutely necessary[6]. Construction of strategically located pond networks can significantly reduce water loss by capturing water of a heavy rainfall event before they become a problem[2]. They are essential receptors for harvesting rainwater and in maintaining groundwater levels[6].

Ponds as biodiversity hotspots

Ponds are common landscape elements which play important role in the global processes of biosphere and preservation of biodiversity[14]. The roles of ponds in supporting aquatic biodiversity are just as important as rivers and large lakes[13]. They provide unique habitat islands for a diverse range of aquatic species[15,16]. Researchers have ascertained that ponds are important biodiversity hotspots both in relation to species composition and biological traits, and they play significant role in terms of providing ecosystem services[2]. Ponds located even in close proximity to each other display quite different hydrologic behaviour, exhibiting different pond types and different environment associated with each pond[17]. Small water bodies display a broader range of physicochemical characteristics than rivers and large lakes. This is because small water bodies, such as ponds, are more easily formed in a variety of landscapes. Local conditions which include geology, altitude and land cover of the catchment area greatly influence characteristics of the ponds. Moreover, these water bodies are fed from small catchment areas. Thus, ponds tend to show different characteristics in a region, even if they are relatively close to each other[13]. Terrestrial biota also benefit from the high productivity of ponds. There are numerous instances of interactions at the aquatic-terrestrial interface[2]. Thus, ponds not only enhance biodiversity of aquatic organisms, but

also of terrestrial organisms that directly depend on aquatic ecosystems[14].

On the scale of regional diversity, a network of ponds shows greater contribution as compared to lakes or rivers. Research indicates different ecological characteristics of ponds from other inland surface water systems[14]. The number of macro-invertebrate species is found more in ponds than rivers as a whole. In comparison to lakes, ponds support similar number of wetland plants. In terms of regional diversity, however, farmland ponds display greater contribution than other water habitats including rivers[11]. Both individual sites and pond networks carry importance for biodiversity. Single ponds can play roles as biodiversity hotspots as well as refuges for both aquatic and terrestrial biota, especially within landscapes which are intensively farmed. Pond networks are a crucial part of the habitat of amphibians, fish on river flood plains, many wetland plant species, and for wetland mammals and avian fauna that cover a range over large areas[4].

Ponds have a small catchment size than rivers, lakes and streams. This physical feature confers both benefit and disadvantage to ponds with respect to their protection. When ponds are severely exposed to environmental impacts they become highly vulnerable to degradation, due to surface water pollution, because of their small volumes. In case of ponds the possibility of buffers or dilution of pollutant impacts is little as compared to rivers and lakes. Thus poor quality ponds suffer degradation to an extreme level which is infrequently seen in large water bodies. In a different perspective, however, ponds can be of outstandingly high quality with complete protection from land derived pollutants due to their small catchments. This feature is rarely seen in rivers and lakes which are often exposed to a great variety of pollutants and other degrading factors due to their much larger catchment areas. Widely degraded landscapes, due to human activity, sometimes show near-pristine ponds. This beneficial factor probably provides an explanation for relative richness of ponds as compared to large waters[11]. Another explanation could be that many aquatic processes, rates, and quantities are more abundant in ponds and other small water bodies, and show more intense and complex nature than in large water bodies. Thus, small aquatic systems are particularly well known for biotic complexity and richness[1]. A pond may show combinations of three different food web components: one based upon cyanobacteria and algae, another based upon large plants, and another based upon decayed plants. Thus, a pond may have many different types of food. The presence of this wide variety of food sources can be one of the reasons for the presence of a large number of species of animals in ponds[10].

Ponds as structures for carbon sequestration

Ponds provide sustainable solutions to problems such as climate change and management of scarce water resources[2]. Ponds have a significant role in the global carbon balance and amelioration of climate change[14]. Small water bodies can have an immense carbon processing intensity. These water bodies may be more heterotrophic than large ecosystems, processing considerable quantities of terrestrial or external carbon. Ponds tend to have low oxygen concentrations than large water bodies, which enhance their carbon sequestration capacity. Ponds and small lakes cover around one third of the area of continental waters which, in biosphere, may be the most important sites for organic carbon sequestration. Sediment organic carbon burial in small water bodies is more than large aquatic systems[1]. For example, the earth's farm ponds, because of their huge numbers[2], alone seem to sequester more organic carbon each year than what is done by the oceans and 33% as much as the earth's river systems deliver to the sea[1]. A single pond with an area of 500 square metres can sequester yearly around 1000 kg of carbon which is equivalent to the amount a car produces during the same time period[2]. Collectively ponds have more surface area than large lakes and they also store more carbon than the latter[14].

Ponds as pollution alleviation factors

Ponds can be used as sedimentation ponds and structures to control water quality[3]. Pond can remove diffuse pollutants including nitrogen, phosphorous, and sediments in surface waters and reduce the nutrient load of the receiving water bodies. In this technique, called nutrient retention, ponds are strategically located in such a way to intercept water from the drainage systems before they debouch into receiving water bodies[2].

Other miscellaneous services

Ponds also perform other beneficial effects such as regulating temperature and humidity (microclimate regulation). Although ponds are small, they maintain a connected landscape by constituting a series of vital stepping stones that run through the landscape as well as presenting a range of benefits to the surrounding ecosystems[14]. Ponds may modify the rates of groundwater infiltration and evaporative loss of water[15,16]. The actions of ponds are not limited to their local and regional scales. They are important beyond these boundaries as they contribute significantly in global biogeochemical cycles[14]. Ponds can be used as model ecosystems to test scientific theories in diverse areas such as ecology, conservation biology, climate change modelling and evolutionary biology[5]. The cultural and historical significance of ponds are profound because their sediment records can provide information about the lifestyle of our ancestors. They are crucial to maintain and encourage link between people and wildlife[10]. The ponds also carry immense recreational values.

Global environmental concerns of ponds

Pond habitats are of immense significance to human civilisation as they are sources of water for domestic, agricultural and industrial use, as well as providing food. Although fundamentally important to humans, the structure and function of these freshwater ecosystems are currently threatened by a multitude of human-disturbances[18]. Human induced developmental activities can deteriorate pond water quality due to accumulation of toxic chemicals (for example, pesticides from agricultural runoff) and sedimentation, rendering the use of ponds ineffective and risky[19]. Ponds are also impacted by excessive nutrient loading, degraded buffer zone and polluted inflows and atmospheric processes[5]. The accelerated evaporation of ponds is due to anthropogenic actions such as of sewage disposal, and fertilizer run-off from agricultural areas[20]. The ponds are more vulnerable to pollution loads, due to their small size which limits their buffering capacity, than large lakes or rivers. The artificial feeding of water fowl is also more likely to damage ponds than large water bodies[4]. Ponds are suffering loss from two accounts, namely, decrease in number and increase in pollution load. As the hydrological conditions govern the abundance and distribution of fauna and flora, species composition, in an aquatic system, deterioration in its water quality may disturb its ecological structure. Hydrological conditions of pond water also affect fish production, other aquacultural activities, and more important eutrophication process[21]. The most important anthropogenic disturbances which can impact ponds include enhanced nutrient enrichment (eutrophication); contamination by trace elements, organochlorines, and endocrine disruptors; acidification; invasion of exotic species; global warming and climate change[18]. A summary of current factors which are threats to pond ecosystems is provided in Figure (Fig.) 1.

The dynamics of ponds, as natural systems, are controlled by both abiotic and biotic components. The physicochemical characteristics of the specific water body collectively give rise to an abiotic frame where only those organisms containing a fundamental niche that suitably fits within this specific abiotic frame can have fitness to survive and reproduce. Within this abiotic frame, the biotic interactions taking place among the organisms further shape the community. The abiotic environment becomes drastically altered due to anthropogenic disturbances, in the form of outcomes such as acidification or eutrophication, which change the abiotic frame position. Consequently, the niche of many organisms will fall outside the abiotic frame and they will not be able to survive in the new system, causing a decrease in the number of species. The frame position will change in different directions on account of different disturbances, giving rise to different compositions of the resulting pond community. This may have dramatic impacts on the freshwater ecosystem functioning such as primary productivity, detritus processes, and transport of nutrients at the water-sediment interface and the food chain and food web. Habitat destruction in the form of activities such as drainage and land filling also affect ecosystem biodiversity[18].

The eutrophication causes reduction in water transparency; accumulation of dead organisms as sediment; reduction in oxygen level; and fish mortality. Thus, eutrophication causes substantial modification in the structure of water ecosystem, which in turn lowers the possibilities of using the waters for drinking water source, fishing and recreation[20]. Recent studies show substantial

number of degraded ponds. Strong negative relationship was obtained between potentially damaging environmental factors (such as nutrient loads and intensive land use) and species richness and rarity in the studies conducted on degraded ponds[11].

Table 1: State wise CPCB data showing % of observations violating desirable limits in pond waters

State	% observations violating desirable limits	
	DO	BOD
Andhra Pradesh	45	100
Assam	10	80
Bihar	0	50
Gujarat	13	25
Kerala	0	58
Odisha	0	83
Uttar Pradesh	25	50

Source: CPCB[9]

The changes become detectable in ponds when pH value reaches lower than 6. When acidification proceeds many flora and fauna become less diverse (although a few acid tolerant groups become high in number). The most important contaminants of ponds are trace elements (not broken) and organochlorine materials (degrade in a very long time). Some of these persistent pollutants accumulate in the food chain. These chemicals also bind to the particles of the water column and become part of the sediments. In consequence, bottom dwelling organisms are also exposed to these toxicants. These toxicants produce a number of negative impacts on normal physiological, biochemical and immunological processes of the organisms. The contamination of freshwaters by endocrine disruptors is an emerging area of environmental biology[18].

Decrease in freshwater biodiversity due to invasion of exotic species, by anthropogenic actions, is also a major environmental concern. The invader can drastically impact different organismal levels,

Table 2: Studies conducted on some pond water bodies in India

Study area/Name of ponds	Publication year	Authors*
Airongmara; Barak Valley, Assam	2007	Bhuiyan and Gupta[30]
Ayodhya-Faizabad region, Uttar Pradesh	2007	Chaurasia and Pandey[31]
Vadodara, Gujarat	2008	Soni and Bhatt[32]
Bilaspur, Chhattisgarh	2008	Shrivastava *et al.*[33]
Bhadra project, Karnataka	2010	Kiran[34]
Villages located in southern part of West Bengal State	2011	Mukherjee *et al.*[35]
Badrinath, Uttarakhand	2012	Kumar *et al.*[36]
Khajod temple, Surat, Gujarat	2012	Ekhalak *et al.*[37]
Pallippuram, Kerala	2012	Dhanya *et al.*[38]
Bhilwara, Rajasthan	2013	Tripathi and Chishty[39]
Urban Vadodara, Gujarat	2013	Tailor and Mankodi[40]
Tapti ponds, Madhya Pradesh	2013	Gajanand *et al.*[41]
Santiniketan-Bolpur-Sriniketan zone, West Bengal	2013	Manoj *et al.*[42]
Chidambaram, Tamil Nadu	2014	Elayaraj and Selvraju[43]
Khandwa, Madhya Pradesh	2014	Mahajan and Billore[44]
Varanasi city, Uttar Pradesh	2014	Mishra *et al.*[19]
Santiniketan area, West Bengal	2014	Nag and Gupta[21]
Erode city, Tamil Nadu	2014	Parithabhanu *et al.*[45]
Samastipur, Bihar	2014	Sinha *et al.*[46]

*The findings of the authors are discussed in the text

such as population and ecosystem levels, of the invaded ecosystem. Some of the consequences include alteration in population growth, density, distribution, community structure, nutrient dynamics, resource utilisation rates and physical habitat[18]. Ponds are vulnerable to introduction of invasive non-native species, particularly when they are present near to urban areas[4].

The global warming may induce changes in the abiotic frame of the freshwater ponds[18]. Ponds are sensitive to anthropogenic climate change through means such as shifts in ambient air temperatures and precipitation patterns. Shifts in air temperatures will impact pond water temperatures through convection process, and by altering rate of evaporation. Thermal mass of these small freshwater lentic systems will be altered due to shifts in precipitation patterns (timing, amount and intensity). Ponds are likely to suffer strongest from these effects because precipitation accounts for a large component of water inflows in them. Change in water temperature induced by thermal mass effects will alter a diverse range of 'population – and community – level processes' in

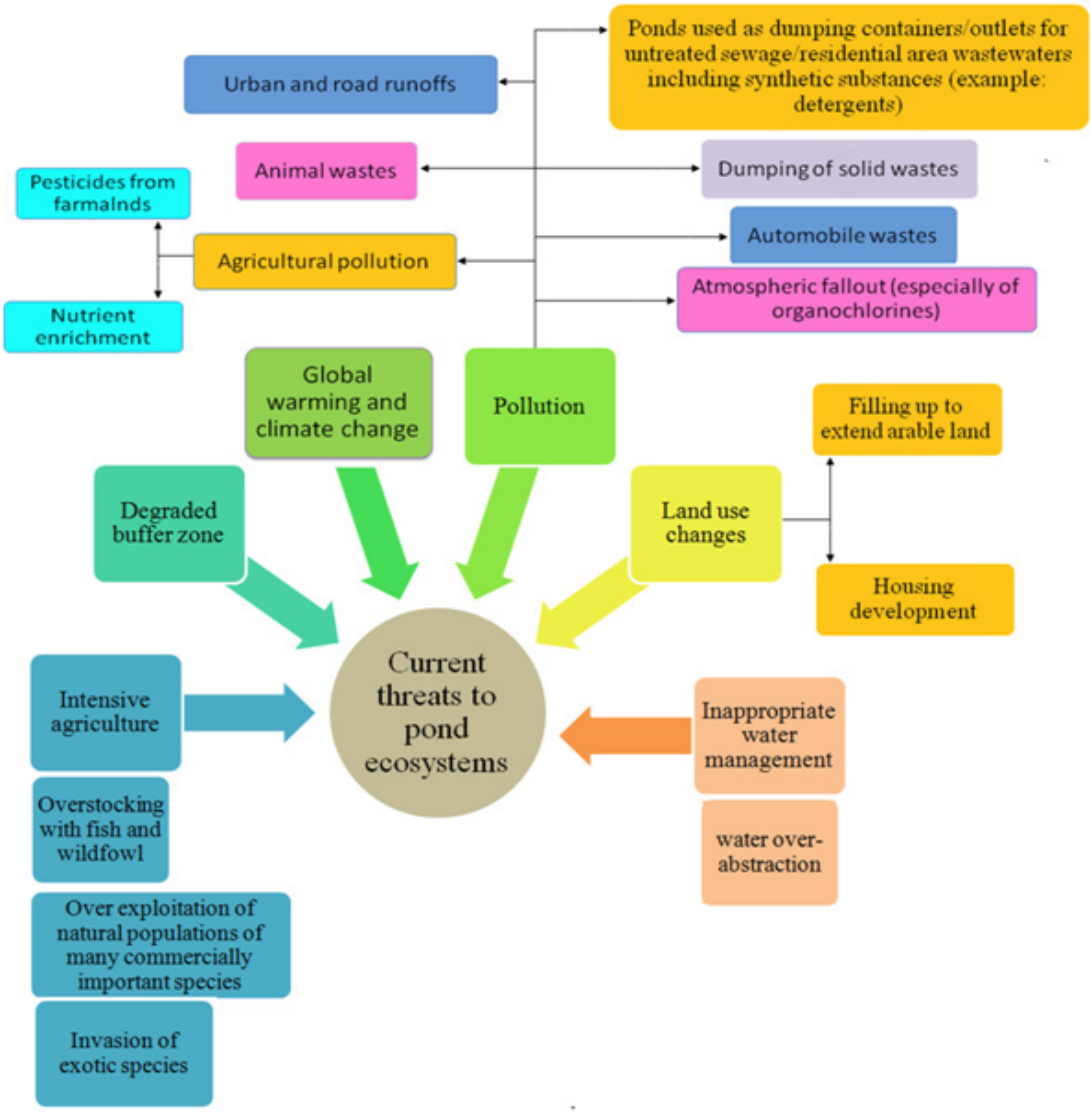

Fig. 1: A summary of factors which are threats to the functioning of the pond ecosystem; modified from EPCN[5]; Biggs *et al.*[11], and Brönmark and Hansson[18]

freshwater macro-invertebrates[22]. Water temperature is closely related to air temperature in freshwater sources such as shallow lakes and ponds, and most of the freshwater species are sensitive to temperature variation because they are scarcely able to regulate their own body heat[23]. It should be noted that the temperature affects physiological processes such as metabolism and developmental rates, and is of prime importance for the life history of the aquatic biota[18]. Temperature increase may also result in increase in productivity in freshwater systems, which may result in growth of unnecessary nuisance algae in them. Temperature increase will not only have direct effects upon freshwater species, the phenomenon, in fact, will have implications for a diverse range of temperature controlled physical, chemical and ecological processes[23].

Alterations in precipitation patterns, which include timing, intensity and quantity of rainwater, combined with rise in temperature are expected to increase evapo-transpiration, which may alter the

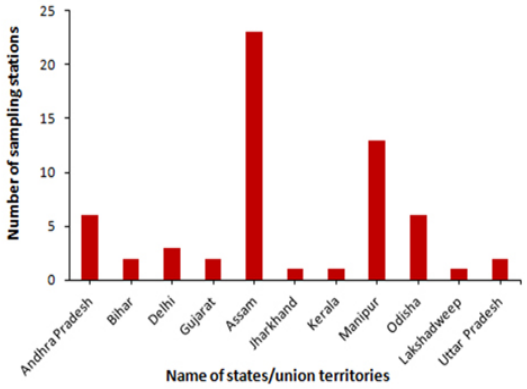

Fig. 2: Number of CPCB pond water monitoring stations present in 11 states and union territories of India; source: CPCB[9]

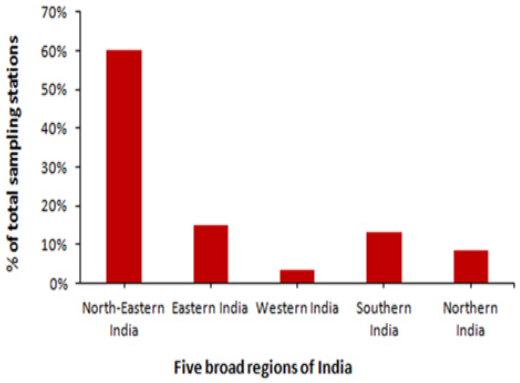

Fig. 4: Percentage wise CPCB data of pond water monitoring stations present in different regions of India (for details see text); source: CPCB[9]

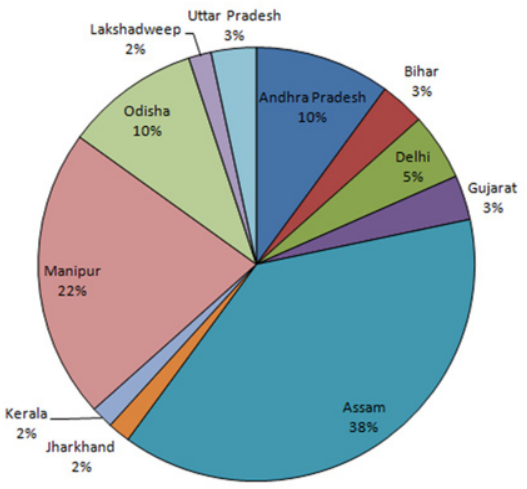

Fig. 3: Percentage wise CPCB data of pond water monitoring stations present in different states and union territories of India; source: CPCB[9]

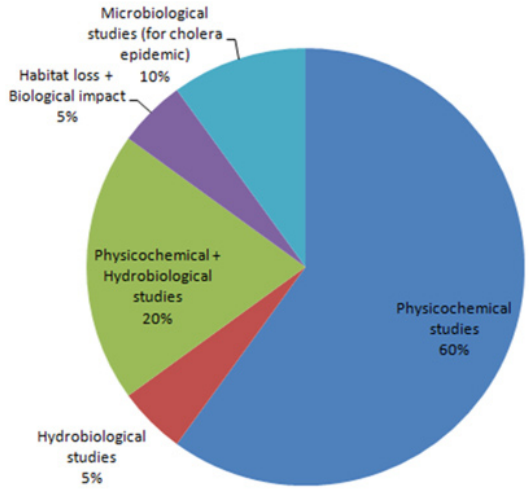

Fig. 5: Different categories of the pond environment investigations taken up by the Indian researchers (in %)

water cycle within catchments. The hydrological changes may have more profound consequences in small water bodies, such as ponds, because of their small contributing catchments as well as small wetted areas[23]. An increased temperature will accelerate evaporation and decrease precipitation, and thereby causing a decrease in water column in small water bodies[18]. Even if there is net increase in rainfall, increase in temperature may not bring any net increase in water content due to enhancement in evaporation rates. Increase in climate induced extreme rainfall and runoff events, on the other hand, may cause greater transport of sediment and nutrients from land to the vulnerable freshwater bodies (from Clarke[23]and reference within). Elevated sediment and nutrient loads, and toxic pollution can adversely affect freshwater species diversity[23]. In addition to higher rates of evaporation, over-extraction during warmer seasons, and a longer span of rainless days may deplete pond water levels. A decline in water level may deteriorate its quality, such as increase in salinity[24]. Climate change induced increase in rate of evaporation, and higher temperatures are likely to alter the upper thermal zone of ponds. As water temperature increases, the dissolved oxygen levels show a declining trend, and these behaviours may be more intense in eutrophic ponds when occurrence of photosynthesis ceases at night. In extreme cases, hypoxic conditions may develop in the epilimnetic zone, causing death of organisms which are unable to migrate to more oxygen rich areas of the pond water body (from Matthews[22] and references within).

Another potential consequence of climate change is that it can aggravate the impact of invasive non-native species by enlarging their potential reproductive range. Climate change may increase the invasive tendencies of a number of problem species by releasing them from current temperature constraints. Experiments simulating warmer conditions in experimental ponds have shown this phenomenon with respect to the exotic invasive plant species *Lagarosiphon major* (from Clarke[23] and reference within).

Changes such as heat loading may have profound impacts on the species composition of aquatic biota including planktonic organisms (phyto- and zooplanktons), benthic invertebrates and fishes[18]. The UV (ultraviolet) radiations can strongly affect organisms in shallow waters. Higher temperature may lead to reduced water levels, exposing the aquatic biota, such as amphibian embryos, to an increasing UV radiation intensity, which in turn may lower resistance to pathogenic infections. The synergistic effects of environmental hazards may lead to some completely unpredictable consequences[18]. Lee *et al.*[17] very recently has demonstrated climate change impacts on pond water bodies in the form outcomes such as earlier drawdown, speedy rate of recession in summer, and reduction in minimum water levels. Climate change induced hydrologic shifts may cause alterations in the patterns of several ecological roles performed by ponds such as – water storage, habitats for plants and animals, water quality (filtration), groundwater recharge, and shifts in cycling of nutrients (biogeochemical cycles). Species such as amphibians and invertebrates are most vulnerable to alterations in wetland hydrologic response, which may even lead to their declines or extinctions in extreme cases. Decline in populations of invertebrates and amphibians may negatively affect the food web involving reptiles, birds, and mammals that feed on them. Species most capable of colonising new habitats (i.e., species that show high dispersal behaviour and species that have the ability to adapt in short-hydroperiod systems), and species that are tolerant of extreme temperature conditions are likely to be favoured by the climate trends in the 21st century[22].

The coastal zone pond water sources are highly vulnerable to climate change induced hazards such as variations in temperature, erratic rainfall patterns, flooding, drought, cyclone and storm surges, and salinity intrusion. Most vulnerable to these climate change impacts on pond water sources are the poorest and most marginalised communities of the remote coastal village households, who depend on pond waters for their daily drinking, other domestic requirements and livelihoods, such as small-scale irrigation activities. For examples, two cyclones, namely, Sidr and Aila which struck Bangladesh in 2007 and 2009 respectively, inundated several ponds of the coastal Bangladesh with saline water, which made lives of climate vulnerable poor households more difficult[24].

The scenarios of water security in India

India accounts for more than 18% of the global human population but has only 4% of the global renewable water resources[25]. As per the record of the recent census, 1.21 billion is the population of India[26]. By the year 2050 AD, the population is expected to undergo stabilisation at around 1.64 billion. The annual per capita availability of the renewable freshwater, which was around 6042 cubic meters in 1947 AD[9] is expected to fall below 1667 cubic meters by the year 2020 AD[27]. Gross per capita water availability which was around 1820 cubic metres/year in the year 2001 AD will decline to value as low as 1140 cubic metres/year by the year 2050 AD. Thus, when compared to 1947 AD, the country is going to face almost 5 times decline in per capita water availability by 2050 AD. By the end of the 21st century, given estimated rise in population size, the per capita availability of water is likely to plummet below 1000 cubic meters, a condition designated as water scarcity[9]. Presently the urban India requires about 50 billion litres of municipal water every day. This figure is expected to cross 110 billion litres per day by the year 2050 AD, when the urban population is expected to exceed over 800 million. On the other hand, the rural population of India (1.1 billion by 2050) will require about 44 billion litres of water per day[9]. The production of food grains which was about 208 million tonnes in 1999-2000 AD will have to be raised to quantity around 350 million tonnes by the year 2025 AD[28]. Around the year 2050 AD the total requirement of water for diverse activities has been assessed to be around 1450 km^3/year. However, current utilisable water resource potential, through conventional development strategies, is estimated to be just at 1122 km^3/year. This value is significantly less than the water requirement scenario in 2050 AD. To bridge this anticipated deficit, there is an urgent need to increase water availability by the year 2050 AD[9]. The preoccupation of the country with an 8 to 9% growth rate having industrialisation as its main growth engine is also taking a toll on water[29]. Based on above discussion, the situation does not look good in terms of water security in India. Of all options available, water conservation measures and rainwater harvesting must get highest priority in water resources development and management[9].

Monitoring of pond water bodies in India

The quality of an aquatic ecosystem depends on its physicochemical qualities as well as biological diversity[30]. Different studies on ponds in India have been taken with the underlying concept that the physicochemical qualities of pond water directly impact pond aquatic ecosystem as a whole. In Indian scenario, the monitoring of pond ecosystems is meagre. The reports available in scientific literature and print and electronic media are discussed henceforth.

Under the National Water Quality Monitoring Programme, the CPCB (Central Pollution Control Board) conducts monitoring of some ponds spread across 11 states and the union territories (UTs)[9]. The number of pond water quality monitoring stations (monitoring network) is 60. The number of monitoring stations present in selected 11 states and UTs is provided in Figure 2. Most of the sampling stations (60%) are located in the North-Eastern part of India (States of Assam and Manipur) followed by the Eastern India (States of Bihar, Jharkhand and Odisha) at 15%. The Southern India (Andhra Pradesh, Kerala and Lakshadweep), Northern India (Uttar Pradesh and Delhi) and Western India (only Gujarat) have around 13%, 8%, and 3% of the sampling stations respectively (Figures 3 and 4). The study conducted by the CPCB in the duration 2010-2011 displayed that the BOD (Biochemical Oxygen Demand) data of most of the states recorded significantly high or extremely high number of observations violating the environmental norms (Table 1). For example, 45% of observations with respect to DO (Dissolved Oxygen) and 100% of observation with respect to BOD violated desired levels in Andhra Pradesh. Some specific cases of BOD values in pond water ecosystems include: Elangabeel system pond (Assam) = 44 mg/l; Laxmi pond (Uttar Pradesh) = 33 mg/l; Swetaganga pond (Odisha) = 21 mg/l; Bindusagar pond (Odisha) = 18 mg/l; and Olpad pond (Gujarat) = 11 mg/l.

Investigations conducted by the independent researchers on pond water ecosystems are also available. Some of the investigations conducted on pond ecosystems are displayed in Table 2. The Indian studies have predominantly focused on physicochemical investigations and hydrobiological inventories, though researches on other areas also exist. For the convenience we have categorised the studies into 5 areas (Figure

5), namely, 'only physicochemical studies', 'only hydrobiological studies', 'combined physicochemical and hydrobiological studies', 'habitat loss and biological impact studies', and 'microbiological studies (for cholera epidemic)'. Where studies on physicochemical parameters, hydrobiological inventories and microbological diseases were found together, the microbiological parameters were taken as separate studies to calculate the percentage of different types of pond environment investigations. It is noted that most of the studies have concentrated on 'only physicochemical studies' of pond water qualities (60%) followed by 'combined physicochemical and hydrobiological studies' (20%). The 'microbiological studies (for cholera epidemic)' comprise 10% of investigations while 'only hydrobiological studies' and 'habitat loss and biological impact studies' occupy 5% share each (Figure 5).

Pond water pollution and global warming/climate change outcomes

Two very important studies substantiated the need for pond conservation in India. The study of Bhuiyan and Gupta[30] showed that the rural ponds can play important roles in providing waters for drinking, other domestic uses and fishery. On the other hand, Mukherjee *et al.*[35] in their study elucidated pond-centred outbreak of cholera in rural areas of West Bengal. The environmental contamination of ponds, which are used for various purposes, can transmit cholera. At high concentration of organic nutrients, such as sewage, the *Vibrio cholerae* survives longer[30]. Ponds used as a dumping ground for wastes can subsequently turn into a natural breeding ground for mosquitoes causing spread of vector-borne diseases in the area[47]. A pond contaminated with pathogens becomes unusable for domestic purposes and, therefore, for sustainable development of community their conservation is essential. It is an incentive that ponds, as small water bodies, are more easily manageable than large water bodies, and are also high yielding[30].

Chaurasia and Pandey[31] reported water quality of some ponds in the Ayodhya-Faizabad region (Uttar Pradesh). All ponds displayed deteriorated water quality, which was evident from the recorded BOD values (23.9-76.3 mg/l). Discharge of wastewaters into ponds was primarily responsible for their pollution and eutrophication. The authors also commented on spread of water borne diseases in the vicinity of poor water quality ponds. Gajanand *et al.*[41] studied Tapti ponds (Upper and Lower ponds), Madhya Pradesh, and found substantial organic load in them (BOD: 4.8-9.2 mg/l). The authors argued that idol immersions can negatively impact pond water quality, such as causing eutrophication; and input of both biodegradable and non-biodegradable materials causes decline in pond water quality and increase in silt load in them. The Lower pond was found more deteriorated in its water quality than the Upper pond because it received a large quantity of raw sewage from nearby densely populated habitation. Mahajan and Billore[44] also examined a pond water body, an important potable water source, in the Khandwa district (Madhya Pradesh). They noted a steady decline in freshwater quality; and the results of chloride, phosphate and nitrate showed inclination of water body towards eutrophication. Manoj *et al.*[42] did hydrochemical analysis of ponds of Santiniketan-Bolpur-Sriniketan zone (West Bengal) and found organic wastes along with phosphate as the most serious polluting agents, undesirable for the proper ecological functioning of the pond ecosystems. In a similar study of ponds from the Santiniketan and adjoining areas, the results of Nag and Gupta[21], using chemical oxygen demand parameter, also indicated organic pollution load in the pond waters. Mishra *et al.*[19] reported alarming levels of nitrate (as high as 52 mg/l) and phosphate (as high as 7 mg/l) in ponds of the Varanasi holy city (Uttar Pradesh). Shrivastava *et al.*[33] investigated four major Bilaspur (Chhattisgarh) pond waters and found them quite heavily polluted, especially with respect to organic pollutants. The results indicated substantial nutrient enrichment and a sharp inclination towards eutrophication. Soni and Bhatt[32] reported maximum BOD up to 50 mg/l and total phosphate as 1.49 mg/l from an urban pond near Vadodara (Gujarat). Disposal of untreated sewage was the most significant factor for water quality deterioration. Another study of Vadodara urban ponds also indicated eutrophication due to sewage and surface runoff[40]. Sinha *et al.*[46] observed high BOD (27-34 mg/l) and high nitrate levels (42-51 mg/l) in two Samastipur (Bihar) ponds. Discharge of domestic wastes and drainage water led to significant decline of pond water quality, and rise in eutrophication status. A physicochemical study of the perennial pond water near Erode city (Tamil Nadu), for aquaculture purpose, indicated that

indiscriminate discharge of toxicants could cause great threat to the pond environment[45]. Ekhalak *et al.*[37] also emphasised on the management of the pond water quality for fisheries and recreational purposes. Kiran[34] reported physicochemical characteristics of two fish ponds, of the Bhadra project region, Karnataka. The ponds were found organically polluted and enriched with phosphate and nitrate (and consequently eutrophied) from sources such as surface soil runoff, and addition of organic cow dung and poultry manure.

Dhanya *et al.*[38] reported nutrient enrichment and algal blooms in some ponds of the Pallipuram (Alappuza district, Kerala) mainly due to phosphates from detergents, fertiliser runoff, residential area effluents, and faulty sanitation system in the region. Blue-green algal blooms were reported from 26 surveyed ponds. The presence of potentially toxic genera (hepatotoxins producing) of *Oscillatoria* and *Microcystis* in the ponds emerged as a basic cause of concern. Elayaraj and Selvaraju[43] reported considerably high BOD levels (6.02-9.7 mg/l) and noticeably significant concentration of phosphate (0.57-1.03 mg/l) in eutrophic Chidambaram ponds, Cuddalore district, Tamil Nadu. The overall results indicated substantial nutrient enrichment and organic load from organic and sewage waste in pond ecosystems. The study also found cyanophycean members as a highly tolerant group of organisms preferring to grow at higher temperatures and in highly organically rich waters. Kumar *et al.*[36] studied two high altitude Badrinath (Uttarakhand) ponds and recorded that most of the phytoplankton (and also zooplankton) species belonged to indicators of higher trophic status. The study clearly showed negative impact of anthropogenic pressure on pond water quality. Recently, Tripathy and Chisty[39] have shown how unplanned landscape modification of ponds can alter the habitat of avifauna particularly in relation to their nesting places. Habitat degradation can result in decrease in pond biodiversity. Dumping of sewerage in ponds and consequent pollution of the groundwater in the surrounding areas has also been reported[48].

Ponds are both sources as well as sinks for a diverse range of activities. These are used as a drinking water source; for irrigation, fishing and other aquacultural activities; bathing and washing of clothes and utensils; idol immersions; household waste dumping; municipal wastewater/sewage discharge point; dumping of animal wastes and other miscellaneous garbage; and recreational purpose. One thing common between CPCB studies and independent researches is the high BOD values in the Indian pond waters. The literature survey reveals that the range of BOD in pond waters is 0.8 to 76.3 mg/l, and the mean pond BOD value (calculated taking only mean of minimum and maximum values recorded in independent researches) is 15.5 mg/l. The literature survey also reveals high eutrophication of pond waters in India due to nutrient enrichment especially with respect to phosphate and nitrate. Almost all studies discussed above held anthropogenic pressure responsible for the degradation of pond ecosystems in India, and most of the studies found pond waters unsuitable for drinking and other domestic purposes.

Other factors, such as, global warming and climate change are also expected to affect pond ecosystems in India. Global warming may lead to excessive growth of highly tolerant cyanophycean group of organisms in pond waters, which prefer higher temperatures for their growth. This in association with high degree of contamination will result in excessive eutrophication of water bodies. Massive bloom of some cyanophycean members in eutrophic ponds[43] can lead to low diversity of other organisms, including other members of the cyanophycean group, in pond ecosystems. Recently, Elayaraj and Selvaraju[43] have attributed low diversity of cyanobacteria in pond ecosystems due to massive bloom of *Microcystis aeruginosa* in eutrophic ponds. Global warming can also affect the micro flora and fauna of the pond ecosystems present at higher altitudes. Bacillariophyceae are general dominant group in temperate aquatic bodies, because under weak light and low temperature conditions diatoms are able to grow but other phytoplanktonic groups find the conditions less suitable[36]. Kumar *et al.*[36], however, recorded chlorophyceae as a dominant group among all the phytoplankton groups in the Himalayan ponds, on account of relatively high temperature coupled with nutrient enrichment. The authors have commented in their literature that aquatic bodies present at higher altitudes are generally oligotrophic. Change in climatic regime, however, may lead to the development of eutrophic

conditions. Climate change is also anticipated to alter the connectivity between freshwater ecosystems. The warmer and drier summers will lead to faster drying of ponds, which will ultimately reduce 'stepping stone' connections between these water bodies[49]. For example, the disappearance of ponds leads to an increase in the isolation of pond habitats and reduction in zooplankton dispersal between pond habitats (Johnson *et al.*[49] and reference within). Sea level rise and salinity intrusion in the coastal pond water sources in India can severely impact lives of the coastal people, especially the marginalised populace. Some other different scenarios that can be expected in response to climate change induced conditions are: increase in rainfall pattern may be counteracted by elevated evapo-transpiration, thus shortening the pond hydroperiod; intense rainfall events may increase the surface runoff and sediment and nutrient loads in ponds; droughts, which could occur frequently and intensely, will drain out the pond water through excessive evapo-transpiration. All these events will have consequences for the pond ecosystems (climate change induced effects are discussed in detail in the section "global environmental concerns of ponds" of this manuscript).

Encroachment

Pollution and degradation are not the only threats ponds are encountering in India, filling up and encroachment are also occurring concurrently both in urban as well as rural India. Ponds, once known as centres of thriving rural environment, are fast disappearing in many states of India. For example, in 21 villages of Ropar district (Punjab state) only 21 ponds (2-4 acres in size) now exist. Earlier each village used to have 3-4 such ponds. One estimates that the state's 90% of the ponds have been encroached upon[48]. Recently in the water-starved Budelkhand region of the Indian state of Uttar Pradesh, 4020 ponds have been reported to disappear. The survey carried out for the region reported high encroachment in the area[50]. In the state more than 19,000 hectares of ponds and other small water bodies are under encroachment[51]. Several ponds in the Varanasi city, Uttar Pradesh, are also facing threat to existence and are disappearing primarily due to encroachment[52]. Realty boom is also responsible for vanishing of ponds in Kolkata, West Bengal. Accelerated land price in the city has led to the indiscriminate filling and encroachment of the ponds[53]. Raj and Azeez[54] have demonstrated that the loss of urban water bodies is highly correlated with the growth of the urban city. During the study period, 1970s to 2008, for the Palakkad city (Kerala), the authors noted the number of artisan ponds to fall from 65 to 32, possibly from draining, filling and conversion. Increased urbanisation through housing and, most likely, industrial development projects is causing extinction of many ponds in India. Waste dumping, especially solid wastes, into the ponds have increased the rate of filling up of pond depressions, turning them into disappeared ecosystems.

Ponds in India are not taken as a priority habitat which makes them a vulnerable ecosystem. Habitat types or elements which carry a unique or important significance to a diverse array of species can be regarded as priority habitats. These habitat types contain a unique composition of flora, succession stage and/or structural factor[55]. It is very hard to say whether ponds are considered in environmental impact assessments (EIAs) of projects, particularly building projects, or not. Ponds are functional ecosystems and provide sustainable solutions to many of our problems. These water bodies are, however, undergoing degeneration due to various factors including encroachments leading to their extinctions[56]. Extinction rate of ponds due to urbanisation is more prominent. The demand of land in urban areas, which is increasing at a rapid rate, is fulfilled not only by expanding the peri-urban areas but also by encroaching breathing spaces in urban localities such as green lands and water bodies. The worst victims of these expansions are natural resources such as tanks and ponds in and around urban areas resulting in their disappearance from the map (excerpts taken from the foreword comments by Deshpande in the literature of Thippaiah[57]). The ponds should be the essential aspect of any landscape development EIAs. Small water bodies, in addition to being important functional wetland ecosystems, can play significant role in enhancing livelihoods of the local community belonging to rural, urban, coastal and tribal areas of India[56].

Ponds and National Water Policy 2002 and 2012 AD

The National Water Policy (NWP) of 2002 AD faintly mentioned about small water bodies in India. The policy stated about planning traditional water conservation practices, such as rainwater harvesting, and to promote frontier research and development in these areas. The policy also vaguely talked about preventing encroachment of existing water bodies and their preservation through necessary legislations[28]. The NWP 2012 AD is slightly more vocal about conservation, development and management of pond water bodies in the country. The policy stresses on increasing water storage capacity, especially in adaption to climate change, in its various forms including ponds and other small water bodies. This strategy also includes revival of traditional water harvesting structures and aquatic bodies. To increase water availability, in agricultural sector, the policy speaks about extending current programmes, such as Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), for farmers to harvest rainwater using farm ponds. The policy advocates about water use efficiency through small local level irrigation including field ponds. The policy opposes pollution and any form of encroachment and diversion of water bodies, such as ponds, and advocates their restoration to the extent possible; and then to maintain them properly. For urban and rural domestic water supply small water bodies can act as available alternate sources of supply[25].

Perspectives on position of ponds: essential comments

It is essential to maintain the water quality of ponds at the desired level. There is relatively very little monitoring of ponds in India compared to rivers and large lakes. This probably reflects the fact that these small water bodies are not regarded as sufficiently important which require monitoring on regular scale. Routine monitoring of single pond is severely rare. Even the NWPs are overwhelmingly engaged with rivers and groundwater management. One peculiar observation is that there is an increase in reports on pond investigations after the announcement of NWP 2012 AD (Table 2). This is probably because, the NWP 2012 AD is slightly more vocal about conservation, development and management of pond water bodies in the country. There is no doubt that the ponds have multiple applications at the micro-community level. Traditionally ponds are important structures to store rainwater in most parts of India. These work as reservoirs of water for various activities such as alternate drinking water source, bathing, washing clothes, irrigation, aquaculture and religious activities. However, Indian ponds are increasingly under threat because of accelerating pollution rate and disappearance due to filling up and encroachment.

Ponds have lacked research probably because they are taken as little systems; and so very little research interest in these areas. Another factor for lack of research on pond ecosystems may be fear of no publication of findings in reputed international journals (probably even international journals may find research on ponds as the local reports). Lack of funds for the research proposals most likely also contributed to dearth of good pond researches in India. The importance of ponds is immense; they play substantial roles in global ecological processes; and recently the ponds have become a threatened ecosystem. Without any doubt the research works on ponds should be encouraged to the fullest extent. It is necessary to promote frontier research and development in these areas. Indian and international journals should come forward by bringing special issues on research works on ponds in India. The future NWPs should put more stress on 'little' sustainable solutions with large impacts. The CPCB pond water monitoring stations is only 60, spread across 11 states and union territories, which cannot be taken as a representative of the whole country. The authorities should endeavour to enlarge the sample size. Since the CPCB has some limitations, local schools, colleges and non-governmental organisations can be passionately involved in monitoring works.

In India, even high rainfall areas encounter water scarcity problem during non-rainy months and, therefore, ponds are essential assets for harvesting rainwater and in maintaining local groundwater levels[6]. Ponds are pivotal to the life and prosperity of the rural ecosystem in India. Ponds not only naturally harvest rainwater and recharge the groundwater, but also store water and serve as natural indicator of the village's water table[10]. Renovation of village ponds will not only play important role in conserving

environment of natural ecosystem, but also will have cascading positive effects on rural economy and recharge of underground aquifers[48] which in India is showing decline in many areas. Because ponds are special components of urban water resources also, their proper sustainable management is absolutely necessary[6] to fight against water scarcity problems in expanding urban areas. Ponds as decentralised water bodies can be more helpful in fight against droughts and floods and, moreover, are less costly water structures[51]. The recent launch of 'Smart City' concept augments the significance of ponds even more. No city can be smart if it cannot use its natural resources smartly, and water is indeed foremost of them. Sustainable solution lies in rainwater harvesting and storage as one of the options to meet the need of the 'Smart City' populace. Ponds as water reservoirs should definitely be developed as a sustainable model in these cities.

It seems that a well-knit system of community managed ponds and other small water harvesting structures have eroded over the years[50]. Very nearly in 2025 AD the population of India is expected to reach around 1390 millions. In this scenario drinking water requirements of people as well as livestock will have to be met. The domestic and industrial water requirements which has largely remained concentrated in or near major cities is also expected to rise acutely in rural areas on account of improvement in economic conditions of the rural populace due to various developmental programmes[28]. Ponds can play very significant roles as sustainable water resources, in India, especially as sources of drinking water, domestic use and aquaculture. At the planning and scientific management level, small reservoirs, such as ponds, are more easily manageable and high yielding than large ones[30]. As a sustainable water resource, the ponds in India need micro-planning and micro-management to protect and conserve these precious small water bodies.

Conservation and management of ponds in India: proposals and discussion

The NWP of 2002 AD[28] talked about appropriate reorientation or reorganisation of various institutions under the water resources sector as well as creation of new institutes, wherever necessary. The NWP of 2012 AD[25] also advocates development of appropriate institutional arrangements for each river basin in the country to collect and collate data on various purposes including monitoring of water quality. In this regard, in the line of river basins, each state should establish its own independent Pond Water Development/Regulatory Authority. These development/regulatory authorities in addition to bureaucrats should also have environment conscious citizens on board. The first task of the authority should be anti-encroachment operation on urgent scale. The concerned citizens who do such anti-encroachment reports are frequently threatened with dire consequences. With a legal authority in place and the concerned citizens on board the work of anti-encroachment drive may bring many positive results.

Biodiversity importance of ponds should be recognised in India. It should start with identifying some high priority ponds. In this regard in line of some European countries[4] a pond habitat and biodiversity action plan can be initiated in India. The number of ponds in India is unknown. Their biodiversity values should be thoroughly and extensively studied. Ponds play important roles in enhancement of regional biodiversity and ecological stability. Ponds promote abundance and high richness of aquatic plants and enhance regional biodiversity of invertebrates, amphibians and aquatic birds. Ponds and other small water bodies are also known for their high productivity. Ponds can be significantly more active biologically than large water bodies. Small aquatic systems are important sites for food production also[1]. The biodiversity value of ponds comes from their role as: critical habitats for many rare and uncommon species, stepping stone habitats and biodiversity hotspots.

As the Red Data List of the International Union for the Conservation of Nature (IUCN) classifies organisms into different categories ranging from not evaluated to extinct[58], the pond water bodies can also be classified into groups such as not evaluated, data deficient, least concern, near threatened, vulnerable, endangered, critically endangered and extinct based on extent of pollution, degradation and encroachment. When the pond water bodies are filled up for housing, urban expansion or other landscape developmental activities they can be declared extinct. This water red data list (WARD) can be a useful tool

in pond conservation, planning and management. An inventory of ponds in India needs to be prepared for which, however, extensive survey is needed. ISRO's (Indian Space Research Organisation) Bhuvan, geo-spatial platform, application service can be used to create database on natural resources of the country and mapping country-wide small water bodies for better results[59].

The conservation of ponds should be connected to the Swachh Bharat initiative. In cities and towns greater municipal-citizen collaboration will help. However, seeing the capacity gap the municipal bodies face in dealing with the municipal works, it is not hard to predict the insensitivity of the urban local bodies towards pond water bodies. How under-equipped the municipal bodies are can be realised from the latest government data which shows that of 1.42 lakh tonnes of solid waste generated per day in urban areas in the month of July, 2015 AD, only 15.32% was processed[60,61]. Thus, citizens themselves should take initiative in cleanliness drive and pond conservation works. The urban populace can learn from the rural habitants who have displayed that sheer perseverance can bring significant results with respect to the sustainable development. In this regard two examples are worth mentioning here (although these are not related to the ponds). A consortium, led by women group, has been instrumental in bringing metamorphic changes in some rural areas of the Madhya Pradesh. Through community participation, the consortium has successfully lifted the rural economy by focusing on land, forest, water and use of manure and vermicomposting[62,63]. Another example in this perspective is the determination of the villagers of the Pratapgarh and Allahabad districts (Uttar Pradesh) to end their water woes. In order to end water crisis, for drinking and agricultural fields, 50 villages of the Pratapgarh and Allahabad districts after 5 years of collective work successfully brought the Bakulahi River back to its natural course through the Bakulahi River Rejuvenation Campaign[64].

Because of their small size, ponds are much more vulnerable to degradation. Ecological assessment and monitoring of ponds is a major topic in their conservation and management. Ecological restoration of degraded ecosystems is one of the management options[14]. Ponds provide sustainable solutions against climate change, even though they themselves look vulnerable to climate change. What is needed is micro-planning and micro-management to minimise the impact of climate change on ponds. For example, to counteract rising water temperatures of small water bodies, increasing the amount of shade around them can be a possible management option[23]. Ponds being highly active carbon sequestration body can help mitigate climate change. By increasing the number of ponds followed by their protection and proper management, climate change induced water scarcity problem can be brought down. Water storage capacity can be elevated, in adaptation to climate change, through rainwater harvesting and groundwater recharge. With proper conservation measures even climate change induced eutrophication of ponds can be minimised. It is necessary to fence the ponds in order to prevent them from becoming dumping grounds for the wastes. Dumping of wastes subsequently make the water bodies natural breeding grounds for mosquitoes spreading diseases such as dengue. To curb the spread of diseases like dengue, the honourable Gujarat High Court recently directed the Ahmedabad Municipal Corporation to fence the city ponds to check the waste dumping activities in ponds[47].

In India, the Gujarat state has taken a proactive approach to push water harvesting and setting up or creating village ponds, especially for irrigation purpose[65]. This irrigation model should also be replicated in other parts of the country. At the Panchayat level small sewage treatment plants can be set up to treat village sewerage before disposing in the pond waters. Village sewage can be used to generate biogas through biogas plants. Around the ponds grasses and other plants can be grown which will acts as filters for the runoff waters from agricultural fields and urban and village lands. There is need to develop a Pond Water Framework Policy especially in terms of climate change, pondscape biodiversity and sustainable development scenarios. The Indian Pond Conservation Network (IPCN) is much needed for the sustainable development and management of ponds.

CONCLUSIONS

The major objective of this communication is to disseminate information on importance of ponds for their conservation and management planning, especially in Indian perspectives. The available studies show that the ponds in India are under threat due to increase in pollution rates and encroachment. There is a need to formulate policy development plan and then endeavour to deliver the plan on the ground. Instead of treating ponds as individual sites, they should rather be treated as part of the pond network or pondscape (more important in terms of climate change problem). The urgently required is a Pond Water Framework Policy and the Indian Pond Conservation Network for the sustainable development and management of ponds. In Indian scenario the exact number of ponds and the volumes of water they store are unknown. Information is lacking on existing storage and large scale benefits the ponds provide. The basic scientific insights needed for planning and management of ponds is inadequate. There is a need to promote frontier research and development in these areas. Based on the lines of the IUCN Red Data List a water red data list (WARD) should be developed which can be a useful tool in pond conservation, planning and management. The preparation of list, however, needs extensive survey and development of inventories. It is essential to do systematic analysis of ponds as alternative storage options in relation to their roles in poverty reduction, and adaptation to climate change in India. It is noteworthy that ponds provide practical water conservation solutions.

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REFERENCES

1. Downing, J. A. Emerging Global Role of Small Lakes and Ponds: Little Things Mean a Lot. *Limnetica,* **29**(1): 9-23 (2010)
2. Céréghino, R., Boix, D., Cauchie, H-M., Martens, K., and Oertli, B. The Ecological Role of Ponds in a Changing World. *Hydrobiologia,* **723**: 1-6 (2014)
3. Downing, J. A., Prairie, Y. T., Cole, J. J., Duarte, C. M., Tranvik, L. J., Striegl, R. G., McDowell, W. H., Kortelainen, P., Caraco, N. F., Melac, J. M., and Middelburg, J. J. The Global Abundance and Size Distribution of Lakes, Ponds, and Impoundments. *Limnology and Oceanography,* **51**(5): 2388-2397 (2006)
4. Keeble, H., Williams, P., Biggs, J., and Reid, N. Important Areas for Ponds (IAPs) and other Small Waterbodies in Northern Ireland. Report prepared by Pond Conservation and the Natural Heritage Research Partnership, Quercus for the Northern Ireland Environment Agency, Northern Ireland, UK (2009)
5. EPCN, European Pond Conservation Network. The Pond Manifesto (2008)
6. Ray, M. K., and Majumdar, S. Evaluating Economic Sustainability of Urban and Peri-urban Waterbodies: A Case Study from Kolkata Ponds. Editors: Sengupta, N., and Badyopadhyay, J. Biodiversity and Quality of Life, Macmillan, New Delhi, 135-146 (2005)
7. Manoj, K., and Padhy, P. K. Discourse and Review of Environmental Quality of River Bodies in India: An Appraisal of Physico-chemical and Biological Parameters as Indicators of Water Quality. *Current World Environment,* **10**(2): 537-571 (2015)
8. IUCN, International Union for Conservation of Nature. World Water Week: A New Course for Water and Development (2015)
9. CPCB, Central Pollution Control Board. Status of Water Quality in India- 2010. Monitoring of Indian National Aquatic Resources, Series: MINARS/ /2010-11, Ministry of Environment and Forests, Government of India (2011)
10. Dubey, T. P. The Biodiversity of the Ponds. Water and Biodiversity, Uttar Pradesh State Biodiversity Board, 30-36 (2013)
11. Biggs, J., Williams, P., Whitfield, M., Nicolet, P., and Weatherby, A. 15 Years of Pond Assessment in Britain: Results and Lessons Learned from the Work of Pond Conservation.

Aquatic Conservation: Marine and Freshwater Ecosystems, **15**: 693-714 (2005)
12. McCartney, M., and Smakhtin, V. Water Storage in an Era of Climate Change: Addressing the Challenge of Increasing Rainfall Variability. International Water management Institute, Colombo (2010)
13. Science for Environment Policy. The Importance of Ponds for Wildlife in Agricultural Landscapes. European Commission DG Environment News Alert Service, Edited by SCU, The University of the West of England, Bristol (2008)
14. Miracle, M. R., Oertli, B., Céréghino, R., and Hull, A. Preface: Conservation of European Ponds-Current Knowledge and Future Needs. *Limnetica,* **29**(1): 1-8 (2010)
15. Smith, S. V., Renwick, W. H., Bartley, J. D., and Buddemeier, R. W. Distribution and Significance of Small, Artificial Water Bodies across the United States Landscape. *The Science of the Total Environment,* **299**: 21-36 (2002)
16. Fairchild, G. W., Anderson, J. N., and Velinsky, D. J. The Trophic State 'Chain of Relationships' in Ponds: Does Size Matter? *Hydrobiologia,* **539**: 35-46 (2005)
17. Lee, S-Y., Ryan, M. E., Hamlet, A. F., Palen, W. J., Lawler, J. J., and Halabisky, M. Projecting the Hydrologic Impacts of Climate Change on Montane Wetlands. *PLoS ONE,* **10**(9) (2015)
18. Brönmark, C., and Hansson, L-A. Environmental Issues in Lakes and Ponds: Current State and Perspectives. *Environmental Conservation* **29**(3): 290-306 (2002)
19. Mishra, S., Singh, A. L., and Tiwary, D. Studies of Physico-chemical Status of the Ponds at Varanasi Holy City under Anthropogenic Influences. *International Journal of Environmental Research and Development,* **4**(3): 261-268 (2014)
20. Brönmark, C., and Hansson, L-A. The Biology of Lakes and Ponds. Second Edition, The Oxford University Press Inc., New York (2005)
21. Nag, A., and Gupta, H. Physicochemical Analysis of Some Water Ponds in and around Santiniketan, West Bengal, India. *International Journal of Environmental Sciences,* **4**(5): 676-682 (2014)
22. Matthews, J. H. Anthropogenic Climate Change Impacts on Ponds: A Thermal Mass Perspective. *BioRisk,* **5**: 193-209 (2010)
23. Clarke, S. J. Adapting to Climate Change: Implications for Freshwater Biodiversity and Management in the UK. *Freshwater Reviews,* **2**: 51-64 (2009)
24. Rabbani, G., Rahman, S. H., and Faulkner, L. Impacts of Climatic Hazards on the Small Wetland Ecosystems (Ponds): Evidence from some Selected Areas of Coastal Bangladesh. *Sustainability*, **5**: 1510-1521 (2013)
25. NWP, National Water Policy. Ministry of Water Resources, Government of India (2012)
26. Census of India. Size, Growth Rate and Distribution of Population. Office of the Registrar General and Census Commissioner, Ministry of Home Affairs, Government of India. http://www.censusindia.gov.in/2011-prov-results/data_files/india/Final_PPT_2011_chapter3.pdf, Accessed on 27.09.2015, (2011)
27. Manoj, K., and Padhy, P. K. Climate Change, Water Resources and Food Production: Some Highlights from India's Standpoint. *International Research Journal of Environment Sciences,* **2**(1): 79-87 (2012)
28. NWP, National Water Policy. Ministry of Water Resources, Government of India (2002)
29. Cullet, P., Suhas, P., Himanshu, T., Vani, M. S., Joy, K. J., and Ramesh, M. K. Water Conflicts in India: Towards a New Legal and Institutional Framework. Forum for Policy Dialogue on Water Conflicts in India, Pune (2012)
30. Bhuiyan, J. R., and Gupta, S. A Comparative Hydrobiological Study of a few Ponds of Barak Valley, Assam and their Role as Sustainable Water Resources. *Journal of Environmental Biology,* **28**(4): 799-802 (2007)
31. Chaurasia, M., and Pandey, G. C. Study of Physico-chemical Characteristics of Some Water Ponds of Ayodhya-Faizabad. *Indian Journal of Environmental protection,* **27**(11): 1019-1023 (2007)
32. Soni, R. N., and Bhatt, S. A. Periodical Ecological Study of an Urban Pond Near Vadodara, Gujarat, India. *Proceedings of Taal2007: The 12th World Lake Conference*, 1591-1596 (2008)

33. Shrivastava, S. K., Gupta, V. K., Vajpai, K., Shrivastava, D. K., and Vajpai, S. K. Study of Physicochemical Quality of Pond Water in Bilaspur, Chhattisgarh. *Current World Environment,* **3**(1): 97-107 (2008)
34. Kiran, B. R. Physico-chemical Characteristics of Fish Ponds of Bhadra Project at Karnataka. *Rasayan Journal of Chemistry,* **3**(4): 671-676 (2010)
35. Mukherjee, R., Halder, D., Saha, S., Shyamali, R., Subhransu, C., Ramakrishnan, R., Murhekar, M. V., and Hutin, Y. J. Five Pond-centred Outbreaks of Cholera in Villages of West Bengal, India: Evidence for Focused Interventions. *Journal of Health Population and Nutrition,* **29**(5): 421-428 (2011)
36. Kumar, P., Wanganeo, A., Sonaullah, F., and Wanganeo, R. Limnological Study on Two High Altitude Himalayan Ponds, Badrinath, Uttarakhand. *International Journal of Ecosystem,* **2**(5): 103-111 (2012)
37. Ekhalak, A., Mohini, G., and Ranjana, S. Water Quality of a Temple Pond (Khajod) of Surat District, India. *Proceeding of International Conference SWRDM,* 27-30 (2012)
38. Dhanya, S., Smitha, S., and Joseph, A. A Survey of Algal Blooms in the Ponds of Pallippuram, Kerala, India. *International Journal of Environmental Sciences,* **3**(3): 1185-1193 (2012)
39. Tripathi, A. K., and Chishty, N. Effect of Urbanization Related Habitat Degradation on Avifauna of Gandhi Sagar Pond Bhilwara Rajasthan (India). *The Journal of Biodiversity. Photon,* **113**: 339-342 (2014)
40. Tailor, M. A., and Mankodi, P. C. Comparative Study of two Urban Ponds of Vadodara City with Special Reference to their Chemical Parameters. *Research Journal of Animal, Veterinary and Fishery Sciences,* **1**(10): 10-15 (2013)
41. Gajanand, T., Vikrant, J., and Sandeep, G. Hydro Chemical Changes in Two Eutrophic Tapti Pond of Madhya Pradesh (Multai) after Immersion of Durga and Ganesh Idol. *Chemistry and Materials Research,* **3**(6): 25-29 (2013)
42. Manoj, K., Ghosh, S., and Padhy, P. K. Characterization and Classification of Hydrochemistry using Multivariate Graphical and Hydrostatistical Techniques. *Research Journal of Chemical Sciences,* **3**(5): 32-42 (2013a)
43. Elayaraj, B., and Selvaraju, M. Studies on Some Physico-chemical Parameters of Cyanophycean Members and Correlation Coefficient of Eutrophic Ponds in Chidambaram, Tamil Nadu, India. *International Letters of Natural Sciences,* **11**(2): 145-156 (2014)
44. Mahajan, S., and Billore, D. Seasonal Variations and Assessment of Water Quality of Nagchoon Pond of Khandwa district (M.P.) India. *Current World Environment,* **9**(3): 829-836 (2014)
45. Parithabhanu, A., Revathi, R., and Vijayaragavan. Characterization of Perennial Pond Water Near Erode City, Tamil Nadu, India for Aquaculture. *International Journal of Pure and Applied Zoology,* **2**(3): 261-265 (2014)
46. Sinha, A., Kumar, B., and Singh, T. Water Quality Assessment of two Ponds of Samastipur District (India). *International Journal of Environmental Sciences,* **4**(4): 567-574 (2014)
47. TOI, The Times of India. HC Orders Fencing of Water Bodies. Bennett Coleman and Company Limited, Ahmedabad (2015a)
48. OneIndia. Ponds Disappearing in Villages in Punjab. http://www.oneindia.com/2007/08/28/ponds-disappearing-in-villages-in-punjab-1188281082.html, Accessed on 03.09.2015, (2007)
49. Johnson, R. K., Battarbee, R. W., Bennion, H., Hering, D., Soons, M. B., and Verhoeven, J. T. A. Climate Change: Defining Reference conditions and restoring Freshwater Ecosystems. In: Climate Change Impacts on Freshwater Ecosystems, Eds. Kernan, M., Battarbee, R. W., and Moss, B. R. John Wiley and Sons, West Sussex, UK (2011)
50. HT, Hindustan Times. 4020 Ponds Disappear in Water-Starved Bundelkhand in a Decade. http://www.hindustantimes.com/india-news/4-020-ponds-disappear-in-water-starved-bundelkhand/article1-1249686.aspx, Accessed on 03.09.2015, (2014)
51. Indiatoday. 10 Ponds Were Vanished for T3 Terminal of Delhi Airport. http://indiatoday.

intoday.in/story/uttar-pradesh-drought-illegal-encroachment-ponds-delhi-airport/1/381203.html, , Accessed on 03.09.2015, (2014)

52. TOI, The Times of India. Protecting Ponds Means Saving Ganga, http://timesofindia.indiatimes.com/city/varanasi/Protecting-ponds-means-saving-Ganga/articleshow/37238039.cms, Accessed on 03.09.2015, (2014)
53. TOI, The Times of India. Ponds Vanish in Realty Boom. http://timesofindia.indiatimes.com/city/kolkata/Ponds-vanish-in-realty-boom/articleshow/14419939.cms, Accessed on 03.09.2015, (2012)
54. Raj, N., and Azeez, P. A. Development of a City and Disappearing Urban Water Bodies a case from Palakkad city of Kerala, India. Geography in Action, 10th ESRI India User Conference (2009)
55. Zacharias, I., and Zamparas, M. Mediterranean Temporary Ponds. A Disappearing Ecosystem. *Biodiversity and Conservation,* **19**: 3827-3834 (2010)
56. Rajasekaran, N. Enhancing livelihoods and ecosystems – role of small water bodies in India. http://www.dhan.org/development-matters/2012/10/enhancing-livelihoods-and-ecosystems-role-of-small-water-bodies-in-india/, Accessed on 14.10.2015, (2012)
57. Thippaiah, P. Vanishing Lakes: A Study of Bangalore City. Social and Economic Change Monographs 17, Institute for Social and Economic Change, Bangalore (2009)
58. Manoj, K., Bhattacharyya, R., and Padhy, P. K. Forest and Wildlife Scenarios of Northern West Bengal, India: A Review. *International Research Journal of Biological Sciences,* **2**(7): 70-79 (2013b).
59. TOI, The Times of India. Isro to Align with 170 Govt Projects to Benefit Aam Aadmi. Bennett Coleman and Company Limited, Ahmedabad (2015b)
60. TOI, The Times of India. 71% in Survey Say Swachh Bharat a Flop in Urban Areas, Bennett Coleman and Company Limited, Ahmedabad (2015c)
61. TOI, The Times of India. 1.42L Tonne of Solid Waste Generated a Day in July. Bennett Coleman and Company Limited, Ahmedabad (2015d)
62. TOI, The Times of India. Red Carpet for Our Green Heroes. Bennett Coleman and Company Limited, Ahmedabad (2015e)
63. TOI, The Times of India. Inspiration from the Hinterland. Bennett Coleman and Company Limited, Ahmedabad (2015f)
64. TOI, The Times of India. 10K Villagers of Pratapgarh Turn 'Manjhi' for River. Bennett Coleman and Company Limited, Ahmedabad (2015g)
65. TOI, The Times of India. Govt to Adopt Guj Model of Irrigation. Bennett Coleman and Company Limited, Ahmedabad (2015h)