Wetlands (2022) 42:107
https://doi.org/10.1007/s13157-022-01624-9

WETLANDS IN THE DEVELOPING WORLD

Current Status of Ponds in India: A Framework for Restoration, Policies and Circular Economy

Shweta Yadav[1] · **V. C. Goyal**[1]

Received: 15 June 2022 / Accepted: 11 October 2022 / Published online: 4 November 2022

Abstract

Healthy pond ecosystems are critical for achieving several sustainable development goals (SDG) through numerous ecosystem services (e.g., flood control, nutrient retention, and carbon sequestration). However, the socio-economic and ecological value of ponds is often underestimated compared to the larger water bodies. Ponds are highly vulnerable to mounting land-use pressures (e.g., urban expansion, and agriculture intensification) and environmental changes, leading to degradation and loss of the pond ecosystem. The narrow utilitarian use-based conservation fails to recognize the multiple anthropogenic pressures and provides narrow solutions which are inefficient to regenerate the degraded pond ecosystem. In this paper, we holistically examined the legal challenges (policies) and key anthropogenic and environmental pressures responsible for pond degradation in India. The country is strongly dedicated to attaining SDG and circular economy (CE) through aquatic ecosystem conservation and restoration. Considerable efforts are required at the administration level to recognize the contribution of pond ecosystem services in attaining global environmental goals and targets. Worldwide restoration strategies were reviewed, and a framework for pond restoration and conservation was proposed, which includes policies and incentives, technologies such as environmental-DNA (e-DNA), life cycle assessment (LCA), and other ecohydrological measures. Nature-based solutions (NBS) offer a sustainable and cost-effective approach to restoring the pond's natural processes. Furthermore, linkage between the pond ecosystem and the CE was assessed to encourage a regenerative system for biodiversity conservation. This study informs the need for extensive actions and legislative reforms to restore and conserve the pond ecosystems.

Keywords Ponds · Restoration · Conservation · Circular economy · Policies · Sustainability

Introduction

Biodiversity loss and consequent decline in ecosystem services pose a major global risk to society, the economy and can be a key driver of emerging infectious diseases (UNEP 2020). Ecosystem degradation, if continued, could result in the loss of Gross Domestic Products (GDP) of US$479 billion/year by 2050 (Johnson et al. 2020). Several countries integrated biodiversity into the Covid-19 policy response, such as ecosystem restoration, invasive species control, and wildlife protection measures (OECD 2020).

Ponds are the biodiversity hotspots that collectively support far more species, including rare and threatened species than other freshwater habitats (Indermuehle et al. 2008; Oertli and Parris 2019). They cover more earth's surface than lakes (Downing et al. 2006). And provide a variety of ecosystem services such as flood alleviation (Williams et al. 2020), aquifer recharge (Bhattacharya 2015), nutrient retention (Riley et al. 2018), carbon sequestration (Céréghino et al. 2014), mitigating urban heat islands (UHI) (Solcerova et al. 2019), fish production, and habitat conservation (Oertli and Parris 2019). Nevertheless, the increased anthropogenic stresses (e.g., urban expansion, and agriculture intensification) driven by population overgrowth and resource demand declined the number of pond ecosystems. The emerging risks of bioinvasion (invasive species) and climate change are also threatening the provision of the pond's ecosystem services. In the UK, the number of ponds declined by 75% between the 19th century and 1980 (Riley et al. 2018). In India, the loss of 80,128 pond/tanks (2006-2007) resulted in the loss of 1.95 million hectares of irrigation potential (Ministry of Jal Shakti, India (MoJS 2022), http://mowr.gov.in/). Loss of ponds is particularly threatening to the water and

✉ Shweta Yadav
shwtdv@gmail.com; yadav.shweta.64s@kyoto-u.jp

[1] Research Management and Outreach Division, National Institute of Hydrology, Roorkee 247667, India

food security of the developing nations, where the freshwater bodies coverage is ≤1.4% of the land than the developed countries with 3.5% (UNESCO 2018).

Despite the ecological and social benefits, the ponds were largely excluded from several international and national legislations and commitments targeting freshwater ecosystem protection and conservation (Hill et al. 2018). Restoration and management efforts are primarily directed towards the larger water bodies and the wetlands of national importance, or are part of a national protected area network (Ramsar-Convention-on-Wetlands 2018). The increasing number of scientific studies on ponds in recent decades indicates the growing concern of the global community. A large number of studies focused on the physicochemical characteristic (Yadav et al. 2016; Ma et al. 2020), specific species-based biodiversity conservation (Biggs et al. 2015; Stewart et al. 2017), and enhancing targeted ecosystem services of ponds (Adhikari and Fedler 2020; Manzo et al. 2020). However, the narrow utilitarian use-based conservation (i.e., conservation of specific species and ecosystem resources to avoid possible shortages in the future with harmful economic and social consequences.) fails to recognize the multiple anthropogenic pressures and provides narrow solutions which are inefficient to regenerate the degraded pond ecosystem.

This paper takes a holistic perspective to review major physical, chemical, and biological pressures degrading the pond ecosystem in India. Following this the paper aims to present the ponds ecosystem restoration and management framework, addressing the legal challenges and anthropogenic pressures sustainably. A healthy freshwater ecosystem contributes to several global commitments such as SDG, CE, and disaster risk reduction (Ramsar-Convention-on-Wetlands 2018). A first-hand attempt has been made to understand how the restored and well-managed pond ecosystems (biodiversity) are linked with the regenerative CE.

Methods

The review comprises two levels of literature survey, (1) scientific publications, and (2) legal documents comprising metadata from the ministries. The scientific publication includes journal articles, conference proceedings, and book chapters addressing distinct aspects of the pond ecosystem. Scientific publications were assessed and retrieved through the widely used publication and citation database Scopus (Elsevier Scopus 2022, https://www.scopus.com/). We focused on the studies published between 2000 and 2022, to capture the most up-to-date knowledge relevant to ponds. Globally, thousands of articles showed up for the keyword *ponds*, which included wastewater ponds, oxidation ponds, and waste stabilization ponds. Given the main objective of the paper, we narrowed down the relevant articles by using various keyword combinations such as *natural ponds*, *manmade/artificial ponds*, *temporary ponds, pond management*, *pond restoration*, *pond rejuvenation*, *pond conservation*, *ponds* and *policy*, *ponds* and *CE and other (e.g., pond biodiversity).* Each of the keywords was used separately for India (e.g., *ponds in India*). Repeated articles were found under different keyword combinations such as pond restoration and pond conservation, temporary ponds, and manmade ponds. Repeated articles were excluded for review. Articles with insufficient replications, speculative conclusions, and indirect reference to keywords were later excluded from the review reducing the number of articles to 232 of which 64 were in context to India. The relevance and robustness of the articles were further assessed through detailed manual screening of their title, abstract, keywords, introduction, and conclusion. In India, a huge gap was found in pond conservation (< 5 articles), management (< 8 articles), and restoration (< 27 articles) related research. Moreover, no articles were found in particular to pond-related policies and circular economy in India. Legal documents include national policies, strategies, laws, and regulations explicitly and implicitly affecting the pond ecosystem, its conservation, management, and restoration. The legal documents and the data of ponds in India were retrieved mainly from the Ministry of Environment, Forest and Climate Change (MoEF&CC 2021), The Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation (MoJS 2022), Ministry of Agriculture and Farmers Welfare (MoAF 2021), Ministry of Housing and Urban Affairs (MoHUA 2021), Ministry of Rural Development (MoRD 2021), Central Pollution Control Board (CPCB 2021) and states pond management authority..

Distribution and Current Status of Ponds

Ponds are the century-old traditional water harvesting structures central to the settlement pattern of India (Meter et al. 2014). In 2017–2018, Space Application Center of India mapped 231,195 water bodies and wetlands in the country covering 15.98 Million hectares of area which accounts for 4.86% of the total geographical area of India (i.e., 328.7 Million hectares) (Gupta et al. 2021). The distribution of ponds and tanks indicate two-third (i.e., 65.67%; 151,815 ponds/tanks) of the total water bodies and wetlands mapped in the country and contribute 11.4% of the total mapped area (Fig. 1a). Aquaculture ponds occupy 2.7% of the total mapped area. The wetlands of size < 2.25 ha were excluded from wetland classification and identified only as point features (Gupta et al. 2021). While the surface area of majority of small ponds in India is < 1 ha. According to the 5th census of minor irrigation scheme (2013–2014), the contribution of the ponds/tanks is 41% (Fig. 1b), which is the largest in the surface flow minor irrigation scheme of India (MoJS, http://mowr.gov.in/).

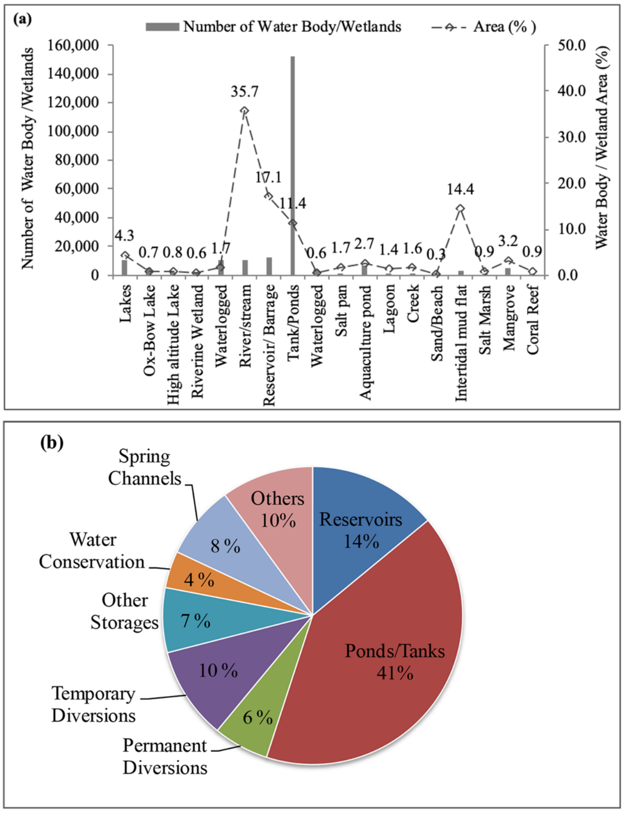

Fig. 1 Status of ponds in India, (**a**) Number of water bodies and wetlands mapped in 2017–2018 and their area distribution (in percentage) including ponds/tanks in the country and excluding wetlands < 2.25 ha (**b**) Contribution of ponds/tanks to surface flow minor irrigation scheme in India during 5.th census 2013–2014 (MoJS, http://mowr.gov.in/)

A large number of ponds are located in the plateau and desert region of the country compared to the Himalayan and Indo-Gangetic plains, indicating their significance as the water-storage structure in the water-scarce region of the country. Large number of ponds and tanks (including aquaculture ponds) located in southern-India. Majority of ponds and tanks are in Andhra Pradesh province (22,255), followed by Tamil Nadu (21,501), Maharashtra (19,816), Karnataka (13,347), and Telangana (11,638). Pond-like structures are also called tanks in the southern states of India (Meter et al. 2014). Figure 2 illustrates the distribution and abundance of ponds and tanks in India.

Historically, ponds were the livelihood source and economic base for the communities. They were mainly managed by the local community which ensures the equitable share and distribution of water to the people (Meter et al. 2014; Bhattacharya 2015). In the eighteenth century, many villages in India contribute ~ 5% of their gross produce to the maintenance of the ponds (Bhattacharya 2015). With the advent of large-scale irrigation projects, the significance of community-managed ponds was neglected (Meter et al. 2014; Rohilla et al. 2017). The perverse incentives and government policies encouraged the over-extraction of groundwater and surface water resource (i.e., non-metering electricity to farmers) disregarding water conservation and deserting the pond ecosystem (Meter et al. 2014; Bhattacharya 2015; Kumar and Padhy 2015; Rohilla et al. 2017). Consequently, the rich pond ecosystem degraded and declined due to numerous physical, chemical, and biological pressures (Kumar and Padhy 2015; Bassi et al. 2014).

Physical, Chemical, and Biological Pressures on Ponds

Physical Pressures

Temperature

Temperature has a pronounced influence on the biogeochemical cycle of shallow water bodies. However, the impact of temperature on the pond ecosystem has rarely been reported. Due to uncontrolled urbanization and impervious surface the urban ponds receives warm water inflow leading to thermal pollution. Warm effluents from the industries and urban heat islands (UHI) largely contribute to the thermal variability in the ponds (Madden et al. 2013; Brans et al. 2018). A study of 30 ponds in Belgium found that the urban-driven warming raised the mean temperature of the urban ponds by 3.04 °C than the rural ponds. Consequently, the growing season is prolonged for up to 45 days in warm urban ponds (Brans et al. 2018). Chemical toxicity in freshwater bodies increases with an increase in temperature. In India, Patra et al. (2015) reported the increased toxicity (e.g., endosulfan, chlorpyrifos, and phenol) in freshwater fish species due to an increase in temperature. Warm water favors the eurythermic species excluding the species intolerant to high temperatures affecting the species diversity (Oertli and Parris 2019). Elevated temperature increases the primary productivity in the shallow water bodies causing nuisance algal bloom and reducing the pond hydroperiod (Kumar and Padhy 2015). High temperature lowers the dissolved oxygen in surface water through increased respiration rate and reduced solubility of atmospheric oxygen. A temperature change of 7°C reduces the biological processes by 50% in an aquatic environment (Madden et al. 2013).

Hydroperiod and Climate Change

Ponds are more susceptible to drying due to changes in hydroperiod than lakes. Hydroperiod indicates the duration of pond inundation in a year is a crucial factor linked directly with pond area. Permanent ponds support far more biotic species than temporary ponds (Oertli and Parris 2019). Ponds with larger surface areas tend to have a longer

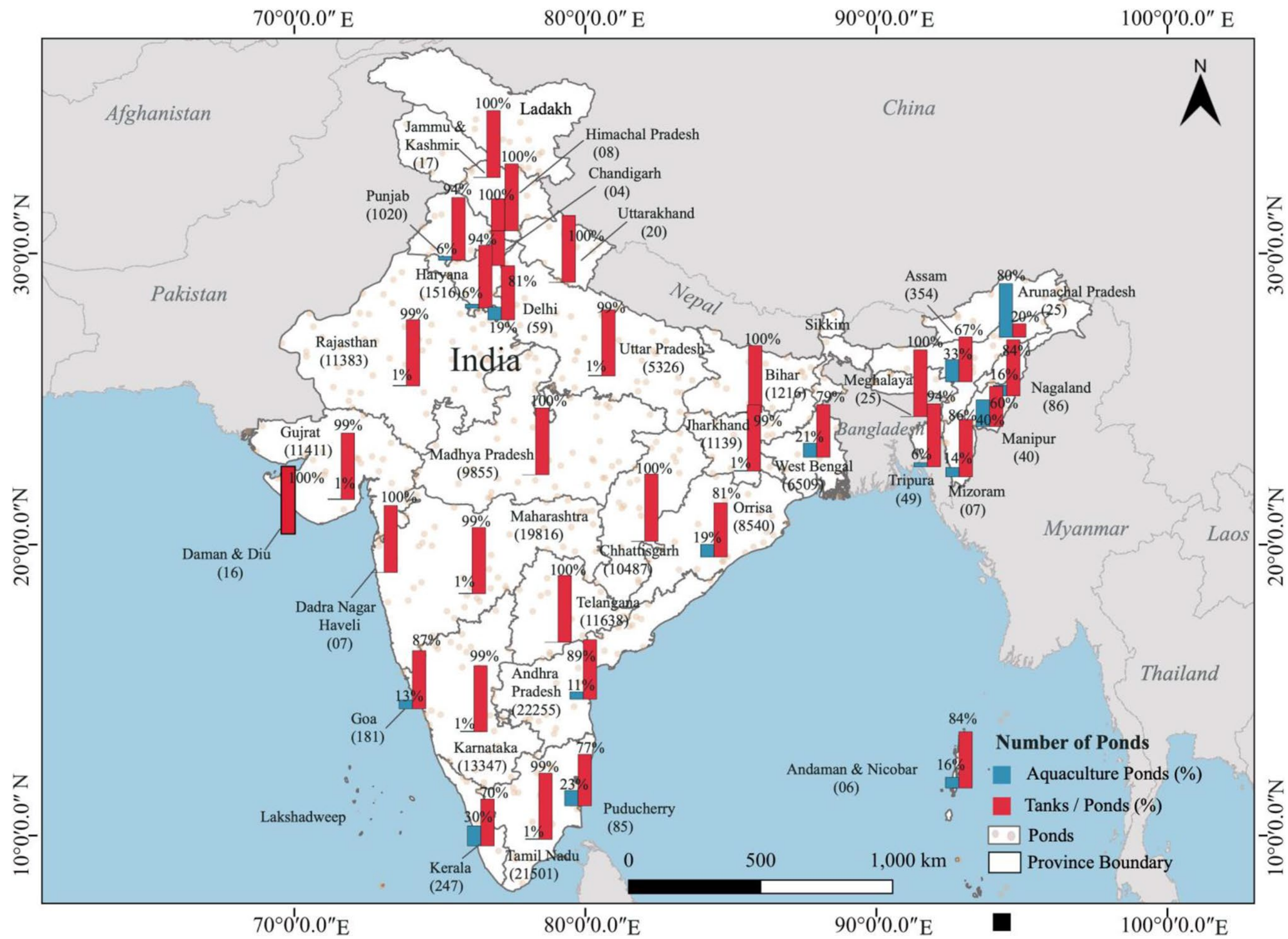

Fig. 2 Spatial distribution of tanks/ ponds (without aquaculture ponds) and aquaculture ponds (coastal and freshwater) across India in 2017–2018 (excluding tanks/ponds < 2.25 hectare)

hydroperiod. Climate extremes such as increased temperature, flood, and droughts can lead to abnormal hydroperiod and negatively affects the biodiversity of the ponds (Chen et al. 2019). In the past few decades (1951–2015), the 6% decline in the summer monsoon rainfall (June–September) increased the frequency and spatial extent of droughts in India. The area affected by drought increased by 1.3% per decade in the country (Krishnan et al. 2020). Increased dry spells and increased water vapor demand in the warmer atmosphere of India adversely affect the hydroperiod of the particularly shallow and small water bodies like ponds and tanks. Aquifer exploitation changes the hydrologic regime of the ponds and results in shorter hydroperiod in ponds. In Spain, the reduced hydroperiod disturbed the population stability of several pond-breeding species which needs a longer hydroperiod to complete metamorphosis (Gómez-Rodríguez et al. 2010). Elevated temperature increases the primary productivity in the shallow water bodies causing nuisance algal bloom and reducing the pond hydroperiod (Kumar and Padhy 2015). Ponds with shorter hydroperiod are highly likely to be encroached for construction and other anthropogenic activities such as solid and liquid waste disposal.

Sedimentation and Soil Erosion

For small ponds, sediment deposition is a serious problem as the rate of siltation is much higher compared to large water bodies and this reduces the useful life of the pond (Verstraeten and Poesen 2000). Apart from geomorphological processes, soil erosion is largely governed by anthropogenic modifications in the catchment such as concrete drainage networks, deforestation, agriculture intensification, road construction, and uncontrolled grazing (Serrano and DeLorenzo 2008; Chen et al. 2019). High rate of topsoil erosion in India threatens the ecological dynamics of the receiving water bodies including ponds (Bhattacharyya et al. 2015). In India, the average rate of soil erosion is 16.35 ton/ha/year, of which 10% are deposits in the reservoirs and ponds leading to the reduction of storage capacity by 1 to 2% annually (Pal et al. 2021). Reduction in the water retention capacity of ponds affects the agricultural productivity and livestock in the developing region (Verstraeten and Poesen 2000). Renwick et al. (2005), studied the sediment budget of the 2.6 million ponds in the USA and found that ponds are the major sediment sink (sedimentation rate: 0.43 to 1.78×10^9 m^3/yr) compared to the large dams (sedimentation rate: 1.67×10^9 m^3/yr; 43,000 reservoirs). Soil erosion and sediment transport not only are responsible for sediment load but also deliver sediment-associated nutrients, organic matter, heavy metals (Goyal et al. 2022), and other emerging contaminants (Riley et al. 2018;) to the ponds (Oertli and Parris 2019). Globally, the erosion of nutrient-rich topsoil (i.e., 25–42 billion tonnes/ year), leads to increased nitrogen (23–42 million tonnes) and phosphorus (15–26 million tonnes) transport (Ramsar-Convention-on-Wetlands 2018). Mukherjee et al. (2022) reported the partitioning of heavy metals in the pond sediment (Pond in East Kolkata Wetland, India) in the order of Pb > Cr > and Cd. In India, a large number of ponds are surrounded by habitation and residential area. The landlocked ponds in the country with narrow or no outlet are highly susceptible to sediment deposition and accumulation of contaminants (Goyal et al. 2021).

Chemical Pressures

Nutrient loading and Eutrophication

Nutrient (i.e., nitrogen and phosphorus) availability governs the net primary productivity and influences the biogeochemical processes in the aquatic ecosystem (Howarth et al. 2021). The primary productivity of ponds is often characterized between mesotrophic and hypereutrophic due to their low dilution capacity and naturally high nutrient concentration (Toor et al. 2011; Chen et al. 2019; Goyal et al. 2021). Eutrophicated pond most likely supports species tolerant to anoxic conditions, limiting the species diversity at the local scale, while negatively impacting the regional biodiversity at the pondscape scale (Oertli and Parris 2019). In India, ponds receive a considerable nutrient load from nearby habitation (i.e., waste disposal), agricultural runoff, and local Industries (Goyal et al. 2021). Uncontrolled wastewater disposal substantially increases the nutrient concentration leading to eutrophication (Chen et al. 2019;). Goyal et al. 2021, studied the ecological status of 12 village ponds in India, the study reported the presence of 37 phytoplankton species of the group Cyanophyceae including *Oscillatoria, Nostoc*, and the harmful algal bloom-forming species *Microcystis Aerugenusa* indicating the hypertrophic conditions in all the studied ponds. Toxic algal bloom is commonly indicated by the presence of toxin-producing-cyanobacteria species such as *Anabaena*, *Microcystis*, *Oscillatoria*, and *Nostoc*, harmful to human and animal health (Serrano and DeLorenzo 2008; Jurczak et al. 2018). The degraded ponds were abandoned for any use and becomes a breeding ground for disease-causing vectors (Toor et al. 2011; Shukla et al. 2020b; Goyal et al. 2021). The waterborne diseases in India affect approximately 37 million peoples which cost 73 million working days/year (EllenMacArthur-Foundation 2016).

Emerging Contaminants and Heavy Metals

Road runoff, unmanaged disposal of hazardous waste and municipal wastewater, often remains the localized source of emerging contaminants in the aquatic ecosystem (Kumar and Padhy 2015; Toor et al. 2011; Riley et al. 2018; Goyal et al. 2022). These trace compounds are broadly categorized as Pharmaceuticals and Personal Care Products (PPCPs), agricultural pesticides, heavy metals, surfactants, and polyaromatic hydrocarbons (PAHs). Although the emerging contaminants are of significant concern to ponds the current monitoring and studies largely focused on large water bodies.

Pesticides from farms emerged as the most widespread organic contaminant in small water bodies and ponds (Riley et al. 2018). Pesticides such as HCH and DDT were particularly prevalent in the rural ponds in India receiving agricultural runoff. Amaraneni (2006) studied eight ponds in India and found the concentration of pesticides (a-BHC, g-BHC, malathion, chlorpyrifos, endosulfan, and ppV-DDT), PAHs (anthracene, anthracene, and chrysene), and heavy metals (Cu, Pb, Cd, Mn, Zn, Ni, Co, As, Cr) higher than the permissible limit in prawns, sediment, and water of the ponds. Ponds receiving stormwater and wastewater inflow adsorbs and accumulate the heavy metals in the deposited sludge. Goyal et al. (2022), studied the heavy metal contamination (Pb, Cu, Ni, Zn, Cr, Cd, Fe, As, and Mn) in 21 village ponds in Uttar Pradesh province of India and found high ecological risk and human health risk (human health hazard index: 0.83 to 21.76) due to heavy metal contamination in pond sludge, with possible contamination of groundwater (Goyal et al. 2022). The accumulation of emerging contaminants in the biota of the pond ecosystem threatens the health and economy of millions of Indians relying on ponds for nutrition and aquaculture. Heavy metal toxicity (As and Pb) was reported in the Labeo Bata fish species in an aquaculture pond in India (Pal and Maiti 2018). PPCPs are the emerging contaminants of concern toxic to aquatic organisms which trigger antibiotic resistance among the pathogens. The source of antibiotics and PPCPs in pond water could be the direct application of human excreta and animal manure as fertilizer in agriculture, the use of antibiotics and their inappropriate disposal (Chen et al. 2018). Road runoff, fertilizer runoff from agricultural fields, and the use of agricultural plastics were identified as the main pathways of microplastics in small water bodies (Riley et al. 2018). A study on seven stormwater ponds in Denmark found that the pond contains

490–22,894 items/m^3 of microplastics dominated by polyvinylchloride, polyester, polypropylene, polystyrene, and polyethylene (Liu et al. 2019). Bordós et al. (2019) studied the microplastic contamination in the fish ponds and found the presence of microplastics in 92% of water samples and 69% of the sediment samples.

Pond Acidification

Freshwater acidification is harmful to various aquatic organisms. Climate warming and changes in water chemistry profoundly affect the pond's pH (Ross and Arnott 2022). The rise in atmospheric carbon dioxide lowers the pH in ponds. Human-induced acidification can be due to atmospheric deposition of carbon dioxide and other inorganic acids or by natural processes and organic acids (Spyra 2017). The emission of gaseous pollutants such as nitrogen dioxide and Sulphur leads to acid precipitation and subsequent acidification of the ponds. The biodiversity of ponds decreases with an increase in acidification, as the species sensitive to low pH could not survive in the acidifying ponds (Chambers et al. 2013). Acidity in ponds alters the solubility of metals in water and increases their toxicity as the metals in dissolved state are more toxic in soft water. Dutta et al. 2016, studied the heavy metal accumulation (mainly Zinc (Zn) and Copper (Cu)) with increased acidification in the bheris (ponds) of East Kolkata wetlands (EKW) in India. The study found a negative relation between pH and dissolved Zn and Cu in the ponds indicating that the acidification accelerates the dissolution of heavy metals in the ponds affecting the floating food chain such as planktons, and fishes through bioaccumulation (Dutta et al. 2016).

Biological Pressure

Non-Native Invasive Species (Bioinvasion)

Bioinvasion is a major ecological disturbance that threatens native biodiversity and ecological processes (Carlton 2002; Kwik et al. 2013; Muralidharan 2017). Invasive vegetation species (e.g., *Eichhornia crassipes*, *Egeria densa*) with relatively fast growth rates dominate the native species, increase siltation, alter the nutrient cycle, impacts fishery, and lead to serious biodiversity loss (Muralidharan 2017; Yadav et al. 2017). Nutrient-rich shallow ponds are highly vulnerable to aquatic vegetation invasion. Pathak and Rana (2021) reported six invasive macrophyte species (*Ipomea aquatica*, *Ipmea carnea*, *Nymphea nauchali*, *Nymphoides hydrophylla*, *Nelumbo nucifera*, and *Potamogeton natans*) in the urban pond of Rajasthan, India. The study found the dominance of anchored floating plants (72%) in the pond, affected its water quality, and biodiversity. In several states of India, 15–59% of the total wetland area is under aquatic vegetation (Bassi et al. 2014) including invasive species such as Water hyacinth, and Water lettuce (*Pistia stratiotes*) (Sandilyan et al. 2018).

Exotic invasive fish species were deliberately introduced into ponds to enhance aquaculture production in India. Sreekanth et al. (2022) studied the impact of three invasive fish species (African catfish (*Clarias gariepinus*), suckermouth catfish (*Pterygoplichthys pardalis*), and Mozambique tilapia (*Oreochromis mossambicus*)) on the pond ecosystem in India. The study found substantial competition between the native and alien fish species, where alien species shared 50% of energy consumption, with high mean prey overlap with native species. The introduction of omnivorous predatory fishes (e.g., *Clarias gariepinus*) impacts the food web, shifts the foraging behaviors of native fish species, and reduces macrophytes and native invertebrates (Riley et al. 2018). Despite the growing awareness of bioinvasion in inland waters, the country lacks robust regulatory measures to control the nuisance.

Legal and Other Challenges

Inadequate Policies and Management Plans

India is a signatory of the Ramsar Convention on Wetlands (1971). The Wetland (Conservation and Management) Rule-2017 of India under the provision of the Environment Protection Act-1986 prioritizes wetland conservation and strictly prohibits encroachment, solid waste dumping, disposal of untreated waste, industrial expansion, conversion, and poaching within the wetland area. However, wetland rules are mainly applicable to the natural water bodies having inundation area > 5 ha, (Ministry of Environment Forest and Climate Change India (MoEF&CC 2021)- http://moef.gov.in) thus ignoring the small ponds under the wetland rule (Hill et al. 2018). In view of the degradation and disuse of existing water bodies causing loss of irrigation potential, the Government of India under MoJS launched a Repair, Renovation, and Restoration (RRR) scheme-2005, later merged with Prime Minister Krishi Sinchayee Yojana-2015 (PMKSY- http://mowr.gov.in/).

Despite the ambitious RRR scheme (restoring 3,341 water bodies), ponds were largely excluded from restoration as the scheme centers on water bodies of size > 5 ha (rural water body) and between > 2 ha and < 10 ha (urban water body), in 2017 (RRR-MoJS 2017). As per new 2022 guidelines, a water bodies of size > 2 ha (rural water body) and > 1 ha (urban water body) are eligible for the RRR scheme (RRR-MoJS 2022). In general small ponds are of size < 1 ha, specifically in rural India. Water is a state subject; every state in India has its classification system for water bodies (MoJS, http://mowr.gov.in/). The nonexistence of a unique water body classification system throughout the country contributes to the deterioration of ponds/tanks. Although no specific policy and legislative frameworks for ponds/tanks exist in India, their conservation and management are indirectly influenced by several other policies. For instance, National Water Policy-2012 (MoJS, http://mowr.gov.in/), National Environment Policy-2006 (MoEF&CC- http://moef.gov.in), National Plan for Conservation of Aquatic Ecosystem -2013 (NPCA; MoEF&CC, http://moef.gov.in), National Action Plan on Climate Change -2008 (NAPCC; MoJS, http://mowr.gov.in/), Atal Mission for Rejuvenation and Urban Transformation (Ministry of Housing and Urban Affairs-MoHUA- (http://mohua.gov.in)), and The Mahatama Gandhi National Rural Employment Guarantee Act-2005 (MGNREGA; Ministry of Rural Development-MoRD, https://rural.nic.in). The number of policies and programs running under various ministries further complicates pond conservation restoration and management.

Land Use Change and Encroachment

Economic growth associated primarily with a seven-fold increase in population (200 million to 1,380 million between 1880 and 2020) has led to land use alterations in India (United-Nations 2019). Flow regime change due to the construction of large dams and weirs reduces the inflow and shrinks the water spread area of ponds, and other wetland ecosystems (Bassi et al. 2014). Land use change, unplanned urbanization, and a dearth of coordinated legal measures paved the way for pond encroachment. Consequently, in India, 15% of the water bodies (mainly ponds and tanks) under minor irrigation scheme-2015 remain unused and non-functional (MoJS, -http://mowr.gov.in/). Urbanization emerged as the major cause of pond degradation and encroachment in India. In Roorkee city (an urban town located on the banks of the Ganges Canal, in the Uttarakhand province of India), the increase in built-up area by 51% (since 2002) led to the reduction in the pond surface area by 11% and subsequent decline in recharge volume by 14.74% (Bhatnagar and Jain 2020). Of 28 provinces and eight union territories, 12 provinces experience the encroachment of the water bodies in India (MoJS, -http://mowr.gov.in/). In a northern India province (Haryana), out of 200 investigated ponds (HPWMA 2021, http://hpwwma.org.in/) 42 are partially or wholly encroached in the year 2020. Surprisingly, pond encroachment and disappearance have rarely been scientifically reported and published.

Strategies for Pond Restoration, Management, and Conservation

A proposed framework for pond restoration and management is illustrated in Fig. 3.

The detailed explanation of the proposed framework for pond restoration and management is given in "Nature-Based Solutions (NBS) for Pollution Control"—"Incentives, Government policies, and Legal Options" sub-section.

Nature-Based Solutions (NBS) for Pollution Control

Nature-based solutions (NBS) offer a sustainable and cost-effective approach to restoring natural processes by altering the fluxes of nutrients, sediment, water, and other pollutants (Nika et al. 2020). It also contributes to several SDG-2030 targets as shown in Table 1. Commonly used NBS consists of green infrastructure (e.g., constructed wetlands, and vegetated buffer strips) ecosystem-based management (e.g., Blue-green network), mitigation and adaptation (e.g., reforestation, and conservation-tillage practice) (WWAP/UN-Water 2018; Williams et al. 2020). Application of one or more NBS together with appropriate grey infrastructure can provide landscape-scale restoration of ponds. A Horizontal Sub-surface Flow Constructed Wetland (HSSFCW) was used along with the grit chamber to restore the village pond in Uttarakhand, India (Kumar et al. 2021). The combined NBS solution improved the water quality of the village pond by reducing the pollutant load with a high removal efficiency of BOD (83%), COD (80%), total coliform (99%), NO_3-N (29%), NH_3-N (81%), and phosphate (75%) (Kumar et al. 2021). The landscape-scale restoration also involves the use of green spaces such as green parks, vegetative buffers strips which enhance infiltration (aquifer recharge), bio-retention (i.e., nutrients, sediments) thus act as the barrier to urban stormwater runoff and pollutants inflow to the receiving water body (Nika et al., 2020). For instance, the vegetated buffer strips acts as the retention zone between the agricultural fields and pond water thus prevent nutrient leaching (Serrano and DeLorenzo 2008). The source water protection through NBS is less costly than managing the downstream impacts. However, due to a lack of awareness and knowledge base, the current investment in NBS is < 1% of total investment in the grey infrastructure globally (WWAP/UN-Water 2018). Developing nations have massive potential for NBS considering the dearth of infrastructural development in the water and sanitation sector.

Hydroperiod Modification and Erosion Control

Principally, the balance between the water depth and hydroperiod needs to be maintained for pond habitat protection. At the pond scale the commonly used hydroperiod modification measures include the removal of sludge, sediment (desiltation), eliminating shading effect, mowing of vegetation (de-weeding),

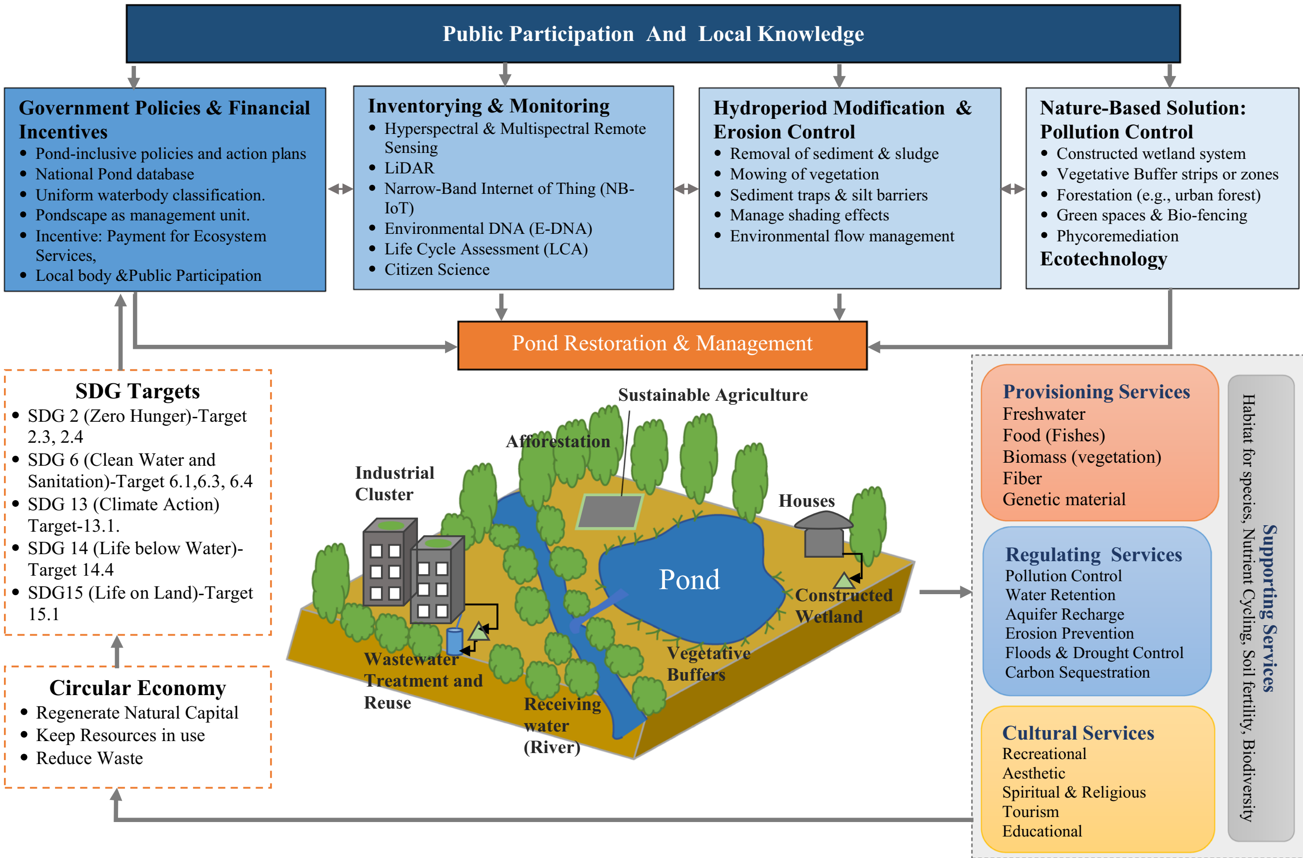

Fig. 3 Framework for pond restoration, management, and conservation- a pathway for sustainable development

Table 1 Indicative research toward Nature-based Solutions contributing to SDG 2030 targets (https://www.un.org/sustainabledevelopment/)

Nature-Based Solutions	Case-Study	Benefits / Outcomes	SDG 2030 Targets	References
Constructed Wetland coupled with Microbial Fuel Cell (MFC)	Domestic Sewage	• Bioelectricity • generation • Enhanced Biodiversity • Improved water quality	SDG-6 Target-6.3; SDG-7 Target-7.3; SDG-15 Target-15.1	(Wang et al. 2017)
Phycoremediation	Dairy Wastewater	• Biofuel – Biodiesel • Bioethanol production	SDG-6 Target-6.3; SDG-7 Target-7.3	(Chokshi et al. 2016)
Vegetative Buffer Zones	Agriculture Runoff	• Pesticide Retention • Reduced pollution load to surface water	SDG-6 Target-6.3	(Syversen and Bechmann 2004)
Urban and Peri-urban Forests	Urban Municipality	• Urban heat island mitigation	SDG-13Target-13.1	(Marando et al. 2019)
Seagrass Meadows	Aquaculture Pond	• Nutrient retention • Suspended particle retention • Pathogen reduction • Oxygenation	SDG-14 Target-14.1; SDG-13Target-13.1	(De los Santos et al. 2020)

CW Constructed Wetlands; *SDG* Sustainable development goals

and algal control (Kumar 2018; Jurczak et al. 2018; Gorsky et al. 2019). The above-mentioned measures aim to manage the water level of the pond ecosystem. Removal of pond sediment and major woody vegetation is important for biodiversity conservation and to maintain open canopy conditions (Walton et al. 2021). Habitat distribution and ecological needs of the native pond species should be accounted for before hydroperiod modification. Structural measures such as silt barriers, sediment trap, stabilization of earthen embankments, sediment detention basin, re/afforestation could be promoted at the pond scale and landscape scale to control soil erosion, and sedimentation (Bugg et al. 2017). Diverted and reduced discharge to the ponds pose serious ecological consequences (reduced dilution capacity) therefore, managing the environmental flow to sustain the pond ecosystem is essential for restoration (Rolls and Bond 2017).

Inventorying and Monitoring Ponds

Asia has the lowest wetland inventories (30%) since 2002 (Ramsar-Convention-on-Wetlands 2018). The central and state pollution control board of India monitors the physio-chemical characteristics of only 97 ponds and 123 tanks (CPCB ENVIS-2019). A reliable inventory of ponds/tanks at different geographical scales is critical to comprehend the biogeochemical cycles and to deal with the associated social, environmental, and economic issues (Chen et al. 2019).

Technologies such as remote sensing/ GIS, Unmanned Aerial Vehicles (UAV), and hydrological modeling are frequently used to remotely monitor hydroperiod alterations (Gómez-Rodríguez et al. 2010), invasive species (Yadav et al. 2017), water quality (Keith et al. 2012), inundation, ecosystem services, and other pond water dynamics (Fu et al. 2018; Karim et al. 2019). With the availability of advanced, high-resolution light detection and ranging (LiDAR), hyperspectral, and multispectral satellite images, the large-scale mapping of the small and scattered ponds/tanks is feasible. The emerging internet of things (IoT) is an advanced technology in remote data collection, multi-sensor data storage (water quality parameters), real-time monitoring, and intelligent control for small water bodies (Chen et al. 2019). The use of Narrow-band Internet of Things (NB-IoT) for real-time aquaculture pond water quality monitoring provides technical help in setting the regulations and deciding the pond management strategies (Huan et al. 2020). Life Cycle Assessment (LCA) tool measures the environmental and economic impact of the technology at every stage of the product thus assisting in the selection of appropriate technology (Garfí et al. 2017). Apart from advanced technological interventions, the use of local people or volunteers for data collection also called citizen science can be a cost-effective approach for pond monitoring. The interested citizens are trained for ecological assessment, data collection, and environmental protection (Biggs et al. 2015).

Ecotechnological methods and Biomanipulation

Ecohydrology is a multidisciplinary approach to restoring the eutrophic aquatic ecosystem in a more sustainable way using both top-down and bottom-up approaches. Ecohydrological treatment involves both in-situ and ex-situ treatment (Paul et al. 2022). Biomanipulation is an in-situ ecohydrological technique that manages the ecologically unstable aquatic food web and modifies the biotic components and their ecological niches by a series of manipulations to improve the water quality of water body (Peretyatko et al. 2009). In general, biomanipulation involves the removal or addition of some important species in the aquatic environments such as zoo-planktivorous, benthivorus, and piscivorous to maintain a healthy species ratio in the aquatic environment (Paul et al. 2022). Zhang et al. 2022, conducted an experimental study and showed that the biomanipulation using silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Hypophthalmichthys nobilis*) rapidly reduced the cyanobacteria and improved the water condition. However, it is recommended to maintain an optimum density of the species for better results. Submerged macrophytes in biomanipulation further improve the water clarity and promote the growth of useful benthic algae by uptaking the nutrients and pollutants (Paul et al. 2022). Freshwater organisms are often difficult to monitor remotely. Environmental DNA (e-DNA) is an emerging cost-effective technique that enables rapid monitoring and analysis of freshwater organisms through their nuclear and mitochondrial DNA in the environment (Harper et al. 2019). The invasive fish species in pond *Procambarus clarkii*, and *Pacifastacus leniusculus* were monitored using e-DNA technique (Mauvisseau et al. 2018). Unlike conventional physical and chemical methods, bioindicators provide a qualitative assessment of direct and indirect biotic responses to environmental stresses and temporal variations. Ladislas et al. (2012) used aquatic macrophytes (e.g., Oenanthe sp., Juncus sp., Typha sp.) as the bioindicators to assess the heavy metal accumulation in the pond receiving stormwater runoff.

Incentives, Government policies, and Legal Options

To promote the practical options discussed above the proposed legislative and regulatory measures are given below:

i. A uniform waterbody classification system applicable to all the water bodies (including small ponds) is vital to ensure better administration and monitoring in all the states. Also, a comprehensive national pond database incorporating states and local bodies is required to facilitate objective policymaking and appropriate intervention at different levels.
ii. Integrate pond conservation into sectoral development plans and sustainable development goals. A coordinated inter-ministerial and inter-departmental approach can formulate a single comprehensive scheme to conserve and restore the ponds at the local level (Top-down approach).
iii. Appropriate demarcation of pond boundaries and its inclusion as a municipal asset under the land records by states can be a vital step to put off pond encroachment. The No Net Loss (NNL) policy can be effectively used as a regulatory instrument to mitigate (i.e., minimize the impact) and offset (i.e., compensate) the

unavoidable losses due to existing or proposed development activity (Sun et al. 2019).

iv. Government incentives to promote sustainable business models supporting pond restoration, conservation, and local economy. The Payment for Ecosystem Services (PES) and Collective Payment for Ecosystem Services (CPES) can be used as effective conservation tools (Jiangyi et al. 2020).

v. Policies to adopt the 6R principle of CE in water and wastewater management which reduces the source water pollution and generate opportunity for local livelihood through reuse, recycling, and resource recovery. Please refer to Online Resource-1 (Supplementary file-1) for details on supportive policies, and action plans for aquatic ecosystem restoration, and conservation promoting a circular economy in India.

vi. Inclusion of local stakeholders in pond-related decision making, policy formulation, and action plans to establish a linkage between the pond ecosystem and various stakeholders (bottom-up approach) ensuring long-term conservation of ponds.

Circular Economy through Pond Ecosystem for Sustainable Ecosystem Services

Circular Economy (CE) approach minimizes the resource input and waste by closing the material and energy loop while keeping the material at the highest utility and value all the time (Geissdoerfer et al. 2017; Kirchherr et al. 2017). The 6R framework of CE (i.e., reduce, reuse, recycle, reclaim, recover and restore) facilitates a closed-loop system for energy and material flow through sustainable resource and waste management, thus reducing the pressure on the natural resources (van Buren et al. 2016). A restorative and regenerative circular economy (CE) strategy is needed to manage natural resources more sustainably.

Linking circular economy (CE) and aquatic ecosystem is vital for the future provision of natural resources (e.g., water, food, nutrient), energy (e.g., biomass, biofuel), and ecosystem services. The upsurge in economic development and consumerism exert pressure on the already limited natural resources leading to resource depletion and ecosystem degradation (Priyadarshini and Abhilash 2020). Unlike developed countries, India has a high resource extraction rate of 1580 tonnes/acre and a low recycling rate of 20–25% (NITI-Aayog 2019). Consequently, many critical raw materials are imported into the country. The country's dependency on imports is 90% for phosphate as raw material or as finished fertilizer (Ministry of Mines—https://www.mines.gov.in/). The transition to a zero-carbon economy, clean and green economy further exerts pressure on natural resources such as biofuels, and biodiesel through increased demand (Mehrabadi et al. 2016; Darda et al. 2019).

The rich biodiversity of ponds provides numerous natural resources (Kumar 2018). Increased demand for natural resources by local industries, agriculture, and households increases the stress on the pond ecosystem. The simple living behavior and 6R framework of CE can reduce the demand for natural resources. The waste and wastewater disposed of in ponds can be a potential source of energy through waste-to-energy initiatives which

Fig. 4 Linkage between circular economy and pond ecosystem

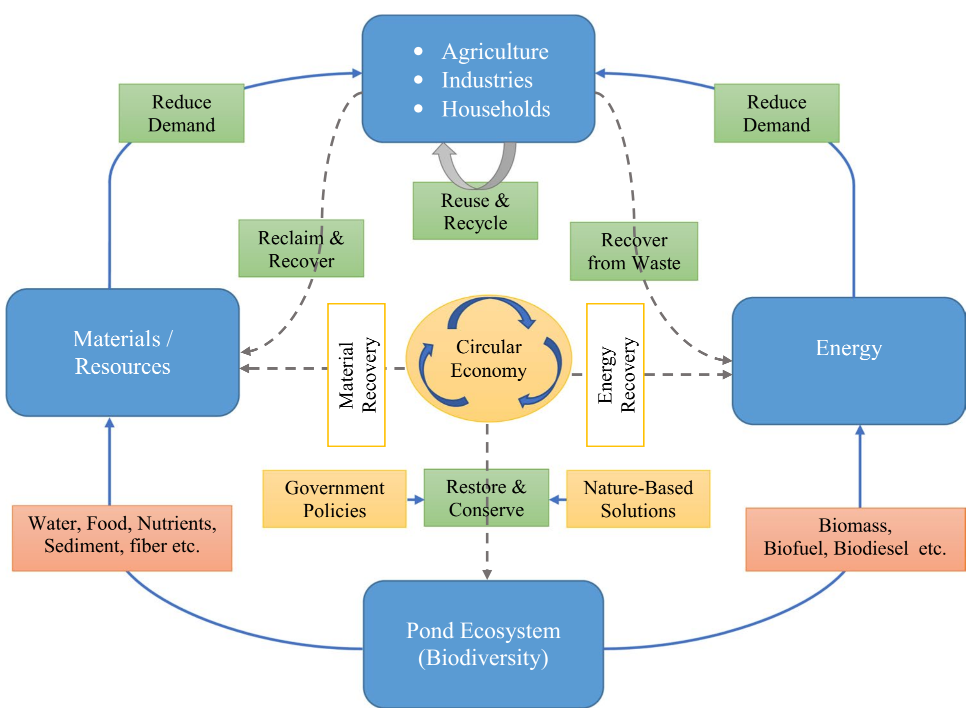

Table 2 Technological and policy interventions for pond restoration and management contributing to CE principles

Restoration and Management Interventions	Ponds/Tanks	Enhanced Ecosystem Services	CE Principles								References
			Regenerate Natural Capital (CE-P1)			Keep Resources in Use (CE-P2)		Design out Waste Externalities (CE-P3)			
			Biodiversity	Water Sources	Water Quality / Nutrients	Material	Energy	Environment	Reduced Waste	Economy	
• Pond Excavation • Pond isolation from adjacent marshes	Experimental Temporary Ponds	• Water bird species richness-Biodiversity	✓								(Sebastián-González and Green 2014)
• Sediment removal • De-shading • Biofiltration (vegetation) • Water circulation	Urban Pond	• Improved water quality • Improved aquatic habitat and species diversity • Enhanced fish production	✓	✓	✓					✓	(Jurczak et al. 2018)
• Biomanipulation • Revegetation	Artificial Pond	• Improved water quality			✓			✓			(Peretyatko et al. 2009)
• Vegetative buffers • Community participation • Waste management	Storm water Pond	• Improved water quality • Macrophyte and plankton control			✓			✓			(Serrano and DeLorenzo 2008)
• Policies and Regulations • Citizen Science • Monitoring & Assessment Technologies	Farm Ponds	• Irrigation • Hydrologic and nutrient cycling • Water conservation				✓		✓	✓	✓	(Chen et al. 2019)
• Constructed Wetland system	Engineered Ponds	• Wastewater treatment • Nutrient retention • Flood Prevention • Biodiversity	✓		✓					✓	(Manzo et al. 2020)
• Distributed Temperature Profiling	Urban Pond	• Reducing Urban Heat Islands (UHI)						✓			(Solcerova et al. 2019; (Manzo et al. 2020)

Table 2 (continued)

Restoration and Management Interventions	Ponds/Tanks	Enhanced Ecosystem Services	CE Principles								References
			Regenerate Natural Capital (CE-P1)			Keep Resources in Use (CE-P2)		Design out Waste Externalities (CE-P3)			
			Biodiversity	Water Sources	Water Quality / Nutrients	Material	Energy	Environment	Reduced Waste	Economy	
• De-siltation tank beds • Repairing sluices, weirs • Repairing feeder channels • Re-sectioning irrigation channels • Peoples participations	Tanks/Ponds	• Improved soil water retention • Groundwater recharge • Silt as fertilizer • Enhanced crop yield • fish production • Increased income/revenue		✓	✓	✓		✓		✓	(Kumar 2018) (https://missionkakatiya.cgg.gov.in/homemission)
• Experimental set-up –High rate algal pond	High-rate algal Pond	• Biomass and Lipid production • Biofuel & Bio-diesel			✓		✓			✓	(Craggs et al. 2012; Mehrabadi et al. 2016)
• Workshops, and awareness programs • Community participation and knowledge sharing	Farm Ponds	• Biodiversity conservation	✓					✓			(Sayer and Greaves 2020)
• Farm Storm water detention system (SDS) • Biomass harvesting and composting	Farm Pond	• Phosphorus (P) Recycling • Water retention • Organic fertilizer • Enhanced soil productivity • Carbon sequestration • Reduced P treatment cost			✓	✓		✓	✓	✓	(Shukla et al. 2020a)

reduce fossil fuel dependency and pollution to the aquatic ecosystem (Kalyani and Pandey 2014). As the recovery of secondary materials requires less energy than the raw ones, the energy-saving opportunity is highly likely through CE practices. Wastewater can also be a source of biofertilizers through nutrient recovery which reduces the dependency on phosphorus imports (Kumar 2018; Shukla et al. 2020a). Under the CE scenario, the use of synthetic pesticides and fertilizers would be 45% lower by 2030 (EllenMacArthur-Foundation 2016). Farm pond biomass valorization and its use as an organic fertilizer in the United States provided economic sustainability to farmers through phosphorus (P) recycling (50%-70%) and reduced the P treatment and energy cost. The application of organic fertilizers further enhances the carbon sequestration in the soil thus contributing directly to crop productivity and climate change mitigation (Shukla et al. 2020a). Mixed land use patterns in India also provides an opportunity for the reuse and recycling of resources fairly easily with limited infrastructural development (Kakwani and Kalbar 2020).

Restoration and management of the pond ecosystems further promote biodiversity richness, ecosystem health, and livelihood through nature-based solutions (Crawford 1979; Jurczak et al. 2018). NBS can be better integrated with CE for sustainable natural resource management and biodiversity conservation. Government policies encourage the 6R framework of CE in ecosystem-related action and management plans. The interaction between the pond ecosystem, natural resources, and energy is illustrated in Fig. 4.

A restored, and well-managed pond/tanks directly or indirectly contribute to the three CE principles (Table 2), (a) Regenerating natural capital (i.e., biodiversity, water cycle, nutrient cycle, and water quality); (b) Keep resources in use (i.e., enhance resource use efficiency of material and energy); and (c) Design out waste externalities (i.e., reduce environmental impacts, waste reduction, and economic sustainability) (EllenMacArthur-Foundation 2016).

Conclusions

Pond ecosystem underpins economic prosperity, social wellbeing, and environmental sustainability through a range of ecosystem services predominantly to the agricultural developing economies. The negative repercussions of uncontrolled developmental activities, land-use alterations, and constrained conservation policies threaten the existence of a biodiverse pond ecosystem. The study highlighted the major physical, chemical, and biological pressures along with the legal challenges which are needed to be addressed systematically. The study revealed pond ecosystem lags behind other aquatic water bodies in research and policy integration. A framework for pond restoration and conservation was presented suggesting the policy reforms, technologies, and other locally accepted conservation measures to attain sustainability through ponds. The study further showcases a linkage between the pond ecosystem and the CE principles, promoting a more regenerative system to lessen the burden on its natural resources and avoid biodiversity loss. The study further highlights the need for better governance and institutional arrangements to encourage various stakeholders for pond conservation and restoration thereby boosting the water security of the region which supports the attainment of SDG 2030 targets.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13157-022-01624-9.

Acknowledgements We are also thankful to the National Institute of Hydrology (NIH), Roorkee, India, for providing the necessary resources needed for this study.

Author Contributions Shweta Yadav: Conceptualization, Methodology, Data collection, Formal analysis, Visualization, Writing–original draft, Writing-review, and editing. V.C. Goyal: Conceptualization, Methodology, Resources, Visualization, Supervision.

Funding We are grateful to the Department of Science and Technology (Government of India) for funding the project "Innovation Centre for Eco-Prudent Wastewater Solutions (IC-EcoWS; grants number- DST/TM/WTI/WIC/2k17/83)".

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing Interest The authors have no relevant financial or non-financial interests to disclose.

References

Adhikari K, Fedler CB (2020) Water sustainability using pond-in-pond wastewater treatment system: case studies. Journal of Water Process Engineering 36:101281. https://doi.org/10.1016/j.jwpe.2020.101281

Amaraneni SR (2006) Distribution of pesticides, PAHs and heavy metals in prawn ponds near Kolleru lake wetland, India. Environ Int 32:294–302. https://doi.org/10.1016/j.envint.2005.06.001

Bassi N, Kumar MD, Sharma A, Pardha-Saradhi P (2014) Status of wetlands in India: a review of extent, ecosystem benefits, threats and management strategies. Journal of Hydrology: Regional Studies 2:1–19. https://doi.org/10.1016/j.ejrh.2014.07.001

Bhatnagar I, Jain K (2020) Simple methodology for estimating the groundwater recharge potential of rural ponds and lakes using remote sensing and gis techniques: a spatiotemporal case study of Roorkee Tehsil, India. Water Resources 47:200–210. https://doi.org/10.1134/S0097807820020025

Bhattacharya S (2015) Traditional water harvesting structures and sustainable water management in India: a socio-hydrological review. International Letters of Natural Sciences 37:30–38. https://doi.org/10.18052/www.scipress.com/ilns.37.30

Bhattacharyya R, Ghosh BN, Mishra PK et al (2015) Soil degradation in India: challenges and potential solutions. Sustainability (Switzerland) 7:3528–3570. https://doi.org/10.3390/su7043528

Biggs J, Ewald N, Valentini A et al (2015) Using eDNA to develop a national citizen science-based monitoring programme for the great crested newt (Triturus cristatus). Biological Conservation 183:19–28. https://doi.org/10.1016/j.biocon.2014.11.029

Bordós G, Urbányi B, Micsinai A et al (2019) Identification of microplastics in fish ponds and natural freshwater environments of the Carpathian basin, Europe. Chemosphere 216:110–116. https://doi.org/10.1016/j.chemosphere.2018.10.110

Brans KI, Engelen JMT, Souffreau C, De Meester L (2018) Urban hot-tubs: Local urbanization has profound effects on average and extreme temperatures in ponds. Landscape and Urban Planning 176:22–29. https://doi.org/10.1016/j.landurbplan.2018.03.013

Bugg RA, Donald W, Zech W, Perez M (2017) Performance evaluations of three silt fence practices using a full-scale testing apparatus. Water (Switzerland). https://doi.org/10.3390/w9070502

Carlton JT (2002) Bioinvasion Ecology: Assessing Invasion Impact and Scale BT - Invasive Aquatic Species of Europe. Distribution, Impacts and Management. In: Leppäkoski E, Gollasch S, Olenin S (eds) Springer Netherlands, Dordrecht, pp 7–19

Céréghino R, Boix D, Cauchie HM et al (2014) The ecological role of ponds in a changing world. Hydrobiologia 723:1–6. https://doi.org/10.1007/s10750-013-1719-y

Chambers DL, Wojdak JM, Du P, Belden LK (2013) Pond acidification may explain differences in corticosterone among salamander populations. Physiological and Biochemical Zoology 86:224–232. https://doi.org/10.1086/669917

Chen D, Liu S, Zhang M et al (2018) Comparison of the occurrence of antibiotic residues in two rural ponds: implication for ecopharmacovigilance. Environmental Monitoring and Assessment 190:539. https://doi.org/10.1007/s10661-018-6883-0

Chen W, He B, Nover D et al (2019) Farm ponds in southern China: Challenges and solutions for conserving a neglected wetland ecosystem. Science of the Total Environment 659:1322–1334. https://doi.org/10.1016/j.scitotenv.2018.12.394

Chokshi K, Pancha I, Ghosh A, Mishra S (2016) Microalgal biomass generation by phycoremediation of dairy industry wastewater: An integrated approach towards sustainable biofuel production. Bioresource Technology 221:455–460. https://doi.org/10.1016/j.biortech.2016.09.070

Craggs R, Sutherland D, Campbell H (2012) Hectare-scale demonstration of high rate algal ponds for enhanced wastewater treatment and biofuel production. Journal of Applied Phycology 24:329–337. https://doi.org/10.1007/s10811-012-9810-8

Crawford SA (1979) Farm pond restoration using chara vulgaris vegetation. Hydrobiologia 62:17–31

CPCB (2021) Central Pollution Control Board, Government of India. CPCB. https://cpcb.nic.in/. Accessed 2 Dec 2021

Darda S, Papalas T, Zabaniotou A (2019) Biofuels journey in Europe: currently the way to low carbon economy sustainability is still a challenge. Journal of Cleaner Production 208:575–588. https://doi.org/10.1016/j.jclepro.2018.10.147

De los Santos CB, Olivé I, Moreira M et al (2020) Seagrass meadows improve inflowing water quality in aquaculture ponds. Aquaculture 528:735502. https://doi.org/10.1016/j.aquaculture.2020.735502

Downing JA, Prairie YT, Cole JJ et al (2006) The global abundance and size distribution of lakes, ponds, and impoundments. Limnology and Oceanography 51:2388–2397. https://doi.org/10.4319/lo.2006.51.5.2388

Dutta J, Saha A, Mitra A (2016) Acidification in EKW water body. Int J Adv Res 3:154–159. https://doi.org/10.22192/ijarbs

EllenMacArthur-Foundation (2016) Circular economy in India

Elsevier Scopus (2022) Scopus. https://www.scopus.com/. Accessed 28 Feb 2022

Fu B, Xu P, Wang Y et al (2018) Assessment of the ecosystem services provided by ponds in hilly areas. Science of the Total Environment 642:979–987. https://doi.org/10.1016/j.scitotenv.2018.06.138

Garfí M, Flores L, Ferrer I (2017) Life cycle assessment of wastewater treatment systems for small communities: activated sludge, constructed wetlands and high rate algal ponds. Journal of Cleaner Production 161:211–219. https://doi.org/10.1016/j.jclepro.2017.05.116

Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ (2017) The circular economy – a new sustainability paradigm? Journal of Cleaner Production 143:757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gómez-Rodríguez C, Bustamante J, Díaz-Paniagua C (2010) Evidence of hydroperiod shortening in a preserved system of temporary ponds. Remote Sensing 2:1439–1462. https://doi.org/10.3390/rs2061439

Gorsky AL, Racanelli GA, Belvin AC, Chambers RM (2019) Greenhouse gas flux from stormwater ponds in southeastern Virginia (USA). Anthropocene 28:100218. https://doi.org/10.1016/j.ancene.2019.100218

Goyal VC, Singh O, Singh R et al (2021) Ecological health and water quality of village ponds in the subtropics limiting their use for water supply and groundwater recharge. Journal of Environmental Management 277:111450. https://doi.org/10.1016/j.jenvman.2020.111450

Goyal VC, Singh O, Singh R et al (2022) Appraisal of heavy metal pollution in the water resources of Western Uttar Pradesh, India and associated risks. Environ Adv 8:100230. https://doi.org/10.1016/j.envadv.2022.100230

Gupta PK, Patel JG, Singh RP et al (2021) Space based observation of Indian Wetlands. Space application centre, Indian space research organisation Ahmedabad, Gujrat, India. https://www.sac.gov.in. Accessed 30 May 2022

Harper LR, Buxton AS, Rees HC et al (2019) Prospects and challenges of environmental DNA (eDNA) monitoring in freshwater ponds. Hydrobiologia 826:25–41. https://doi.org/10.1007/s10750-018-3750-5

Hill MJ, Hassall C, Oertli B et al (2018) New policy directions for global pond conservation. Conservation Letters 11:1–8. https://doi.org/10.1111/conl.12447

Howarth RW, Chan F, Swaney DP et al (2021) Role of external inputs of nutrients to aquatic ecosystems in determining prevalence of nitrogen vs. phosphorus limitation of net primary productivity. Biogeochemistry. https://doi.org/10.1007/s10533-021-00765-z

HPWMA (2021) Haryana pond and wastewater management authority. http://hpwwma.org.in/. Accessed 2 Jan 2021

Huan J, Li H, Wu F, Cao W (2020) Design of water quality monitoring system for aquaculture ponds based on NB-IoT. Aquacultural Engineering 90:102088. https://doi.org/10.1016/j.aquaeng.2020.102088

Indermuehle N, Oertli B, Biggs J et al (2008) Pond conservation in Europe: the European Pond Conservation Network (EPCN). SIL Proceedings, 1922-2010 30:446–448. https://doi.org/10.1080/03680770.2008.11902163

Jiangyi L, Shiquan D, El Housseine HA (2020) Cost-effectiveness analysis of different types of payments for ecosystem services: a case in the urban wetland ecosystem. Journal of Cleaner Production 249:119325. https://doi.org/10.1016/j.jclepro.2019.119325

Johnson JA, Baldos U, Hertel T et al (2020) Global Futures: Modelling the global economic to support policy-making. Wwf Uk 105

Jurczak T, Wojtal-Frankiewicz A, Kaczkowski Z et al (2018) Restoration of a shady urban pond – the pros and cons. Journal of Environmental Management 217:919–928. https://doi.org/10.1016/j.jenvman.2018.03.114

Kakwani NS, Kalbar PP (2020) Review of Circular Economy in urban water sector: challenges and opportunities in India. Journal of Environmental Management. https://doi.org/10.1016/j.jenvman.2020.111010

Kalyani KA, Pandey KK (2014) Waste to energy status in India: a short review. Renew Sustain Energy Rev 31:113–120. https://doi.org/10.1016/j.rser.2013.11.020

Karim M, Maanan M, Maanan M et al (2019) Assessment of water body change and sedimentation rate in Moulay Bousselham wetland, Morocco, using geospatial technologies. International Journal of Sediment Research 34:65–72. https://doi.org/10.1016/j.ijsrc.2018.08.007

Keith DJ, Milstead B, Walker H et al (2012) Trophic status, ecological condition, and cyanobacteria risk of New England lakes and ponds based on aircraft remote sensing. Journal of Applied Remote Sensing 6:1–22. https://doi.org/10.1117/1.JRS.6.063577

Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy: an analysis of 114 definitions. Resources, Conservation and Recycling 127:221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Krishnan R, Sanjay J, Gnanaseelan C et al (2020) Assessment of climate change over the Indian region: A report of the ministry of earth sciences (MOES), government of India. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. https://doi.org/10.1007/978-981-15-4327-2

Kumar J, Pandey VK, Singh R et al (2021) Performance of constructed wetland installed in Ibrahimpur village, Haridwar district, Uttarakhand state. The Pharma Innovation Journal 10:1887–1894

Kumar M, Padhy P (2015) Environmental Perspectives of Pond Ecosystems: Global Issues, Services and Indian Scenarios. Current World Environment 10:848–867. https://doi.org/10.12944/cwe.10.3.16

Kumar MD (2018) Chapter 7 - Mission Kakatiya for Rejuvenating Tanks in Telangana: Making it a Mission Possible. In: Kumar MDBT-WPS and P (ed) Water Policy Science and Politics: An Indian Perspective. Elsevier, pp 115–128

Kwik JTB, Kho ZY, Quek BS et al (2013) Urban stormwater ponds in Singapore: potential pathways for spread of alien freshwater fishes. BioInvasions Records 2:239–245. https://doi.org/10.3391/bir.2013.2.3.11

Ladislas S, El-Mufleh A, Gérente C et al (2012) Potential of aquatic macrophytes as bioindicators of heavy metal pollution in urban stormwater runoff. Water, Air, & Soil Pollution 223:877–888. https://doi.org/10.1007/s11270-011-0909-3

Liu F, Olesen KB, Borregaard AR, Vollertsen J (2019) Microplastics in urban and highway stormwater retention ponds. Science of The Total Environment 671:992–1000. https://doi.org/10.1016/j.scitotenv.2019.03.416

Ma J, Niu X, Zhang D et al (2020) High levels of microplastic pollution in aquaculture water of fish ponds in the Pearl River Estuary of Guangzhou, China. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2020.140679

Madden N, Lewis A, Davis M (2013) Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature. Environmental Research Letters. https://doi.org/10.1088/1748-9326/8/3/035006

Manzo LM, Epele LB, Horak CN et al (2020) Engineered ponds as environmental and ecological solutions in the urban water cycle: a case study in Patagonia. Ecological Engineering 154:105915. https://doi.org/10.1016/j.ecoleng.2020.105915

Marando F, Salvatori E, Sebastiani A et al (2019) Regulating Ecosystem Services and Green Infrastructure: assessment of Urban Heat Island effect mitigation in the municipality of Rome, Italy. Ecological Modelling 392:92–102. https://doi.org/10.1016/j.ecolmodel.2018.11.011

Mauvisseau Q, Coignet A, Delaunay C et al (2018) Environmental DNA as an efficient tool for detecting invasive crayfishes in freshwater ponds. Hydrobiologia 805:163–175. https://doi.org/10.1007/s10750-017-3288-y

Mehrabadi A, Craggs R, Farid MM (2016) Biodiesel production potential of wastewater treatment high rate algal pond biomass. Bioresource Technology 221:222–233. https://doi.org/10.1016/j.biortech.2016.09.028

MoJS Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation (MoJS) (2022) http://mowr.gov.in/. Accessed 15 May 2022

MoEF&CC (2021) Ministry of Environment, Forest and Climate Change (MoEF&CC), India. http://moef.gov.in. Accessed 14 Jan 2021

MoAF (2021) Ministry of Agriculture and Farmers Welfare (MoAF), India. https://pmksy.gov.in/. Accessed 14 Jan 2021

MoHUA (2021) Ministry of Housing and Urban Affairs (MoHUA), India. http://mohua.gov.in. Accessed 14 Jan 2021

MoRD (2021) Ministry of Rural Development (MoRD), India. https://rural.nic.in. Accessed 14 Jan 2021

Mukherjee P, Das PK, Ghosh P (2022) The extent of heavy metal pollution by chemical partitioning and risk assessment code of sediments of sewage-fed fishery ponds at East Kolkata Wetland, a Ramsar site, India. Bulletin of Environmental Contamination and Toxicology 108:731–736. https://doi.org/10.1007/s00128-021-03447-6

Muralidharan M (2017) Do alien species matter? Impacts of invasions in Indian freshwater systems and challenges in management. International Journal of Aquatic Biology 5:114–127

Nika CE, Gusmaroli L, Ghafourian M et al (2020) Nature-based solutions as enablers of circularity in water systems: a review on assessment methodologies, tools and indicators. Water Research. https://doi.org/10.1016/j.watres.2020.115988

NITI-Aayog (2019) Composite Water Management index 2019, Ministry of Jal Shakti and Ministry of Rural Development, Government of India

OECD (2020) Biodiversity and the economic response to COVID-19 : Ensuring a green and resilient recovery

Oertli B, Parris KM (2019) Review: toward management of urban ponds for freshwater biodiversity. Ecosphere. https://doi.org/10.1002/ecs2.2810

Pal D, Maiti SK (2018) Seasonal variation of heavy metals in water, sediment, and highly consumed cultured fish (Labeo rohita and Labeo bata) and potential health risk assessment in aquaculture pond of the coal city, Dhanbad (India). Environmental Science and Pollution Research 25:12464–12480. https://doi.org/10.1007/s11356-018-1424-5

Pal SC, Chakrabortty R, Roy P et al (2021) Changing climate and land use of 21st century influences soil erosion in India. Gondwana Research 94:164–185

Pathak V, Rana S (2021) Studies on some invasive alien macrophytes in Arthuna Pond of Garhi Tehsil in District Banswara of South Rajasthan, India. Plant Archives 21:1543–1549

Patra RW, Chapman JC, Lim RP et al (2015) Interactions between water temperature and contaminant toxicity to freshwater fish. Environmental Toxicology and Chemistry 34:1809–1817. https://doi.org/10.1002/etc.2990

Paul B, Das PK, Bhattacharya S, Gogoi N (2022) Eco-bioengineering tools in ecohydrological assessment of eutrophic water bodies. Ecotoxicology 31:581–601. https://doi.org/10.1007/s10646-021-02509-z

Peretyatko A, Teissier S, de Backer S, Triest L (2009) Restoration potential of biomanipulation for eutrophic peri-urban ponds: the role of zooplankton size and submerged macrophyte cover. Hydrobiologia 634:125–135. https://doi.org/10.1007/s10750-009-9888-4

Priyadarshini P, Abhilash PC (2020) Circular economy practices within energy and waste management sectors of India: a meta-analysis. Bioresource Technology 304:123018. https://doi.org/10.1016/j.biortech.2020.123018

Ramsar-Convention-on-Wetlands (2018) Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat

Renwick WH, Smith SV, Bartley JD, Buddemeier RW (2005) The role of impoundments in the sediment budget of the conterminous United States. Geomorphology 71:99–111. https://doi.org/10.1016/j.geomorph.2004.01.010

Riley WD, Potter ECE, Biggs J et al (2018) Small Water Bodies in Great Britain and Ireland: ecosystem function, human-generated degradation, and options for restorative action. Science of the Total Environment 645:1598–1616. https://doi.org/10.1016/j.scitotenv.2018.07.243

Rohilla SK, Matto M, Jainer S et al (2017) Policy Paper on Water Efficiency and Conservation in Urban India, Centre for Science and Environment, New Delhi

Rolls RJ, Bond NR (2017) Environmental and Ecological Effects of Flow Alteration in Surface Water Ecosystems. Water for the Environment: From Policy and Science to Implementation and Management, pp 65–82

Ross AJ, Arnott SE (2022) Similar zooplankton responses to low pH and calcium may impair long-term recovery from acidification. Ecological Applications 32:e.2512

RRR-MoJS (2022) Guidelines for the scheme Repair, Renovation, and Restoration (RRR) of water bodies under pradhan mantri krishi sinchayee yojna (HKKP)

RRR-MoJS (2017) Guidelines for the scheme Repair, Renovation, and Restoration (RRR) of water bodies under pradhan mantri krishi sinchayee yojna (HKKP)

Sandilyan S, Meenakumari B, Kumar B, Mandal. A and R (2018) A review on Impacts of invasive alien species on Indian inland aquatic ecosystems. National Biodiversity Authority, Chennai. Chennai

Sayer CD, Greaves HM (2020) Making an impact on UK farmland pond conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 30:1821–1828. https://doi.org/10.1002/aqc.3375

Sebastián-González E, Green AJ (2014) Habitat use by waterbirds in relation to pond size, water depth, and isolation: lessons from a restoration in Southern Spain. Restoration Ecology 22:311–318. https://doi.org/10.1111/rec.12078

Serrano L, DeLorenzo ME (2008) Water quality and restoration in a coastal subdivision stormwater pond. Journal of Environmental Management 88:43–52. https://doi.org/10.1016/j.jenvman.2007.01.025

Shukla A, Shukla S, Hodges AW, Harris WG (2020a) Valorization of farm pond biomass as fertilizer for reducing basin-scale phosphorus losses. Science of the Total Environment 720:137403. https://doi.org/10.1016/j.scitotenv.2020.137403

Shukla BK, Gupta A, Sharma PK, Bhowmik AR (2020b) Pollution status and water quality assessment in pre-monsoon season: A case study of rural villages in Allahabad district, Uttar Pradesh, India. Materials Today: Proceedings 32:824–830. https://doi.org/10.1016/j.matpr.2020.03.823

Solcerova A, van de Ven F, van de Giesen N (2019) Nighttime cooling of an urban pond. Frontiers in Earth Science 7:1–10. https://doi.org/10.3389/feart.2019.00156

Spyra A (2017) Acidic, neutral and alkaline forest ponds as a landscape element affecting the biodiversity of freshwater snails. The Science of Nature 104:73. https://doi.org/10.1007/s00114-017-1495-z

Sreekanth GB, Mujawar S, Lal DM et al (2022) Modelling the mixed impacts of multiple invasive alien fish species in a closed freshwater ecosystem in India. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-022-19794-8

Stewart RIA, Andersson GKS, Brönmark C et al (2017) Ecosystem services across the aquatic–terrestrial boundary: linking ponds to pollination. Basic and Applied Ecology 18:13–20. https://doi.org/10.1016/j.baae.2016.09.006

Sun Z, Sokolova E, Brittain JE et al (2019) Impact of environmental factors on aquatic biodiversity in roadside stormwater ponds. Scientific Reports 9:5994. https://doi.org/10.1038/s41598-019-42497-z

Syversen N, Bechmann M (2004) Vegetative buffer zones as pesticide filters for simulated surface runoff. Ecological Engineering 22:175–184. https://doi.org/10.1016/j.ecoleng.2004.05.002

Toor AS, Khurana MPS, Sidhu BS et al (2011) Suitability of village pond waters for irrigation-a case study from district Ludhiana, India. Environmental Monitoring and Assessment 172:571–579. https://doi.org/10.1007/s10661-010-1355-1

UNEP (2020) UN Environment Programme UNEP Finance Initiative and Global Canopy. Beyond "Business at Usual": Biodiversity targets and finance. Managing biodiversity risks across business sectors. UNEP-WCMC, Cambridge, UK

UNESCO (2018) The United Nations world water development report 2018: Nature-Based Solutions for Water

United-Nations (2019) Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations

van Buren N, Demmers M, van der Heijden R, Witlox F (2016) Towards a circular economy: The role of Dutch logistics industries and governments. Sustainability (Switzerland). https://doi.org/10.3390/su8070647

Van MKJ, Basu NB, Tate E, Wyckoff J (2014) Monsoon Harvest -leaving legacy of rainwater harvesting system in suth India.pdf. Environmental Science and Technology 48:4217–4225. https://doi.org/10.1021/es4040182

Verstraeten G, Poesen J (2000) Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. Progress in Physical Geography 24:219–215

Walton RE, Sayer CD, Bennion H, Axmacher JC (2021) Once a pond in time: employing palaeoecology to inform farmland pond restoration. Restoration Ecology. https://doi.org/10.1111/rec.13301

Wang J, Song X, Wang Y et al (2017) Bioenergy generation and rhizodegradation as affected by microbial community distribution in a coupled constructed wetland-microbial fuel cell system associated with three macrophytes. Science of the Total Environment 607–608:53–62. https://doi.org/10.1016/j.scitotenv.2017.06.243

Williams P, Biggs J, Stoate C et al (2020) Nature based measures increase freshwater biodiversity in agricultural catchments. Biological Conservation 244:108515. https://doi.org/10.1016/j.biocon.2020.108515

WWAP/UN-Water (2018) The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris, UNESCO

Yadav A, Sahu PK, Chakradhari S et al (2016) Urban pond water contamination in India. Journal of Environmental Protection 07:52–59. https://doi.org/10.4236/jep.2016.71005

Yadav S, Yoneda M, Tamura M et al (2017) A satellite-based assessment of the distribution and biomass of submerged aquatic vegetation in the optically shallow basin of Lake Biwa. Remote Sensing. https://doi.org/10.3390/rs9090966

Zhang Z, Shi Y, Zhang J, Liu Q (2022) Experimental observation on the effects of bighead carp (Hypophthalmichthys nobilis) on the plankton and water quality in ponds. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-022-19923-3