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Nature-Based Solutions as Tradition in India: Lessons for Water Sustainability in the Peri-Urban

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Abstract: The discourse around 'nature-based solutions' (NBSs) is quite recent, but this paper contends that, as knowledge and practice, the notion of NBS is not novel. Indigenous and rural communities are known to work closely with nature to fulfil their water needs, eke out sustainable livelihoods, and cope with climate variability and the impacts of natural disasters. India is a country where NBS has been a tradition for millennia. Water has been sustainably managed here and related societal challenges successfully met through the use of nature, natural systems, or natural processes within rural as well as urban settings. However, despite the merits, in recent times, many of the old NBSs have come to be neglected and degraded, being increasingly replaced by gray infrastructure. These changes are deepening the water crisis in the country, with the rapidly transforming peri-urban locations being an important area of concern. This paper outlines some of the major NBS forms traditionally established and used in different parts of India. Thereafter, using an integrated analytical framework for assessing sustainability of NBS (developed under project NATWIP), the value of the NBS legacy in India will be analyzed. Finally, the paper proposes important lessons as a way forward for enhancing water sustainability in peri-urban India that is based on the adoption and rejuvenation of the disappearing NBS science in the country.

Keywords: nature-based solutions; traditional ecological knowledge; peri-urban; India; water management; water challenges

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1. Introduction

1.1. Background

The discourse around 'nature-based solutions' (NBSs) is comparatively recent. The term itself has gained prominence during the past decade, primarily through the efforts of practitioners, notably those in the International Union for Conservation of Nature (IUCN), European Commission and UN World Water Assessment Program (WWAP). NBS is an "umbrella" concept signifying approaches that rely on the use of nature, natural systems, or natural processes to address societal challenges [1,2]. These are intended to address a variety of challenges in areas such as water security, biodiversity conservation, climate adaptation, disaster risk reduction, food security, resilient cities, health, and sustainable development [3–7]. In general, NBSs tend to focus on the benefits to people and the environment, enabling sustainable solutions that are responsive to environmental changes and hazards in the long-term [8].

Though multiple sectors can draw benefits from NBS, what cannot be overemphasized is their centrality for the water sector. Focusing more directly on the water-related benefits of NBS, the UN World Water Assessment Program (WWAP) has conceptualized that "NBS are inspired and supported by nature and use, or mimic, natural processes to contribute to improved water management" [7] (p. 22). NBSs are foreseen to have the potential to enhance overall water security by improving water availability as well as water quality. Simultaneously, these also have the potential to reduce water-related risks and generate additional social, economic, and environmental co-benefits. These are thus said to allow for the "identification of win-win outcomes across sectors" [7] (p. 5). Given the multiple benefits offered by NBS, these have emerged as the preferred way forward for overcoming the deepening water crisis across the globe.

At this point, it is worthwhile to pause and muse over the question: is NBS, in terms of both knowledge and practice, only as recent in origin as mentioned above? Or do NBS have older roots in human society? Working closely with nature to create effective human settlements with sustainable water supplies for domestic and productive purposes, coping with climate variability and protection from natural disasters while maintaining healthy ecosystems has been a cornerstone of many ancient civilizations as well as traditional/indigenous communities for millennia. Many indigenous people are known to have rich traditions of land and water management based on nature [9–13].

The traditional knowledge and practices around NBSs existing in many human societies are a sub-set of what is commonly referred to as 'Traditional ecological knowledge' (TEK), with other related usages being 'Indigenous knowledge' and 'Indigenous and local knowledge' [9,12]. On this basis, it can be contended that what is today seen as the 'novel' concept of NBS is based on age-old TEK that has only come to be renewed, revitalized, and systematized in recent years. If that is true, is it possible to learn some useful lessons from the past to address our contemporary water challenges?

The current NBS discourse and practices lay emphasis on stakeholder participation as well as participation of local communities as stakeholders. However, just like the development approaches adopted in the past, the NBS approach continues to be "top-down", driven by "expert" knowledge, rather than being "bottom-up", rooted in a rich TEK base [14,15]. The inability to appreciate TEK, compounded by forces of industrialization, urbanization, and multi-faceted globalization through, for example, changes in land use, loss of access to resources, mechanization of resource systems, and general technological development, has led to widespread decline in TEK across the globe. What is more important is that this decline in TEK has worked hand-in-glove with industrialization, urbanization, and globalization processes more directly to pose challenges for water security and sustainable development, especially in the global South within the context of changing climate regimes.

India is an important growing economy in South Asia, with a large population that is increasingly dependent on water for socio-economic development. However, rapid and unplanned urbanization, together with industrialization and globalization processes, pose grave water challenges for urban cores as well as their transforming fringes. The water resources available to urban centers and peri-urban surroundings are becoming progressively degraded, quantitatively as well as qualitatively [16,17]. Water development and management in these locales are driven by gray infrastructures, and the traditional NBSs rooted in TEK are fast disappearing.

In this light, this paper has a three-fold aim. The first is to present an overview of some of the major NBS forms traditionally established and used in different parts of India (The authors would like to clarify that this paper does not intend to present detailed accounts of the diverse traditional NBSs for water management in India. Such details abound in the existing literature on the subject. (see the 'references' for some examples)). The second is to assess the value of the NBS legacy for water management in India using an integrated analytical framework (developed under the project NATWIP (NATWIP is the acronym for a project titled "Nature-Based Solutions for Water Management in the Peri-Urban: Linking Ecological, Social and Economic Dimensions")). The third is to analyze the relevance of NBS traditions for addressing the emerging water challenges in peri-urban India. For the conclusion, the paper outlines key lessons emerging from the paper for enhancing water sustainability in peri-urban India. This paper is an output of research conducted under the NATWIP project. The content pertains to the part of the research conducted in India (Other countries included in the NATWIP project were Brazil, Norway, Spain, South Africa, and Sweden).

1.2. Conceptual Framework

The conceptual framework for this paper weaves together the notions of NBS, peri-urban areas, their connection with water-related sustainability, and TEK. It also includes a simplified analytical framework adapted from the "NATWIP Framework" referred to above.

1.2.1. Nature-Based Solutions, Peri-Urban Contexts, Traditional Ecological Knowledge, and Sustainability

NBS is a holistic approach of using nature for sustainable development. This term was originally coined by the International Union for Conservation of Nature (IUCN) with the European Commission later redefining it in social and economic terms [2,18,19]. The concept of IUCN insists on the management and restoration of ecosystems as the baseline of any NBS, while the concept of the European Commission is more elaborate and gives stress on the application of solutions that do not only use nature but are also supported and inspired by it [1]. Many other authors defined NBS as problem-solving direction, connecting these two definitions [20–22]. NBS is recurrently in use as an umbrella concept, comprising a wide domain of sustainability and conservation measures. Terms like ecosystem-based mitigation, green infrastructures, hybrid infrastructures, ecosystem-based adaptation, ecosystem protection, or ecosystem restoration are all outlined under the NBS concept and that is why the NBS definitions are consciously unexplicit in the different literatures [23].

Dorst et al. identified four core principles of NBS [18]. The first principle states that nature, as the concept's central foundation, may take many forms while the second principle characterizes NBS as a solution orientation to address environmental, social, and economic challenges simultaneously. The third principle states that NBS needs a holistic planning and governance approach, and the fourth principle mentions that adaptation to place-based conditions is important to NBS. The fourth principle highlights that NBS cannot be implemented as a universal intervention that can be cloned from one place to another. If NBS would not match with the socio-spatial environment, then it will no longer qualify as a solution. The concept stands for "many different interventions in any given context to many different actors" [18] (p. 5).

There is no consensus on the definition of "peri-urban", but the word is used with a triple connotation: a place, a concept, or a process [24]. Willis [23] (p. 80) defined a peri-urban area as "rural-urban fringe where city and country land uses overlap". However, the traditionally dichotomized rural and urban spaces themselves are fluid, with geographically shifting boundaries. The urban fringes expand geographically, 'eating' their way into the countryside, and shrink by being swallowed by the expanding urban core area [24]. Peri-urban areas are thus transition zones, where land-use patterns are constantly changing [25]. The concept of peri-urban is related to urbanization. A few urban theorists like Guldin and McGee mark the peri-urban as a "new kind of rural/urban hybrid landscape", "a partially urbanized countryside", or "a dramatic new species of urbanism" [25–27]. In the light of these definitions, peri-urban areas can be considered as 'Urban Buffer Zones' which provide inevitable resources like water and land for urban expansion and receives urban wastes in return. These are the areas which are constantly losing rural characteristics and moving a step ahead towards urbanization [28,29].

The definition of the 'peri-urban area' changes as per the circumstances and area perspective. That is why it has been argued that it is more convenient to recognize peri-urban areas by processes and features, such as intense land-use change, social, and economic heterogeneity, contested natural resource use, and occupational diversification, than by observing fixed geographical stretches from the city [29]. Since peri-urban areas are areas in transition, they perform different functions for different people, with steady land-use changes from agriculture to real estate, nature conservation, industry, and more. Hence, peri-urban areas become "contested spaces" with multiple competing demands upon local natural resources [24]. Due to all these features, consideration of NBSs for enhancing sustainability in peri-urban areas in general and for water security in these contexts, in particular, becomes profoundly important.

The concept of TEK is tied to the notion of 'tradition'. The Latin root *trader* literally means "something handed over". Thus, tradition denotes those cultural features or practices that have been passed down within a group and has symbolic significance or unique significance [30]. Tradition is also perceived as a 'reservoir'—offering strength to draw upon, and a sense of safety, specialness, or difference, especially within a context of change. Traditions may have roots in the past but are also continually modified or even created. Thus, tradition is generally imbued with a sense of timelessness or sometimes historicity, which invests them with authority that is difficult to challenge [30,31].

TEK denotes that 'knowledge-practice-belief' complex rooted in traditions that comprise knowledge, beliefs, practices, institutions, and worldviews developed and sustained by indigenous, rural, or local communities in interaction with and concerning their biophysical environment [11,32]. These are generally culturally transmitted from generation to generation–emerging from a place-based understanding of the relationships between living beings (including humans), with the environment, and each other–and have evolved through adaptive learning processes in specific places over time [32–34].

As a complex whole, TEK has been seen as comprising multiple dimensions, such as: hydrological, ecological, and other related knowledge; cultural values; local or traditional practices for management of the natural resources; social mechanisms behind these practices for the generation, accumulation, and transmission of the knowledge; the local institutions that provide leaders/stewards and rules for social regulation [32,35]. Furthermore, TEK is not only functionally valid, but also not static—it is essentially a flexible entity which can easily integrate skills, insights, and innovations from other knowledge systems and practices [34]. Consequently, TEK is increasingly recognized as important for creating resilient, sustainable responses to current water and climate crises.

Conceptualized as above, NBSs for water as traditional knowledge and practices then form an important subset of the TEK possessed by any local/indigenous community. Furthermore, building on the above point, as the spaces occupied by the local communities in the peri-urban locales start undergoing transformations through the process of urbanization, their natural environment, natural resources, and the connected TEK start getting eroded. This goes together with the NBSs rooted in such knowledge systems themselves getting degraded. Research shows that TEK and NBSs rooted in such knowledge systems have tremendous potential to support sustainable water resource management, sustainable development, and adaptation to climate change (e.g., [12,14,33,36,37]). The UN World Water Development Report 2018 states that "NBS tend to be in harmony with customary laws and traditional/local knowledge that can be important locally" [9]

(p. 25). More importantly, the International Indigenous Peoples Forum on Climate Change (IIPFCC) stated:

> "For generations, we have managed ecosystems nurturing their integrity and complexity in sustainable and culturally diverse ways... Traditional knowledge, innovations and adaptation practices embody local adaptive management to the changing environment, and complement scientific research, observations and monitoring" [38].

However, not many studies elaborate on what lessons can be learnt and applied from these TEK-based NBSs to improve water management and enhance water sustainability. Extending the concept of sustainability to the water sector, water sustainability can be understood as the ability to meet the present societal and environmental water needs without compromising similar abilities in the future [39]. In order to support various TEK-based NBSs to promote water sustainability, a multidisciplinary and integrative approach is necessary that can address diverse technical, environmental, economic, social, and cultural challenges [40].

Water sustainability may be argued to be an elusive goal, but given the current state of water resources, and the multiple water-related challenges facing the world, there is definitely a need to work continuously towards this goal. Among the few studies in the subject is the one by Cassin and Ochoa-Tocachi [14] who have explored the contribution of TEK to NBS for water, also discussing the effectiveness of these technologies in delivering water security outcomes. They described a number of examples of nature-based indigenous systems for sustainable land and water management, primarily from the mountain highlands of Latin America, Philippines, Hawaii, and Sri Lanka. Linking NBS to water sustainability, they state:

> "Indigenous people and local communities around the world have developed nature-based, resilient, and sustainable solutions for water security based on traditional knowledge-practice-value systems" [14] (p. 283). Water security has been variously defined, but according to a broad conceptualization by the United Nations, it refers to the "capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against waterborne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" [41].

In the context of India, several writings have recently elaborated on traditional knowledge and practices for water management, which are basically NBSs in principle (e.g., [42–46]). Some of these consider the relevance of TEK for water management in disaster risk reduction while others tend to either elaborate on the content itself or explore their connections with sustainable development. This paper enriches the literature by deepening knowledge on the applicability of traditional NBSs to address water challenges in the peri-urban context in India.

1.2.2. Analytical Framework for Evaluating Traditional Nature-Based Solutions for Water

In order to assess the value of the NBS traditions in India for water management, an analytical framework was derived from the main NATWIP framework, as mentioned before [47]. This framework for evaluating traditional NBSs for water is presented in Figure 1 and described briefly here. It has three distinct parts: context assessment, implementation process, and results.

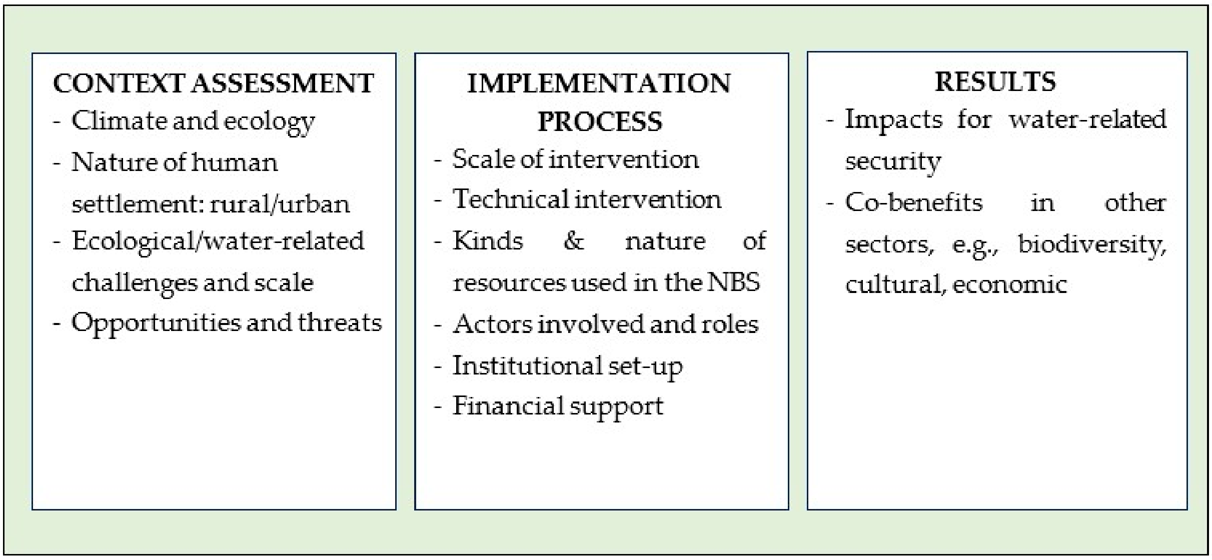

Figure 1. Analytical framework for assessing traditional nature-based solutions for water.

The **context assessment** is primarily aimed at identifying the spatial, climatic, and ecological context within which the traditional NBS has been operational. It examines the climatic and ecological background, the nature of human settlement, ecological/water-related challenges and their scale, and different kinds of threats and opportunities associated with the NBS itself, as well as with the local and regional stakeholders involved.

Next is the **process** of **implementing the NBS**. Here, important considerations are the scale of the intervention, the technical dimensions of the NBS intervention, nature of the resources utilized in creating the NBS and whether these are local or external in origin, the actors involved in implementing and operating the NBS, the underlying institutional structure, and financial dimensions. Lastly, the **results** of the NBS must be assessed with respect to water-related security at the scale of the intervention and beyond, as well as any co-benefits delivered in other sectors.

2. Materials and Methods

Data presented and analyzed in the research for this paper are drawn from primary and secondary sources. A detailed literature review was first conducted to draw a background data set regarding TEK-based NBSs existing in the different parts of the country. The sources included relevant peer review articles as well as the gray literature comprising reports, historical accounts, and policy documents. The current status of selected NBS forms was then investigated through qualitative ethnographic field studies in India, conducted primarily in rural and/or urban pockets in the states of Bihar, Gujarat, Karnataka, Rajasthan, Uttarakhand, and West Bengal. First, a pilot study was conducted in the above states to identify local communities where the selected NBSs currently exist and/or are in use. These included 5 local communities in Bihar, 3 in Karnataka, 6 in Rajasthan, 3 in Gujarat, 4 in Uttarakhand, and 4 in West Bengal.

Primary data from the identified local communities were collected through different methods. Semi-structured interviews were conducted with key informants, quasi-participant observation was made in different seasons of the NBSs regarding their usage and maintenance, and focus group discussions were organized in the small groups within the communities. Women, men, girls, and boys were included among the informants in order to maximize the breadth of the user and management groups. Older women and men were especially consulted for drawing historical perspectives regarding the NBS in question.

Descriptive field notes were taken based on the interviews, observations, and focus groups. In addition, visual data was collected from the field using the camera, which helped in two ways: first, by enriching the findings from interviews, observations and focus groups, and second, by helping identify missing links leading to deeper inquiries. The data were later classified and coded based on the components of the analytical framework derived from the "NATWIP Framework", as mentioned earlier [47]. The datasets were also enriched later through interview-based data from two grassroots practitioners of NBSs in India. Since the NATWIP framework is a tool to guide implementation and evaluation of NBS projects from the baseline, through monitoring impacts after the project, the classified datasets were further qualitatively analyzed using this framework.

3. Nature-Based Solutions as Tradition in India: Key Findings

India is a vast tropical country, known for its diverse geography and eco-climatic variations. The range of climates varies from tropical in the south, tropical semi-arid in the west, sub-tropical in the east, tropical savannahs in the peninsular region, to finally temperate and alpine in the Himalayan north. Throughout the winter, snowfall is consistent in elevated locations. The overall climate is more tropical because the Tropic of Cancer runs through the midst of the country [48,49]. As a result of the dynamics of geography and climate, there exists large variation in rainfall as well as water availability in the country. Rajasthan in the west is among the driest states of the country where the north and north-western parts receive a mere average annual rainfall of 140 mm [50], with the westernmost district of Jaisalmer recorded to have received only 190.8 mm during the period 1901–2021 [51]. On the contrary, in the easternmost corner, i.e., on the eastern border of Arunachal Pradesh, an average annual rainfall of 3106.23 mm has been recorded for the period 1971 to 2007 [52]. In the northern corner, during the period 1951 to 2000, maximum annual precipitation (including snowfall) of 2050 mm in the Reasi district, Jammu, and 100 mm in the Leh district of Ladakh have been recorded [53]. In peninsular India, the annual rainfall during the period 1977 to 2016 was found to vary between a maximum of approximately 4506.3 mm over coastal Karnataka to a minimum of approximately 1590.4 mm over Konkan and Goa [54].

To accommodate and adapt to the eco-climatic and hydrological variations, and geological and physiographic conditions of the respective areas, local communities in India have devised a range of rich traditional water management systems based in nature and natural processes. Ancient Indian history demonstrates that both floods and droughts were regular phenomena in the country. Floods meant excess water that needed to be controlled and simultaneously stored for future use. Droughts, on the contrary, were drivers that necessitated the availability of buffer water stocks. Consequently, a good variety of NBSs traditionally developed in India are based on water harvesting methods of different kinds, mainly rooted in the process of catching the rain where it falls, either as raindrops or runoff [55]. The harvested water is used following different means. Additionally, the tapping of naturally occurring aquifers is widespread while the creation of artificial, perched aquifers through simple technologies is also known. In contemporary times, the various NBS techniques are becoming less popular, but they are still in use and effective. Table 1 presents a selection of examples of various kinds of traditional NBSs for water management in India. These various examples are further described briefly in this section.

Table 1. A selection of traditional nature-based solutions for water management in India.

No.	Type of NBS	Working Principle	Examples	Location	Ecological Region (Source: [55])	Climatic Zone (Source: [56])	Purpose
1	Step-well	Collection and storage of rainwater in tank, combined with withdrawal of groundwater through dugwell	Baoli	Delhi	Indo-Gangetic Plain	Semi-Arid	**Main function:** Source of water for drinking, washing, bathing, and irrigation **Co-benefits:** Groundwater Recharge Shelter to travelers Place for social interactions and meetings, even political Venue for religious functions
				Uttar Pradesh	Indo-Gangetic Plain	Humid Subtropical	
			Baori/Bawari	Rajasthan	Thar Desert, Central Highland	Arid, Semi-arid	
			Vav	Gujarat	Western Coastal Plain and Thar Desert	Semi-Arid, Arid	
2	Drinking water tank	Closed top structure, diverting rainfall/runoff from a small catchment around	Kund, Kundi, Tanka	Rajasthan	Thar Desert	Arid	**Main function:** Source of sweet Drinking Water **Co-benefits:** Drought Mitigation Reduced Water-borne Diseases
3	Drinking water reservoir	Open reservoir harvesting rainwater and runoff, having controlled water inflow and outflow	Temple Tank	Chhattisgarh, Karnataka (several more states)	Eastern Highland and Deccan Plateau	Tropical Wet and Dry, Humid Subtropical	**Main function:** Source of Water for Religious and Cultural Activities **Co-benefits:** Rainwater Tapping for long-term storage Flood Control Groundwater Recharge
3	Pond	Open Runoff Harvesting Reservoir	Talab	Gujarat Uttar Pradesh (several other states)	Western Coastal Plain, Indo-Gangetic Plain	Semi-Arid, Humid Subtropical	**Main function:** Major Water source for drinking and domestic use Irrigation of crops **Co-benefits:** Place for social interactions Groundwater Recharge
			Johad	Rajasthan	Central Highlands, Thar Desert	Semi-Arid and Arid	**Main function:** Groundwater Recharge to enable sweet water abstraction through shallow wells **Co-benefits:** Drinking Water for Animals Livelihood opportunities like agroforestry through enhanced soil moisture and water availability Support local Stream Flow Drought Mitigation
			Pukur	West Bengal	Indo-Gangetic Plain	Tropical Wet and Dry, Subtropical Humid	**Main function:** Major Water source for drinking and domestic use Irrigation of crops **Co-benefits:** Fish rearing for domestic consumption Groundwater Recharge
4	Dug well	Collection of sweet water as seepage from perched aquifer through small shallow wells	Beri, Kuin	Rajasthan	Thar Desert	Arid	**Main function:** Source of sweet water for drinking and cooking **Co-benefits:** Drinking water for animals Community meeting point, especially for women
		Extraction of saline groundwater from deep aquifers through large and deep wells	Patali Kuan	Rajasthan	Thar Desert	Arid	**Main function:** Water source for domestic purposes like washing, bathing **Co-benefits:** Drinking water for animals Community meeting point
		Collection of drinking water from shallow aquifers	Kuan	Uttar Pradesh, Bihar (several other states including those in the Coastal Plains)	Indo-Gangetic Plain	Tropical Wet and Dry, Humid Subtropical	**Main function:** Source of sweet water for drinking, cooking and other domestic purposes **Co-benefits:** Venue for social interactions and community meetings, including political Religious functions when associated with temple

Table 1. *Cont.*

No.	Type of NBS	Working Principle	Examples	Location	Ecological Region (Source: [55])	Climatic Zone (Source: [56])	Purpose
5	Spring-fed water source	Tapping of groundwater emerging as springs	Naula, Dhara	Uttarakhand	Western Himalayas	Humid Subtropical	**Main function:** Source of water for drinking, cooking, washing, and other domestic use **Co-benefits:** Venue for social interactions and community meetings Religious functions if associated with temple
6	Irrigation Tank	Collection and Storage of Rainwater	Cheruvu	Andhra Pradesh	Eastern Ghat, Deccan Plateau and Coastal Plain	Semi-Arid, Tropical Wet and Dry	**Main function:** Irrigation **Co-benefits:** Groundwater Recharge Soil Conservation Flood Control Drought Mitigation Provision of additional livelihood opportunities like forestry, fishing
			Kere	Karnataka	Deccan Plateau and Coastal Plain	Semi-Arid, Tropical Wet and Dry	
			Eri	Tamil Nadu	Eastern Ghat and Coastal Plain	Semi-Arid, Tropical Wet and Dry	
7	Catchment reservoir and Gravity based Diversion Channel	Earthen Embankment to store runoff with Diversion Channel for Fields	Ahar-Pyne	Bihar	Indo-Gangetic Plain	Subtropical Humid	**Main function:** Irrigation **Co-benefits:** Flood Control Drought Mitigation Ahar Bed used for Winter Cropping
8	Earthen Embankment in Fields	Field-based Reservoir to harvest runoff to enhance soil moisture for raising winter crop	Khadin	Rajasthan	Thar Desert	Arid	**Main function:** Soil Moisture Enhancement for winter cropping in Khadin bed **Co-benefits:** Irrigation Increased Soil Fertility Groundwater Recharge to create artificial perched aquifer as drinking water source Flood Control Drought Mitigation Soil Erosion Prevention
9	Diversion Canal	Gravity Based Stream Diversion	Kuhl	Himachal Pradesh	Himalayan Region	Mountain	**Main function:** Irrigation
			Dong	Assam	Brahmaputra Valley	Humid Subtropical	**Main function:** Irrigation (wet paddy cultivation) **Co-benefits:** Fish rearing for domestic consumption
			Pyne	Bihar (e.g., Gaya district)	Indo-Gangetic Plain	Subtropical Humid	**Main function:** Irrigation **Co-benefits:** Flood Control Drought Mitigation
10	Drip Irrigation System	Regulated diversion and distribution of irrigation water from streams and perennial springs through bamboo-piped network	Bamboo Drip Irrigation	Meghalaya	North-eastern Hill Range	Tropical Wet and Humid Subtropical	**Main function:** Major Source of Irrigation **Co-benefits:** Saves Water Quantity Check soil erosion on hillslopes

The various NBSs outlined in Table 1 can be classified into two major kinds on the basis of a functional criterion, namely the manner in which the harvested water becomes available for use. First are those NBSs where the harvested water becomes directly available for use. The usage may be for meeting drinking or domestic needs, such as in the case of drinking water tanks and reservoirs, stepwells (Stepwell is a NBS generally constructed on a vast deep area which gets filled with rainwater in the monsoon season. In the most basic plan, stepwells are deep-dug trenches or rock-cut wells or ponds of water reached by a winding set of stairs or steps. These are variously known in different parts of the country as 'bawari', 'bawdi', 'baoli', 'vav', 'vavdi', 'vai', 'kalyani', or 'pushkarni' [57]. In many cases, these have two inter-connected compartments. The first one is the shallower open tank surrounded by multiple staircases that pass through various floors to finally reach the bottom of the water. The floors often have pavilions which serve as venues for ritual and social gatherings and relaxation in a hot summer. The second compartment is a deeper well for supplying groundwater recharged by the tank and runoff infiltrating from the vicinity [57,58]). and ponds, or for agriculture and other productive purposes, such as through catchment reservoirs, diversion canals, ponds, irrigation tanks, and drip irrigation. The second kind of NBSs are those where the harvested water becomes available for use only indirectly via aquifer recharge. Examples here include dugwells of different kinds, stepwells, and spring-based sources.

Traditionally, the most common NBSs found widely across the country in rural as well as urban areas are ponds and dug wells. The pond itself harvests rainwater, directly functioning as surface water storage and aids in groundwater recharge via percolation. However, dug wells not only catch the rain directly and from runoff seepage but also recharge deeper aquifers by dripping down the rainwater into the pores and cracks of soil and rocks, hence enhancing the water table [59]. In addition, specific forms of NBSs were developed in different regions, mainly depending upon the rainfall, other climatic conditions, topography, geology, etc.

In arid and semi-arid areas, such as Rajasthan and Gujarat in the west, and in the rain shadow of the Western Ghats covering the states of Maharashtra, Karnataka, and Tamil Nadu, the dominant approach has followed a drought mitigation approach to store the rainwater and/or recharge aquifers. Thus, closed drinking water tanks, as well as stepwells and ponds, have been common. In the hills and mountains, groundwater often emerges through cracks and fissures in the rock, where the emergent water flow is intercepted in the form of springs. The water from the spring flow may be harvested naturally or through different kinds of built structures such as the 'naula' (Naula is a structure for harnessing water from a seepage spring which is often in the shape of an inverted trapezoid tank that is closed on three sides and covered. The fourth side, which is open, has steps that lead down to the tank. There is generally a pillared verandah around which may be plain (unadorned) or specially constructed like a temple and embellished with a variety of nature sceneries and idols of deities [60,61].) and 'dhara' (Dhara is a drinking water fountain emerging from a hillside. It could occur naturally and be used directly or be a protected structure with boundary walls and an outflow passage [61]) in Uttarakhand (for drinking and domestic use).

In the river basins, such as that of the River Ganges or Brahmaputra, where sloping lands are drained by a rich network of watercourses that tend to swell during the monsoon season, the flood water is diverted and harnessed for irrigation through the NBS of gravity-based diversion canals such as 'pynes' ('Pynes' are artificial channels that withdraw monsoon floodwaters directly from rivers like the Falgu to be utilized in agricultural fields or store in reservoirs called 'ahar', thereby also helping flood mitigation [62].), and 'dong' ('Dong' represents a system of man-made canals that route water from available water sources such as small rivers, perennial swamps, wetlands, streams, etc., which are usually perennial, to fields for enabling wet paddy cultivation [63].). Depending on the local geographical context, these may be combined with earthen embankments along catchments to make reservoirs, resulting in systems like the 'ahar–pyne' (An 'ahar' is a rectangular catchment having a low embankment on three sides, with the fourth side receiving the runoff during the monsoon season. Pynes (channels) act as outflows to help distribute the floodwaters received, and aid irrigation and agriculture [59].). Another gravity-based irrigation system is the 'kuhl' (in Himachal Pradesh), which a network of surface channels diverting glacial meltwater from local streams [64].

4. Discussion

4.1. Value of Traditional Nature-Based Solutions for Water Sustainability: An Assessment

In the previous section, an attempt was made to examine the working principles and forms of several traditional NBSs for water management. In this sub-section, an attempt will be made to assess the value of the various NBS traditions in India for water management using the simplified NATWIP framework presented at the outset. The assessment is summarized in Table 2.

Table 2. Assessment of various NBS traditions in India for water management.

Dimension	Aspect	Characteristic
Context	Climate and ecology	Structural and functional 'fit' with local eco-climatic, hydrological, and geophysical conditions
	Nature of settlement	Found in rural and urban settlements, as applicable
	Water-related Challenges and Scale	Address primarily water scarcity, floods, and water quality problems
	Opportunities and Threats	Multifunctionality brings opportunities while neglect and replacement by alternate contemporary solutions bring threats
Implementation	Scale of intervention	Scale of creation, operation, and maintenance are primarily local (within a rural or urban community), while scale of impact may extend across multiple local communities
	Nature of Technical Intervention	Simple and grounded in local context, largely based on locally available knowledge, skills, and expertise
	Kind and Nature of Resources used	Mostly local and naturally available material, e.g., soil, stone, mortar
	Actors and their Role	Members of local community engaged in design, production, and management
	Institutional Set-up	Embedded in religious, economic, and socio-political institutions at a decentralized scale
	Financial Support	Local grounding enables financial viability
Results	Impacts on Water-Related Security	Generally multi-functional, primary services include water supply for drinking and other domestic needs, water for agriculture and other productive activities, flood management, and drought mitigation
	Co-benefits in Other Sectors	Aquifer recharge, support to ecosystems and biodiversity

4.1.1. Context Assessment

NBSs have already been identified as solutions that are not universal interventions, which can be cloned from one place to another. In order to qualify as a solution, a NBS must always match the local socio-spatial context. The preceding section clearly shows that the various NBS traditions for water management in India have been designed and implemented in a way that 'fits' well—structurally as well as functionally—with the local eco-climatic, hydrological, and geophysical conditions. Regarding the connected human settlement, a number of these NBSs, such as the dugwells, stepwells, ponds, tanks and spring sources (in hilly regions) were found to be an integral part of rural as well as urban water supply systems, while others like the ones for irrigation, were more relevant for the rural milieu.

The water-related challenges addressed by these NBS are diverse. What is significant is that a single NBS is often multi-functional. For example, in the arid and semi-arid regions, NBSs like the 'johad' ('Johad' is a concave-shaped mud barrier built across the slopes to arrest rainwater runoff. This results in a water reservoir that, apart from helping in groundwater recharge (that, in turn, is used for irrigation), also serves as a watering point for cattle [65].), 'kuin' and 'beri' help address water scarcity as well as water quality (salinity) challenges. Meanwhile, in the Indo-Gangetic Plains, 'ahar-pyne' and 'pyne' networks not only facilitate irrigated agriculture but also help mitigate floods. Similarly, the ponds and tanks serve as ready-to-use freshwater sources but, simultaneously, they also help recharge the aquifers that in turn support ecosystems as well as alternate water sources like the well. Many of the NBSs serve important social and cultural functions as well.

4.1.2. Implementation Process

The scale of creation, operation, and maintenance of the NBS studied is primarily local, confined either within a local rural or urban community (for example, a village pond or tank) or even a single household (for example, a family-owned well or small drinking water tank). In the case of larger systems, such as large ponds, 'ahar-pyne', 'kuhl', or the 'khadins' (Khadin is a reservoir in the agricultural field created by raising earthen embankments around. It is used for holding the monsoon runoff to raise the soil moisture in the field so that crops can be grown in the winter season. A Khadin is generally large, with several adjacent rural communities holding a share [66].) of Rajasthan, several adjacent communities may be involved in the process.

The scale of impact is also generally local, which could extend to one or more adjacent rural or urban communities. In the case of larger systems, such as the 'ahar-pyne', 'kuhl', or 'dong', several villages are often connected in a series through canal networks. Similarly, ponds and tanks are often known to be interconnected with overflow from the one upstream, filling up the next one downstream and so on in the sequence, until the overflow from the last one drains into an adjacent watercourse. In the case of 'khadin', farmers from all the participating villages draw the most benefits.

In terms of technical intervention, the NBSs for water management are generally simple, largely based on locally available knowledge, skills, and expertise. Regarding the resources used, many NBSs are simply constructed by digging out the soil (such as in the pond, tank/reservoir, well, and canals) using simple tools like the manually operated hoe and shovel. Some NBSs like the well, tank, or spring may require a lining that is generally prepared using naturally available materials like stones or locally produced bricks, joined together using lime and mortar.

The institutional set-up underlying the construction and management of NBSs is embedded in religious, economic, and socio-political organizations at a decentralized scale. For example, water in general is regarded as precious, and its conservation and preservation sanctified by religion. Community-based local institutions that could be multi-functional in nature have been responsible for steering the production and maintenance of these NBSs. However, larger systems like the 'ahar-pyne' networks, stepwells, or bigger drinking water tanks ('kund'), have been produced with external resources under royal patronage or even with the support of wealthy merchants. The actors involved in producing and managing the NBS technologies at a community or individual scale continue to be an integral part of the local communities. In some cases, special craftsmen with specific skills are required, such as the 'well diggers' who specialize in this work. Locally available resources and manpower generally makes these technologies financially viable at the local scale.

Whenever the NBS is used for drinking and cooking, protection from water contamination is often a concern, and this is achieved either naturally and/or through community rules. In the case of NBSs like the stepwells and different kinds of dugwells, the technology first helps filter the water naturally as it passes through multiple layers of sand and/or soil. Social rules about the maintenance of cleanliness around the source and during usage of the wells further ensure that quality is protected. In the case of NBSs like drinking water reservoirs and ponds of different kinds, the social rules of maintenance and usage are often elaborate and strict. For example, the pond bed and, if possible, the immediate catchment are cleaned by the community before the onset of the monsoon rains. Afterwards, the users are forbidden from carrying out polluting activities such as washing and cleaning at the water source. Wastewater drainage is not allowed in or near any such drinking water sources.

4.1.3. Results

The impact of the various traditional NBSs for enhancing water-related security is more than obvious from the foregoing presentation. Most of the NBSs are multi-functional and have provided a diversity of water-related services to local communities for centuries. Cumulatively, the primary services include water supply for drinking and other domestic needs, water provision for agriculture, other productive activities—which may include irrigation, moisture-based cropping, animal raising, and fish production—flood management, and drought mitigation. Aquifer recharge, which is a co-benefit of several different NBSs (such as pond, tank/reservoir, well, 'ahar-pyne'), reinforces not only the water supply but also supports ecosystems and biodiversity. Several other co-benefits often accrue from these NBS. Examples include social functions such as provision of venue for women/men/community to meet and interact, political functions if used as a venue for meetings of local village heads/authorities, and cultural and religious functions if associated with temple or sacred values along with serving as a venue for observing festivals and fairs. The fairs may also serve as local markets enabling financial transactions.

4.1.4. Opportunities and Threats

The above analysis indicates that the NBS traditions of India have much to offer from a water sustainability perspective. Seen along the environmental axis, these are solutions regarding water that rely on principles of nature, natural systems, or natural processes that are locally grounded; they are built upon locally available geographical, hydrological, ecological, and climatic knowledge, as well as technologies that are simple and utilize resources primarily derived from the local natural context. These may also be argued to be rooted in processes that promote harmony with nature, rather than being over-exploitative or causing other kinds of damage to nature. The benefits for flood and drought mitigation are more than obvious. Economically, their local contextualization not only makes these more affordable, but their multi-functional role facilitates communities with additional livelihood opportunities (for example, fishing and forestry). Socially, for reasons cited above, these may be seen to offer the potential of greater equity in distribution of benefits as well as participation in creation and management of the technologies, in addition to the variety of socio-cultural co-benefits as described earlier.

Despite their environmental, economic, and social potentials, NBS traditions in India are presently facing significant neglect and degradation. A complex range of technological changes as well as socio-economic-political transformations (like dilution of caste-based professions, rapid urbanization, industrialization and political changes) have played a massive role in changing the context within which these NBSs developed, functioned, and thrived until some decades ago. This changing context presents a substantial threat, especially because rejuvenating and sustaining NBS requires not only revival of the technologies per se but also institutional and governance frameworks to support and promote them.

Putting together the various benefits that NBS traditions bring for water management, as elucidated above, it has emerged that these offer immense opportunities to enhance water sustainability in an era when climate change and other environmental challenges increasingly threaten the quantity and quality of water resources available for society and nature. What is needed is the (re)designing of appropriate institutional and governance frameworks that can 'fit' well within with the current transforming socio-economic-political settings to support and promote NBSs.

4.2. Relevance of NBS Traditions for Water Management at the Peri-Urban 'Interface'

Within a transforming context, peri-urban areas are fast emerging as "contested spaces" where multiple competing demands are made upon local water resources. These are seen as locations where the negative ecological footprint of urbanization emerges and extends rapidly, mainly due to the failure to integrate urban with environmental planning [29,67]. Among the most common water-related challenges encountered in peri-urban areas are water shortage, flooding, and compromised drinking water quality. Some examples of relevant NBS traditions for water management at the Indian peri-urban 'interface' are presented in Table 3.

Table 3. Relevant NBS traditions for water management at the Indian peri-urban 'Interface'.

Water-Related Challenge	Proposed TEK-Based NBS Intervention	Co-Benefit
Water shortage	Enhancing water supply through storage of harvested rainwater in structures like 'tanka'	Conservation of groundwater
	Rejuvenation of closed/dilapidated dugwells and construction of new ones	Conservation of groundwater Aquifer recharge
	Construction of stepwells and rejuvenation of old ones	Conservation of groundwater Aquifer recharge
	Rejuvenation of disappearing ponds and tanks and creation of new ones	Aquifer recharge
Flooding	Restoration and rejuvenation of encroached or dried up ponds, tanks and lakes for buffering floods	Aquifer recharge
Water quality	Rainwater harvesting for recharging shallow aquifers to procure safe drinking water through shallow wells or from rainwater ponds	Aquifer recharge Conservation of groundwater

Water shortage is a multifactorial issue which commonly results from a population rise that exceeds the carrying capacity of existing local water resources, disappearance of local water bodies due to encroachment, and over-exploitation of existing groundwater reserves coupled with a reduced pace of recharge. The latter could be a result of catering to the needs of the newly settled peri-urban populations or bulk supply to the urban core where conventional sources have become inadequate. Flooding is commonly associated with encroachment of local water bodies for land development and other kinds of changes in peri-urban landscapes, which end up interfering with the local hydrological regimes.

Considering these challenges on the one hand and looking back at the merits of NBS-based traditions on the other, it is more than obvious that (re)integrating the latter into peri-urban contexts can undoubtedly help address the challenges to an appreciable extent and foster sustainable urban development. In this section, an attempt will be made to examine how the traditional wisdom of NBSs can help address the water-related challenges in the peri-urban context of India.

A rapid population rise in peri-urban areas brings increased water demand. Augmenting the water availability from locally existing sources can help fulfil this need substantially. This is possible by integrating multiple NBS water sources at household and community levels. An example here is the different kinds of infrastructures based on rainwater harvesting that are similar to the 'tanka', 'kund' and 'kundi'. Furthermore, since NBSs are multi-functional in character, restoring, rejuvenating, or creating NBSs can simultaneously address other water-related challenges. For example, rejuvenation of closed/dilapidated dugwells and construction of stepwells (where appropriate) can help in water supply, prevent over-exploitation of groundwater, as well as enable aquifer recharge. Rejuvenation of disappearing ponds and tanks and creation of new ones (wherever possible) can help counter the problem of disappearing local water bodies. This would enhance water availability at the local scale as an immediate effect, but additionally, it would counter over-exploitation of local groundwater reserves. Furthermore, construction/rejuvenation of water bodies would enhance the pace of local aquifer recharge, which would further help address the problem of groundwater depletion.

In fact, the NBS water traditions can be further modified to adequately and appropriately address specific problems. For example, rainwater harvesting can be based on the constructed rooftop as a catchment, and the rainwater collected can be put to consumptive use at home (e.g., drinking, washing, bathing, flushing) or be diverted for aquifer recharge underground. Similarly, rejuvenated dugwells are not only meant to draw water for different kinds of use, but these can also be used as recharge wells to augment groundwater reserves, such as those being tested in Bengaluru [68,69].

Regarding the challenge of flooding in urban and peri-urban spaces, restoration and rejuvenation of encroached or dried-up surface water bodies can play an important role. The runoff resulting from monsoon spells or otherwise can get stored in the rejuvenated ponds, tanks, and lakes (if any), thereby buffering floods. Additionally, the stored water can help recharge local aquifers while preserving biodiversity and cultural functions, including tourism.

Wherever groundwater is known to have compromised quality from natural or anthropogenic causes, NBS traditions have the potential to provide safe drinking water, particularly through rainwater harvesting. In the Thar Desert of Rajasthan, groundwater in several villages is saline and rich in fluoride, supplied through government tubewells. Similarly, in West Bengal, arsenic in the shallow aquifers ends up poisoning peri-urban handpumps. In both these contexts, harvested rainwater has helped to solve these challenges, which is used either from an annually recharged perched aquifer yielding safe water through shallow wells (in Rajasthan) or from rainwater ponds (in West Bengal) [70].

5. Conclusions

The strength of NBS traditions for water management lies in their integrative, systemic nature, which can be seen as holding immense promise from a water sustainability perspective. A number of traditional NBSs (such as dugwells, stepwells, ponds, tanks, and spring sources) have been an integral part of rural as well as urban water supply systems, also bringing several co-benefits such as flood mitigation, drought resilience, and biodiversity. A complex web of factors has gradually interfered with their existence and well-being as discussed, but there definitely lies a way forward.

Some important lessons to learn from this paper in this regard are summarized here. First and foremost, the value of TEK-based NBSs for addressing water challenges in peri-urban settings is enormous. Hence, every effort should be made to integrate these principles and practices for water management in peri-urban India. Second, since TEK is a place-based science, any NBS tradition to be integrated for this purpose should be adaptive to the local environmental settings, such as eco-climatic, biophysical, and hydrological aspects. Third, the very nature of being localized further implies the need for adaptiveness within the given social, cultural, economic, and political contexts. Thus, any policy promoting adoption of NBS traditions for peri-urban water management must be based on the principle of decentralization. Fourth, depending upon the nature and extent of the water-related challenges in the problem context, attempts should be made to customize the traditional NBS forms for maximum output. Fifth, in order to ensure that the revived NBS traditions thrive and develop, appropriate institutional structures and organizational routines will need to be innovated and applied. Finally, given a scenario of increasing water demands in peri-urban settings due to rapid population rise as well as changing water-use patterns, the effectiveness of TEK-based NBSs that generally operate in small-scale settings may be questioned. In order to address such possible limitations, innovative solutions that combine NBS traditions alongside the conventional water management approaches are implied.

In order to enhance the integration of TEK-based NBSs for managing water challenges in peri-urban India, their alignment with existing policies in the country is essential. The National Water Policy (2012) outlines a common integrated perspective to govern the planning and management of water resources, considering local, regional, and national contexts and to be environmentally sound [71]. Within the scope of the policy, Jal Shakti Abhiyan, which was a water conservation campaign launched by the government in 2019, already focused on the theme "Catch the Rain—Where it Falls When it Falls" and aimed to cover all the blocks of all districts (rural as well as urban) across the country. Rainwater harvesting, renovation of traditional water bodies, and watershed development have been important components in this campaign. Water-related NBSs are further supported by several programs and schemes on protection and improvement of green covers that includes the National Afforestation Program and Green India Mission [72]. Thus, a sound policy background already exists. What is needed is a clear focus on the water-related challenges in the peri-urban sector, and a blue-plan for addressing these through integration of context-based, water-related NBS traditions.

The recommendations arising from this study closely align with the Global Standard for NBS promoted by the International Union for Conservation of Nature and Natural Resources (IUCN) for enhancing the effectiveness, sustainability, and adaptability of NBS interventions [73]. According to this practical framework, comprising eight important criteria, the NBS should be designed as a response to a societal challenge that has been identified as a priority by those who are directly affected by the challenge (i.e., the stakeholders) (Criterion 1). Furthermore, the NBS design should be informed by their knowledge about the interactions between different aspects of the landscape using a three-scale framework that considers not only the concerned landscape itself but also among its various parts and the wider environment around it (Criterion 2). Also, the NBS intervention must afford opportunities for the stakeholders to engage with and participate in its design and implementation, advocating clearly to uphold their own rights and interests (Criterion 5). Furthermore, the NBS should be managed adaptively based on evidence, which draws on scientific understanding as well as indigenous, traditional, and local knowledge. Finally, the NBS design, implementation, and lessons learnt should be shared for upscaling and mainstreaming to trigger transformative change (Criterion 8).

Within the scope of the national policy framework and the IUCN Global Standard, the TEK-based NBS forms outlined in this paper are functionally valid in need of time in the contemporary peri-urban Indian context. These must be comprehended as essentially flexible entities with the potential to integrate skills, insights, and innovations from other knowledge systems and practices. TEK-based NBSs must therefore be increasingly integrated into policy and practice for creating resilient, sustainable responses to current peri-urban water crises within a climate change regime.

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Abbreviations

The following abbreviations are used in this manuscript:

NBS	Nature-based solution
TEK	Traditional ecological knowledge
IIPFCC	International Indigenous Peoples Forum on Climate Change
WWAP	World Water Assessment Program

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