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A Review on Traditional Ecological Knowledge and Its Role in Natural Resources Management: North East India, a Cultural Paradise

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Abstract
Sustainable management of natural resources plays a critical role in poverty alleviation and overall socio-economic development. North East (NE) India is blessed as a biodiversity hotspot, being also home to around 150 ethnic tribes with diverse ethical, cultural and traditional beliefs, endorsing the region as a cultural paradise rich in natural resources and traditional ecological knowledge (TEK). Conversely, the severely constrained nature of TEK, has juxtaposed TEK practices and sustainable natural resources management (NRM) in this review. Deliberating on the broader perspectives of TEK and ensuing practices, we have identified twelve sustainable development goals (SDGs) which are directly correlated to the TEK and practices of NE region. This review has meticulously detailed TEK and practices that can help in achieving various sustainable development targets of different SDGs in a more comprehensive and eco-friendly manner. Houde's manifestation to differentiate each element of TEK and practices present in the NE region of the country, such as traditional farming and irrigation systems, sacred groves, and cultural belief systems of different tribes, have been systematically analyzed and documented for each of the eight states of this region. The benefits accrued modern practices related to NRM are correlated with TEK, or adaptive empirical knowledge system. Indigenous agricultural systems, watershed management, biodiversity conservation, and ethnomedicinal therapeutic systems in NE India formed a vital part of the review. However, rapid urbanization, industrialization, and deforestation warrant an urgent need to systematically collate, document, analyze, and conserve the TEK of the indigenous communities of NE India.

Keywords Traditional Ecological Knowledge · Indigenous communities · Natural Resource Management · Houde's manifestation · Sustainable development goals

Introduction

Traditional Ecological Knowledge (TEK), garnered and renewed across generations, chaperons protect human society through manifold interactions with the immediate environment (Nakashima et al. 2012). The point of convergence of this definition is the TEK capital, created and conserved by communities over time, that buffers environmental challenges and aids natural resource management (NRM). As a natural corollary, TEK is credited with anchoring the kinship between living and the environment (Whyte 2013). Yet, this line of reasoning is not universally green-lighted, and many researchers do not qualify TEK as a body of basic knowledge. McGregor (2004) designates TEK as a stewardship activity characteristic of the indigenous people and their societies. Pierotti and Wildcat (2000) consider the concepts of "fully" and 'responsibly' in TEK philosophy akin to moral underpinning. In addition, TEK is viewed as a retrospective knowledge/response system that evolved in the native societies under constant pressure on the availability of vital and indispensable resources. TEK predominantly covers the cultural practices, spiritual values and normative rules present in the indigenous societies. Indigenous men and women use their collective environmental wisdom and

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ethics as a part of cultural practices and secure their livelihood by managing resources.

Natural resources that improve the quality of human life have been propelled into crisis mode by relentless exploitation for an exponentially increasing human population (Beura 2015; Reddy 2016; Subramanian 2018). Though, the proficiency of modern NRM significantly improves productivity, but it does not guarantee longer sustainability. Consequently, the TEK-based conservation and sustainable use of natural resources, developed and preserved by the indigenous people, has gained considerable ground worldwide. The major conflicts of TEK and scientific method-based NRM are due to the differences in culture and values between indigenous people and those of Western origin (Adamowicz et al. 1998). Therefore, urgent, effective assimilation of TEK and modern science-based NRM is highly required. The first step in this endeavor would be to address the similarities and dissimilarities between TEK and modern science; it has been said that TEK and modern science-based NRM share many similarities with some notable differences (Mazzocchi 2006). In terms of similarities, both knowledge systems are based on observation and generalization derived from identified observations with several concepts developed by ancestor resource managers, validating concepts derived from ecological sciences (Berkes et al. 2014). In terms of differences, methodologies used for observation and data collection vary significantly; TEK offers qualitative data based on trial and error-based studies versus the quantitative data derived from systematic experimentation and observation of modern science-based NRM. Thus, the basic point of divergence is the nature of the data derived; modern science-based NRM generates empirical, systematic, verifiable, and replicable data (Inglis 1993; Ruddle 2008; Whyte 2013); while data from TEK are moral, ethical, intuitive, spiritual, and holistic in nature. Western science hardly measures ecological attributes quantitatively, whereas TEK measures ecosystem qualities in terms of eco-cultural attributes, goods, and services (Burger 2011). Consequently, in most cases, modern scientific methods, on which NRM is based, are more materialistic and reductionist and do not possess social values (Kloppenburg 1991; Nakashima et al. 2002; Ludwig and Poliseli 2018). In addition, TEK provides more diversified methodologies for designing management strategies than contemporary scientific methods (Kloppenburg 1991). TEK supports sustainability in resource use, while NRM is based on the modern scientific approach that primarily emphasizes exploitation efficiency in terms of physical and monetary yields (Berkes et al. 2014). In the conventional species conservation method, spiritual values are often ignored (Lopes and Atallah 2020). However, TEK-based beliefs, customs, and herbal expertize have been widely discussed, appreciated, and assimilated in ethnobotanical research (Chakraborty et al. 2012). TEK of indigenous communities on forest ecology and animal behavior help to mitigate problems associated with human-wildlife interaction and also assist in protecting endangered species and preserve local biodiversity (Agnihotri et al. 2021).

India is considered one of the twelve megadiverse countries based on species endemism and rarity, with two major hotspots, i.e., Western Ghats and Eastern Himalayas (Myers et al. 2000). As part of the eastern Himalaya hotspot, the extraordinarily rich biodiversity of NE India, is complemented in equal measure by the rich cultural and ethnic diversity contributed by around 150 tribal groups inhabiting the region (De 2021). The diverse communities of NE possess varied beliefs, rituals, and cultures, obtained either through observation or through trial-and-error experiments, from their interactions with the natural ecosystem (Phonglo 2019). Such knowledge is further accumulated and mobilized to develop different practices that enhance their livelihood and support natural resource conservation process.

TEK is considered as an effective tool for achieving seventeen interlinked Sustainable Development Goals (SDGs, initiated in 2015 and projected for completion by 2030) of the United Nations General Assembly (Segger and Phillips 2015). The fact that seven SDG goals plus the sustainable food production goals that allay unpredictability in climate, significantly resonate with TEK, is indeed a good validation (Singh and Singh 2017; Kumar et al. 2021).

Most of the literature covers the rules, practices, and traditional knowledge of various indigenous communities present in NE India. Still, the importance of these knowledge systems toward achieving SDGs is sparsely discussed. In the present review, the broader relevance of TEK and NRM, and their role in achieving SDGs, has been critically assessed through systematic and organized perusal of chosen extant data. Appraisal of the different TEK and practices of the NER with NRM and SDGs has been evaluated, emphasizing socio-ecological wellbeing. Therefore, with a community-centric approach on the anvil, the objectives of this review were to examine critically: (1) the roles of TEK in NRM, (2) various manifestations of TEK in the context of NRM, (3) different types of TEK in NE India concerning NRM, and (4) TEK practices of NE India and their potential roles in achieving SDGs.

Methodology

This review is based on 103 studies published between 1991 and 2021 and, to the best of our knowledge, is comprehensive in its inclusion of relevant studies. To carry out our bibliographic research, keywords such as "traditional ecological knowledge in NE India", "indigenous tribal knowledge", "community of northeast", "traditional ecological in natural resource management" were used in databases such as Google Scholar, Scopus, Web of Science, and Science Direct. Apart from online resources, newspaper articles, books, and the gray literature, like NGO reports, were collected from the Central library of Indian Institute of Technology Guwahati (IITG). The materials in hand were first screened to remove redundant data. Subsequently, information was collated on traditional knowledge studies, state-wise practices and customs, and sections-wise work on sacred groves, sacred animals, aromatic and medicinal plants. The observations contained in secondary data sources such as the forest report data; local community data were also screened for this review. By and large, the research and studies included in this paper cover almost two decades, emphasizing the interlinking of TEK and NRM in NE India and the articulation of SDGs post 2015.

Importance of TEK in Natural Resource Management

Natural resources are integral parts of nature's gift that do not require any action of mankind for its production or generation (Subramanian 2018). The burgeoning anthropogenic activities impose immense pressure on limited natural resources indispensable for the survival of all living creatures, including humans on earth. In developing countries like India, the extraction rate of natural resources is around 1580 tons/acre, approximately three times higher than the global extraction rate (Ministry of Environment, Forest and Climate Change, 2019). The well-known "storehouse of natural resources" for the NE region of India is under threat by unplanned exploitation and the ensuing significant resource scarcity. Unscientific mining methods have caused severe environmental degradation in the NE state of Meghalaya (Chabukdhara and Singh 2016). Likewise, hydropower projects in Arunachal Pradesh have a significant and notified impact on the surrounding Himalayan ecosystem. Therefore, this critical situation necessitates the adoption of the community-based approach as a sustainable and feasible means for NRM (Rai 2007; Milupi et al. 2017). Community-based NRM (CBNRM) is a people-centered approach that fulfils the conservation objectives and generates economic benefits through community involvement (Milupi et al. 2017).

With the emergence of TEK as an efficient and practical tool, the knowledge of the indigenous people has become pivotal for inclusive NRM through community participation (Khumbongmayum et al. 2005; Harisha et al. 2016). The community-oriented traditional forest resource management practices are necessary for livelihood generation, ensuring food security, water availability, and biodiversity conservation. Several narratives collected from the indigenous people reveal holistic information on various natural phenomena, their effect on productive habits, and life cycle of different plant and animal species (Tiwari et al. 2010; Russell-Smith et al. 2015; Garnett et al. 2018). Such information strongly endorses the conservation practices and even helps the local community to accrue monetary benefits.

The best example of traditional community-based natural resource management can be seen in the worldwide protection of sacred groves. Every sacred grove is associated with its legends, folklore, and myths. The local people believe that the deities reside in them and protect them from natural disasters and diseases (Khan et al. 2008). India's diverse cultural and natural heritage is conducive to the occurrence of a large number (~100,000) of sacred groves. Besides being used for cultural or spiritual practices by the indigenous people, the sacred groves play a vital role in conserving the threatened flora and fauna from extinction (Vipat and Bharucha 2014). Thus, they may also be considered as one of the best cultural and spiritual practices of biodiversity conservation, rehabilitation of degraded ecosystems, and sustainable utilization of natural resources (Upadhyay et al. 2019).

The interrelationship between NRM and TEK of NE plays a significant role in achieving SDGs. We identified twelve SDGs such as "Zero Hunger" (SDG-2), "Good health and wellbeing" (SDG-3), "Gender equality" (SDG-5), "Clean water and Sanitation" (SDG-6), "Industry, Innovation and Infrastructure" (SDG-9), "Reduced Inequalities" (SDG-10), "Responsible Consumption and Production" (SDG-12), "Climate Action" (SDG-13), "Life Below Water" (SDG-14), "Life on Land" (SDG-15), "Peace, Justice and Strong Institution" (SDG-16), and "Partnership for the Goals" (SDG-17) which are directly linked to the TEK and practices of NE region (Fig. 1).

Since the impact of climate change on ecological processes and phenomena for different organisms, habitats, and others is best understood and assisted by TEK (Paul 2010), it has a considerable impact on the 13th SDG on "Climate action," which deals with various strategies to combat and adapt to climate change. TEK has emerged as the most popular, environmentally friendly, and socially acceptable strategy support against climate change (Lauer and Aswani 2010; Lemi 2019). The integration of TEK to achieve SDGs and natural resource conservation strategies must be based on in-depth understanding of the different elements of TEK and their correlation with modern science-based NRM. Therefore, it is essential to work in collaboration with the tribal communities to assess the potential of TEK in the context of NRM, instead of merely collecting specific informations from the tribal communities.

Fig. 1 Interlinkages of the traditional ecological knowledge and SDGs

The manifestation of TEK and practices

Globally, several researchers have divided TEK elements into specific categories, which help us comprehend this ancient knowledge for efficient environmental management. Houde (2007) recognized six interconnected and mutually informing manifestations of TEK to identify the areas of difference and convergence where TEK and modern science are brought together (Fig. 2). The first three manifestations, i.e., factual observation, management system, past and current uses are non-contextual in accordance with TEK, whereas the other three, ethics and values, culture and identity, cosmology are more specific to the TEK and allow improved understanding of the involvement of TEK in NRM.

TEK is a body of knowledge developed by non-aboriginal researchers through folk taxonomy studies; thus, recognition, classification, and naming of several discrete components of the environment are the first manifestations of TEK; yielding records of factual and specific observations of the stakeholders (Wenzel 1999; Usher 2000). Indigenous communities of NE region have extensive knowledge about the interaction of plants, animals, and people within their ecosystem. In fact, they are proficient and seasoned practitioners of identification, classification, distribution, and utilization of different flora present in their ecosystem (Chakraborty et al. 2012). Their specific awareness and information essay significantly affect biodiversity conservation, resource management, environmental impact assessment, and risk assessment. For instance, Kala (2005) documented 150 medicinal plants utilized by the Apatani community, which further assisted the management of natural resources and addressed their intellectual property rights. However, the factual TEK is sometimes misinterpreted by the government and the private sector when it fails to serve the particular interests of the community (McGregor 2004; Houde 2007).

The second manifestation of TEK is the system that ensures sustainable use of local resources sustains natural resources (Turner et al. 2000; Agrawal and Ostrom 2001). It supports the contention of various researchers that TEK plays a crucial role in satisfying all livelihood requirements; and the adaptation of such systems would improve ecosystem functions and services. Farming practices in the NE region are eco-friendly, sustainable and self-reliant (Deka et al. 2006). In the hilly areas of NE, indigenous communities invest in various crops and pest management mechanisms, such as slash burning, mixed cropping, green manuring, clean cultivation, and medicinal plant-based pest control practices (Kumar et al. 2009). The Garo, Khasi and Jaintia ethnic communities mobilize and implement their TEK for designing such strategies (Barooah and Pathak 2009; Majumder et al. 2013). These ecologically sensitive farming practices could enable the successful resolution of the deficiencies of modern agricultural practices. However, diversification of management regimes and the development

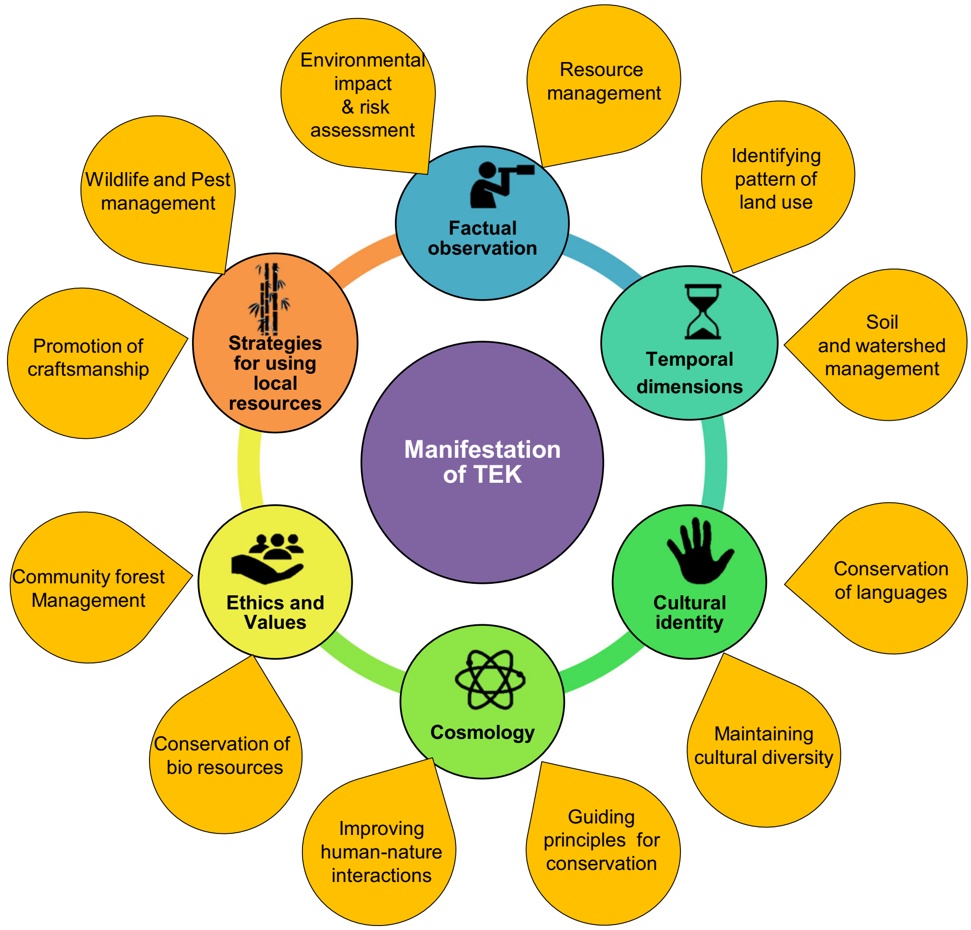

Fig. 2 Manifestations of the traditional ecological knowledge with respects to the NRM

of context-specific management models are some of the significant challenges of this manifestation (Houde 2007).

The third manifestation of TEK recognizes the temporal dimension of TEK, mainly the past and current uses of an environment, which is transmitted through oral history (Usher 2000). The major part of the oral history constitutes life stories transmitted from generation to generation as narratives and provides a sense of family and community. These narratives divulge historical patterns of land use, occupancy, and harvest levels (Duerden and Kuhn 1998; Usher 2000). These manifestations help us to comprehend the indigenous soil and watershed management practices present in NER. Profound knowledge and experience about the landscape, climatic conditions, and available natural resources help the Jaintia and Khasi hills' farmers divert water from streams into their fields during the dry seasons (Debnath et al. 2020). Therefore, by identifying the opportunity and threats of an ecosystem, the oral history approach can successfully develop a management regime for conservation (Semken et al. 2011). Significant limitations of this facet of TEK are misinterpretations generated by inadequate information obtained from oral history and unequal distribution of benefit accrued from such knowledge (Houde 2007).

The fourth manifestation of TEK reflects the interrelation of local community beliefs and customs with the organization of facts and actions. It is the expression of values related to the correct attitudes, especially respect towards the nonhuman, animal, environment, and between human beings (Duerden and Kuhn 1998; McGregor 2004). It supports the concept of in situ biodiversity conservation such as sacred groves, sacred animals, and sacred landscape. NE region is home to about 150 ethnic tribes with their diverse ethical, cultural and traditional beliefs. Their gratitude towards nature and natural forces is reflected in religious beliefs, traditional values, taboos, and sociocultural practices. The deeply rooted belief systems like "sacred groves," "sacred animal", or even "sacred landscape" help and motivate the world beyond their boundaries to conserve the regional biodiversity through community participation (Upadhyay et al. 2019b; Vipat and Bharucha 2014). The limitation of this manifestation is that values are not explicit in current management models (Houde 2007).

The fifth manifestation of TEK highlights the role of language and epitome of an ancient era in culture. It acknowledges the stories, values, and social relationships which have contributed to the survival, reproduction, and evolution of indigenous cultures and identities (Lewis and Sheppard 2005). The close association between the ethnic tribal groups and their environment is the key to sustaining the cultural components. Cultural identity helps comprehension of the ancient ways of NRM. In Arunachal Pradesh, NE India, the Borpa community of the Monpa tribe, is dependent on Yak rearing for livelihood (Singh 2009). They not only consider the Yak as a social and cultural identity of their community but have used indigenous knowledge to develop specific animal husbandry strategies (Singh 2009). The exploration of the language and cultural identity of indigenous tribes by scientific communities has helped in designing new strategies for NRM. The major drawback of this manifestation is that it does not provide a standard dimension for the people coming from non-TEK backgrounds (Houde 2007).

The sixth identified manifestation is culturally oriented cosmology, which acts as the foundation for all other manifestations. It comprises various principles that regulate the human–animal interactions and role of a human in the world. For thousands of years, the indigenous groups of NE believed in the cosmology of conservation. They believed that humans as elements of nature, had a non-negotiable responsibility to protect its ecosystem (Sarma and Barpujari 2011). Such beliefs contain complex sets of information and interpretations that indicate sustainability, which by and large, does not form an integral part of modern science-based NRM (Adom 2018). It is noteworthy that TEK is considered to be more philosophical than ideological. Therefore, structural and methodological problems faced by the TEK stakeholders while working in structured institutions become a major challenge of this manifestation of TEK (Abele 1997; Houde 2007).

Traditional knowledge and practices of North East India

Geographically NE India comprises the eight states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. The home of 150 major indigenous tribes is replete with humid evergreen and temperate and alpine forests (Table 1). The conservation of medicinal species, medical practices, and the sustainable utilization of natural resources is the cynosure of TEK in this region (Tynsong et al. 2020). The irrigation system and farming practices reveal extant land and water resources and form a continuum of the regional TEK; and therefore, traditional wisdom developed by aboriginal people are integral to creating sustainable NRM practices (Rai 2007). In this section, an in-depth appraisal of four cardinal TEK practices or systems are undertaken; (a) traditional farming practices, (b) indigenous irrigation systems, (c) sacred groves and animals, and (d) traditional health care and cultural belief systems.

Table 1 Important tribes of the North East India and their livelihoods

Sl. No.	States of NE	Important tribes of the areas	Tribal dominated landscape or geographical region	Major livelihood	References
1	Assam	Bodo, Mishing, Karbi, Rabha, Dimasa.	Karbi hill, Floodplain of Brahmaputra river valley near the Kaziranga National Park.	Agriculture, Bamboo craftsmen, pig rearing.	(Das et al. 2017)
2	Arunachal Pradesh	Adi, Aka, Apatani, Nyishi, Tagin, Khampti, Bugun, Mishmi, Monpa.	Border area close to Bhutan, Myanmar.	Agriculture, Bamboo craftmen, Weaving, Wetland cultivation	(Mandal 2014)
3	Manipur	Aimol, Angami, Chiru, Meiteis, Chothe.	Imphal Valley, river banks and border areas of the state.	Agriculture, Livestock rearing, Weaving, Blacksmith.	(Singh 2017)
4	Meghalaya	Garo, Khasi, Jaintia.	Garo hills, Khasi hills and Jaintia hills.	Jhum Cultivation, Hunting.	(Shangpliang 2012)
5	Mizoram	Lusai, Pawi, Ralte, Hmar.	Southern part of the state, Kolodyne river banks, Border area of the state	Agriculture, Weaving.	(Lalengzama 2019)
6	Nagaland	Angami, Chakhesang, Khiamniungan, Kuki, Konyak, Lotha, Phom, Pochury, Rengma, Sangtam, Zeliang.	Hutton and Mills, In the border areas of the state.	Food Gathering, Shifting Cultivation, Hunting, Wet Cultivation.	(Shantirani Devi and Rajesh Singh 2015)
7	Sikkim	Lepcha, Bhutia, Kirati, Limbu, Shresthas, Naong, Mon, Chang.	Dzongu Valley, Border areas of Nepal.	Agriculture, Livestock rearing.	(Sharma et al. 2018)
8	Tripura	Tripuri, Jamtia, Chakma, Halam, Garo, Chaimal, Bhutia, Lepcha.	Slopes of the hills, Border area close to Bangladesh.	Shifting Cultivation, Agriculture, Pig rearing, Fisheries, Honey collection, Forest Produce selling.	(Datta et al. 2015)

Traditional farming practices

Slash and burn agriculture or Shifting cultivation (locally known as *Jhum*) is one of the oldest and predominant land-use systems in the hills of NE India; it is a time-tested agricultural system based entirely on TEK. *Jhum* cultivation evolved as a response to the unique physiographic characteristics of the land and the socio-cultural tradition followed by the tribal cultivators. The people involved in this agricultural practice are known as *Jhumias* across the entire region (Singh and Gupta 2002). At the preliminary stage of the *Jhum* cultivation process, either a dense forest cover with ten years of bamboo growth or a reasonably dense secondary forest situated on hilly slopes is selected for agriculture. Subsequently, a small area inside the chosen land is cleaned, and rituals are performed to secure the blessings of the higher beings or supernatural powers. If the blessings are not forthcoming, the land is abandoned and another site is searched out. After the final selection of land, the village head distributes the whole land among villagers based on their family size (Gupta 2000). After plot selection and allocation, the next phase entails clearing vegetation followed by slashing and burning the plant parts along with debris to increase soil fertility (Fig. 3a). After continuous cropping of 2–3 years, the soil fertility of the land decreases, and the cultivators shift to another virgin land (Kithan 2014). The used land is left fallow for period of 10–15 years, which helps vegetation regeneration, and renders the land reusable for the next cultivation cycle (Alam 2019). Several practices performed during shifting cultivation, such as a period of sequential cropping, and fallow periods, vary widely and are tribe specific (Chaturvedi and Munda 2003). It has been scientifically proved that shifting cultivation played a significant role in conserving agrobiodiversity, especially the germplasm of native crop varieties. It is also an effective and sustainable way for land use optimization and space utilization, which helps in cultivation of around 60 different types of crop at a time in a single piece of land. The practices adopted during shifting cultivation can also control soil-borne pathogens, weeds, and other diseases of crops (Tomar et al. 2012). Though practices related to shifting cultivation support sustainable land use and NRM by the tribal communities, several limitations are also associated with this agriculture practice. Often, the fallow period required for regeneration has to be drastically decreased to 3–5 years due to excessive population pressure on land (Ninan 1992). This short fallow period leads to the degradation of soil microbes, flora, fauna, and the whole soil fertility cycle. Repeated land use over a short period results in transforming the

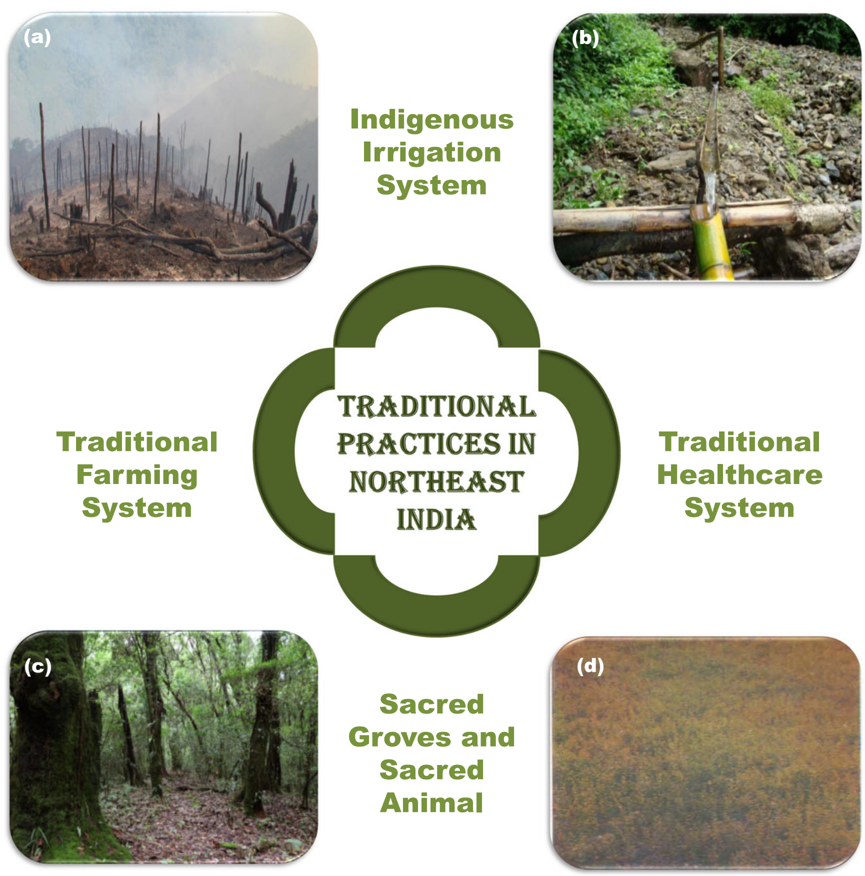

Fig. 3 Popular traditional practices in North East India: **a** Jhum cultivation, **b** Bamboo drip irrigation (Picture Source: http://cpreecenvis.nic.in/Database/BamboodripIrrigation_3767.aspx), **c** Sacred groves, **d** Medicinal Plants of NE region [Picture Source: Report of the Task Force on Conservation & Sustainable use of Medicinal Plants – Planning Commission Government of India (2000)]

primary forest into the secondary forest and later into a degraded wasteland.

Apart from shifting cultivation, the tribal communities of NE also practice several other indigenous agricultural systems. Rai (2005) discussed the paddy-cum-fish cultivation (locally known as *Aji* cultivation), a highly evolved agricultural system, followed by the Apatani tribes of Arunachal Pradesh (Rai 2005). Apatanis are the tribal community of Arunachal Pradesh in the eastern Himalayas, with a distinct civilizational characteristic based on TEK for conserving and managing the natural resources (Kumar and Madhukar 2019). The Apatanis link this agricultural system with animal husbandry, involving Mithun, Swine, Cattle, and Poultry. Apatanis are considered one of the relatively advanced tribal societies of the region due to their highly developed TEK and land management practices. This agricultural system combines paddy and fish cultivation, with millets grown on bundhs separating each plot. It was further elaborated that in *Aji* cultivation, a small pit is dug in each terrace of a series of a terrace. Fingerlings are usually put in water present in these pits. When sufficient water supply is available during the monsoon season, the fishes emerge from the pits to swim into the paddy fields submerged in 5 to 10 cm of water. During the drier, non-monsoon period, when water is only present inside the pit, the fishes go back into the pits to grow. The growth of the fishes improved with access to the large surface area during submergence and better nutrition from the manuring of the paddy fields. In this agricultural system, both fish and paddy are produced together by efficient and productive rainwater utilization (Tynsong et al. 2020).

In the NER, the terrace used for paddy production is segregated into three categories, locally known as *Jabi, Aane*, and *Ditor* based on artificial and natural water supply availability. *Jabi* and *Aane* are entirely dependent on natural water supply, whereas *Ditor* relies on irrigated water supply (Tynsong et al. 2020). This paddy-cum-fish agroecosystem is entirely dependent on nutrient washout from the hill slopes. Thus, organic manure produced at the houses and granary above the cultivated fields is decayed and decomposed on the lower fields. Utilization of these organic wastes and crop residue recycling help in sustainable retention of soil fertility (Das et al. 2012). Therefore, the Apatani farming system is a sustainable agricultural method that requires minimal external input; but it is highly productive, economically viable, and ecologically efficient (Rai 2005). This wet rice cultivation method provides an excellent example of land and water conservation and nutrient recycling.

Another indigenous farming system used for rice cultivation on the terraced fields of Nagaland is locally known as the Zabo system. This agriculture system originated in the Kikuma village of the Phek district of Nagaland (Das et al. 2012). Kithan (2014) reported that the *Zabo* system of paddy cultivation is a combination of forest, agriculture, and animal husbandry. In this agricultural system, the protected forest occupies the top portion of the hill slopes, water harvesting tanks are present in the middle part, and the cattle yard and paddle fields are located in the lower part of the hills (Sarma and Goswami 2015). The Zabo agricultural practice depends heavily on monsoon rainfall alone and provides a well-established base for water resource development and water management, with the added advantages of soil conservation and environmental protection(Dabral 2002).

Jeeva et al. (2006) discussed various traditional agriculture practices followed in the states of Meghalaya, where the tribal communities follow both slash and burn agriculture (locally known as *Jhum*) and terrace cultivation (locally known as *Bun*) (Upadhaya et al. 2020). *Jhum* cultivation is usually practiced in forest land, whereas *Bun* cultivation is practiced on the hilly slopes and foothills and occasionally inside the plantation forests. The hill slopes are converted into a bench terrace, and the space between two terraces or *buns* is levelled by the hill and cut method. The horizontal spacing between the terraces, maximizes rainwater retention and safely removes excess water from the slopes to the foothills. These agricultural practices can produce cereals and other crops by using the traditional wisdom of local tribes and maintaining ecological balance. Thus, *Bun* agricultural practices followed by Khasi and Jaintia tribes are sustainable crop cultivation practices under complete rainfed conditions using limited biomass, land resources, organic fertilizer, and pesticides (Upadhaya et al. 2020). A fallow period of one to three years is used in this farming system to restore soil fertility. *Bun* cultivation is a settled cultivation system that improves productivity, conserves soil moisture, and prevents land degradation and soil erosion (Prokop et al. 2018).

Alder-based agroforestry system is another outstanding example of a sustainable farming system based on the TEK of farmers living in Angami, Chakhasang, Yimchunger, Chang, and Konyak areas of Nagaland. The Alder tree is deciduous or semi-deciduous and capable of developing and retaining soil fertility (Das et al. 2012). The presence of nodules in the root is responsible for the high fertilizing ability of the alder tree, whereas the extensive spreading of the roots prevents soil erosion on the hill slopes (Benson and Silvester 1993). In alder based *Jhum* field, a 4-year cycle with two years of cropping followed by two years of fallow period is maintained. The Alder tree is worked as a canopy tree to produce primary crops such as rice and secondary crops such as chili, potato, tapioca, colocasia, and many other crops, during the two years of cropping. Seedlings planted in the *Jhum* field have a space of 3–4 m between two plants and 5–6 m between two rows (Das et al. 2012).

Kahie (2018) described the indigenous alder-based farming system as a sustainable land use model in the hill slopes of Nagaland (Kehie 2018). Alder-based agroforestry system is also practiced in the high altitude areas of Sikkim, where large cardamom (*Amomum subulatum*) is grown under the shade of alder tree. This age-old farming system is purely organic and economically efficient (Das et al. 2012). In NRM, the alder-based cultivation method provides good knowledge about soil conservation methods in hilly areas.

Apart from developing agroforestry systems, the development of temporary cowshed in the paddy field is an indigenous practice done by the tribes of Sikkim. In such a farming system, a temporary cattle shed is constructed in the terrace field before cultivating various cole and tuber crops; ginger and turmeric are examples. The cattle or cows are kept in each shed for 2–3 days, and the shed is then transferred to neighboring areas until the whole field is covered. In situ collection of urine, cow dung, litter inside the field, and further incorporation of such materials in the soil through plowing shows appropriable fertility management (Das et al. 2012). This agriculture method shows a faster and eco-friendly process of fertility management of the soil using animal wastes.

The traditional form of farming knowledge and practices in NER must be preserved and well documented. This indigenous knowledge also incorporates animal husbandry, fish cultivation, and forestry into the most sustainable and diversified farming systems. Ecological sensitive TEK and practices of NE India can potentially reduce the usage of chemical fertilizer and pesticides, thereby curtailing the environmental risk and enhancing food production. Moreover, it is apparent that traditional agricultural practices of NE India can help to achieve SDG-2, 6, and 17 by providing essential remedies for land degradation, ecosystem destruction, and food security (Table 2). However, most of these agricultural practices are confined to their place of origin; or on the verge of extinction by the adoption of non-eco-friendly high production-oriented modern technologies. Thus, in-depth studies are warranted to collate and analyze the scattered information about the various traditional farming systems and their contribution toward NRM and environmental protection. We have analyzed the traditional farming practices in terms of Houde's manifestation (Table 3).

Indigenous irrigation system

Traditional irrigation systems and water conservation practices are predominant in NE India. These irrigation systems are highly location-specific and traditionally managed by indigenous communities and farmers (Devi 2018). Many such irrigation systems such as *Dong*, bamboo drip irrigation, *Cheo-ozihi* are prevalent in hill slopes and riverine planes. Bamboo drip irrigation is an indigenous irrigation system developed by the tribal farmers of Muktapur, in the Jaintia hill district of Meghalaya, to overcome the problems of irrigating crops grown on hill slopes (Das et al. 2012). This irrigation system can provide sufficient water to cultivate several crops such as areca nut, black pepper, betel vines in the moderately steep hills of the Jaintia and Khasi districts. Water from the natural streams located at the higher elevation is tapped and transported using various bamboo channels and supports and finally propelled by gravity to the plantation site (Fig. 3b). The water is discharged at the base of crop plants in the form of drips or trickles. Sen et al. (2015) estimated that around 18–20 L of water enters the bamboo channel, is transported a few hundred meters, and reduced to 20–80 drops/min at the plant site (Sen et al. 2015). This 200-year-old irrigation system is helpful in areas of water scarcity, characterized by rocky and undulating topography with low water retention capacity soils (Singh and Gupta 2002). Since the water is only transported through the bamboo channels to the farming area, clearing forest and constructing artificial irrigation channels are not needed, indirectly protecting the forest area (Jeeva et al. 2006). Bamboo drip irrigation also supports settled cultivation instead of shifting cultivation, thus reducing deforestation (Das et al. 2012). Thus, the bamboo drip irrigation system passively helps to protect the environment and conserve the natural resources present in the hilly region of the state Meghalaya. This TEK sets an excellent example of low cost and eco-friendly irrigation system on hilly slopes.

Likewise, the *Dongs* system in Assam is 100 year old, highly efficient community-managed irrigation system developed by Bodo tribes. In this traditional irrigation method, water is diverted from nearby rivers or lakes by digging small canals that reach the villages to supply water for domestic, drinking, and agricultural uses (Devi 2018). The utilization of *Dongs* is prominent during prolonged winters when the water becomes scarce, even for drinking purposes. Typically, the starting point of a *Dong* network is a river or water source. Large *Dongs* originating from the river possess a 7–12 ft width; they are then divided into the smaller subsidiary channels that are 3–5 ft wide; these channels are further split into field channels that supply water to the agricultural fields (Sarma and Goswami 2015). Water in the cultivation field is accumulated inside a pond-like structure. The required portion of water is lifted and taken out using an instrument locally known as *Lahoni*. Another wooden boat, like a structure known as *Koon*, is also used to harvest water from the pond to the paddy field (Kumar and Madhukar 2019). With *Koon*, about 25 L water is harvested each time, and is sufficient to cover a plot of 1–1.5 acres in a day, whereas, with the help of *Lahoni*, about 10 L water is harvested each time to cover a land of

Table 2 Different ecosystem approaches for NRM in North East India

Sl. No.	Name of the approaches	Tribe/ State	Approaches for NRM	Scale of applications	Framework	Aspects of SDGs
1.	Wet Rice Cultivation	Apatani/Arunachal Pradesh	Land use management, Soil Conservation, Watershed Management.	Local	Based on the climate, area topography, traditional belief/Inspires co-cultivation method for paddy and fish production.	SD-2,8,13,14,15
2.	Terrace Cultivation	Khasi & Jaintia/Meghalaya	Soil Conservation, Biodiversity Conservation, Land use management.	Regional	Acquired or developed knowledge about local ecosystem and climate/ Inspires cultivation methods in hilly slopes.	SD-2,8,13, 14
3.	Alder based Farming System	Angami, Cheksang, Yimchunger, Chang, and Konyak/Nagaland	Soil Conservation	Local	Organic farming method based on local knowledge/Inspires tree-based farming system at higher altitude.	SD-2,14
4.	Bamboo drip irrigation	Jaintia & Khasi/Meghalaya	Watershed management, Forest Conservation.	Regional	Based on the area topography and available forest products/Inspires irrigation system at higher altitude.	SD-6,13,15
5.	Dong System	Bodo/Assam	Watershed Management, Water harvesting	Regional (Assam & West Bengal)	Based on the area topography & community participation/Inspires water storage and use method during dry period.	SD-6,15
6.	Sacred groves	Bodo & Rabha/Assam, Bhutia and Nepalis/Sikkim, Meiti/ Manipur, and many more	Wildlife conservation, Biodiversity Conservation, Forest Conservation.	Global	Inheritance belief system / acquired or developed belief system/ Inspires biodiversity conservations.	SD-13, 15
7.	Bamboo cultivation and conservation	Meiti/Manipur, Jaintia & Khasi/ Meghalaya, Chinlampianga/ Mizoram and others	Forest Conservation, Soil Conservation.	Regional	Wide availability, Fast cultivation process/ Inspires utilization of local products.	SD-8,9, 13, 15

Table 3 Traditional farming systems as per Houde's manifestation

Manifestation of TEK	Shifting Cultivation (*Jhum* Cultivation)	Wet rice Cultivation (*Aji* Cultivation)	Zabo farming system	Terrace Cultivation in Meghalaya (*Bun* Cultivation)	Alder based Agroforestry system	Rotatory cowshed based agroforestry system
Factual Observation	Controlled fire before cultivation process help to remove the invasive plant species and regulate the population of plant and animal parasites.	The nutrients are usually washout from the hills and stored in the flat land which also reduce the requirement of fertilizer.	The preservation of forest causes high rainfall.	These agricultural practices are effective in hilly slope with highly rainfed climatic condition.	Alder trees can successfully restore soil fertility by nitrogen fixation.	In situ collection of urine, litter, cow dung and other animal waste increases the soil fertility.
Management Systems	Various crop and pest management system such as mixed cropping, green manuring etc. successfully reduce the pest population in sustainable manner.	Recycling of agricultural by products and utilization of organic waste of villagers help to restore soil fertility for long period of time.	Strategies designed to transfer water from top hill area to the lower part of the hill. Water harvesting tanks are designed in the middle part to store water.	Several strategies such as terrace formation inside the plantation forest, removal of excess water from agricultural field are important for sustainable agriculture.	Co cultivation of agricultural crops with Alder tree helps to regain the soil fertility without any external input.	Various strategies such as formation of temporary cattle shed throughout the field before cultivation help in fertility management.
Past and current use of environment	Grass understory of the area was maintained by low intensity fire in the past.	Prior knowledge about land topography and nutrient distribution in soil help to choose the appropriate rice variety.	Prior knowledge about land topography and soil quality help to develop the channel and tanks.	Long history of resource utilization is present.	Past knowledge about alder trees and surrounding environment helps to develop this agroforestry system.	Prior knowledge about the nutrient potential of animal waste is present.
Ethics and Values	Ethnic groups of Northeast India considered forest, plant and animal as sacred and worshiped them.	They put human labors for the agricultural system and does not use any animal for the farming practices.	The farming system does not require chemical fertilizer. The farmers also live simple lifestyle which helps in natural resource conservation.	The farmers followed this farming system worship nature and try to conserve ecological balances of nature.	These agroforestry systems help in environment protection and ecological equilibrium maintenance.	The farmers also live simple lifestyle which helps in natural resource conservation.
Cultural Identity	Traditional people possess a strong connection with forest.	Bamboo is socially selected by the Apatani tribes as a keystone species which is use around the agricultural plot.	Traditional people possess a strong connection with forest.	Traditional farmers of Jaintia and Khasi hills followed this settled agriculture.	Traditional people possess a strong connection with forest and uses.	Traditional possess a strong connection with forest and animals.
Cosmology	The fertile land selection and allocation to the societies are based on cultural belief and decided by the village headman.	According to the cosmology of Apatani tribe, they isolated themselves in the valley and feel protected from other rivalrous tribes and outsiders.	Biophysical interaction and human intervention help to determine the conservation of natural resources.	Biophysical interaction and human intervention help to determine the conservation of natural resources.	Biophysical interaction and human intervention help to determine the conservation of natural resources.	The farmers believe in animism.

~1 acre in a day (Kumar and Madhukar 2019). *Dongs* ensure equal water distribution to every household for agricultural purposes and efficiently utilize the water resource without any waste (Sen et al. 2015). Another indigenous irrigation system similar to *Dongs* is known as *Jampai* in the Jalpaiguri district in West Bengal. *Jampais* are small irrigation canals that link the rice fields to the streams of the Brahmaputra (Kumar and Madhukar 2019). The *Dong* system shows an efficient way of water conservation and watershed management practices.

The rivers that flow along the Angami village of Kwigema in Nagaland are tapped at seven different elevation points for channel diversion (Kumar and Madhukar 2019). The river water moves down through an extensive channel that is further divided into the terraces, using bamboo pipes. One such channel is *Cheo-oziihi*, where *Oziihi* means water, and *Cheo* means the person responsible for laying those 8–10 km long channels with many branches (Jeeva et al. 2006). This channel irrigates a large number of terraces in Kwigwema and other nearby villages. If there are three *Khels*, and the water is divided among them (Kumar and Madhukar 2019). This TEK shows a more efficient way of water distribution.

The Adi tribe in the East Siang district of Arunachal Pradesh construct traditional water harvesting structures such as *Yeung Linsang* and *Linkup* (locally known as *Carsick*) based on their indigenous wisdom (Kumar and Madhukar 2019). In this irrigation system, terrace paddy fields present in the valley land are irrigated by tapping the steam water near its point of emergence and then channeling the water through the bench terraces. The water continuously flows from the terrace at a higher elevation to the lower ones without soil erosion. Yeung Linsang and Linkup block the perennial streams to divert the water towards low land for paddy cultivation in kharif season and remunerative vegetable crop production in the following Rabi season. Though the water harvesting structures are constructed based on traditional beliefs, this indigenous irrigation system can provide cost-efficient, eco-friendly, and sustainable water resource management (Pattanaaik et al., 2012). The indigenous water management developed by the Apatanis to support their paddy-cum-fish cultivation, has remained sustainable for centuries. In this system, all streams coming out from a surrounding hill are taped at the starting of the valley and further channelized and diverted through a network of primary, secondary and tertiary channels (Kumar and Madhukar 2019). Small feeder channels are constructed just above the terraces to supply sufficient water through numerous branches to the paddy fields (Kumar and Madhukar 2019). The feed channel branches (locally known as *Hurburs)* are present at an angle with the lead channel and can be blocked or opened as required to flood the field. These feeder channels are pitched with locally available stones or boulders to prevent soil erosion. The outlet pipes are kept at a certain height to maintain the water level in the paddy fields. The excess water is disposed of in the Kale river, which flows along the midsection of the valley. These irrigation channels also carry several natural fertilizers, such as rotten leaves from the wooded land to the paddy fields (Rai 2005). Thus, Apatanis, with the cooperative effort, have successfully optimized the water and nutrient use in their paddy fields. This system is an impetus for creating and maintaining efficient processes of water conservation.

Rauza or *Zabo* irrigation system is another well-known traditional water management system developed by the Chakesang tribe, inhabiting the Phek district of Nagaland. Though they receive heavy rainfall, they face a chronic scarcity of potable water (Sen et al. 2015). To remedy the situation, the Chakhesang villagers construct a channel to collect a large amount of rainwater from the hilly forest slopes and divert it to the ponds located in every paddy field. The water in these ponds is used for agriculture, drinking, domestic, and aquaculture (Kumar and Madhukar 2019). The *Zabo* irrigation system is the best example of an efficient and low-cost rainwater harvesting method. In Mizoram, indigenous water harvesting structures (locally known as *Tuikhur*) are created at the foothills. The rainwater or stream water coming from the higher elevations is collected through bamboo pipes and stored in the *Tuikhurs* for the entire community. The stored water is then used for domestic, agriculture, and other purposes during the dry season. This traditional water harvesting method provides an innovative and sustainable model for water resource management (Sen et al. 2015).

In Sikkim, local tribes have evolved an efficient water harvesting system along with proper land management. Bench terrace irrigation is primarily used for rice cultivation, whereas no adequate distribution of irrigated water is done during cardamom cultivation. Construction of water channels, regulation of water distribution, and fetching of drinking water is indigenously done through community participation. *Kholas* are the traditional tanks used as a primary source of drinking water (Sen et al. 2015). The bench terrace irrigation system in Sikkim is an example of an efficient and low-cost water irrigation method.

Sustainable water management using traditional wisdom has been widely used in NE India since human settlement began in the NE hills. Utilizing locally available materials like bamboo and stones, the indigenous communities of NE India construct various water storage structures, crop irrigation equipment, and pipe laying strategies (Kumar and Madhukar 2019). These traditional irrigation systems provide an appropriate model for effective natural resource conservation and management (Table 4). Incorporating such detailed information in modern irrigation systems can offer integrated models to achieve various targets under SDGs

Table 4 Indigenous irrigation systems are detailed using Houde's manifestation

Manifestation of TEK	Bamboo drip Irrigation	*Dong* Irrigation System	*Cheo-oziihi* Irrigation System	*Yeung Linsang* and *Linkup*	Water Management for Wet rice cultivation	Zabo Irrigation System
Factual Observation	Most freely available natural resource, bamboo is used as a channel to tap the water from stream present at higher elevation.	Diversion of water from nearby streams or river is possible by creating the channels or canals and can be stored in the ponds for future use.	Agricultural land can be irrigated by branching the river at different points.	Blocking the perennial stream at higher elevation and branching the water towards agricultural plots.	The water coming from different streams or rivers are outside the valley and then diverted as per requirement.	The preservation of forest causes high rainfall. Storage of rainwater by making.
Management Systems	The zigzag design of the bamboo channels, water transport strategy from higher elevation, discharge of water at field in the forms of trickles are used to design sustainable irrigation system.	The water distribution network, instruments like *Koon* and *Lahoni* developed by tribal people help to design sustainable irrigation systems.	Water distribution network developed using the traditional knowledge of ethnic tribes can solve the issues of water irrigation at water scarce area.	Water harvesting structure development, Minimization soil erosion, branching of water towards agricultural plots are important to develop sustainable irrigation models.	Construction of water distributing network and water supply system help to design the irrigation system.	Construction of rainwater harvesting structure and development of water distributing network help to design the sustainable irrigation systems.
Past and current use of environment	The farmers are aware about land topography and soil quality from past..	Prior knowledge about land topography and climate conditions help to design such systems.	Prior knowledge about land topography, climatic condition, water requirement helps to design such systems.	Long history of resource utilization, land topography is present.	Past knowledge about adjacent waterbodies and land topography help to design such systems.	Prior knowledge about land topography, climatic condition helps to design such systems.
Ethics and Values	Strong belief in community participation for building this irrigation.	Strong belief in community participation for building this irrigation.	Strong belief in community participation for building this irrigation.	Strong belief in community participation for building this irrigation.	Strong belief in community participation for building this irrigation.	Strong belief in community participation for building this irrigation.
Cultural Identity	Bamboo is recognized as a cultural identity of northeast India.	This irrigation system is also influenced by the heterogenous mixture of Aryan, Dravidian and Austric culture.	Traditional people possess a strong connection with river and nature.	High quality design, local technology used to design water harvesting structure is cultural identity of the Adi tribe.	Traditional people possess a strong connection with river and nature.	Traditional people possess a strong connection with river and nature.
Cosmology	Biophysical interaction and human intervention help to determine the conservation of natural resources.	The villagers believe in animism. Their socio religious life maintains the interconnection established between nature and man.	Biophysical interaction and human intervention help to determine the conservation of natural resources.	Adi tribe worship different God and Goddess in order to achieve prosperity and livelihood.	According to the cosmology of Apatani tribe, they isolated themselves in the valley and feel protected from other rivalrous tribes and outsiders.	Biophysical interaction and human intervention help to determine the conservation of natural resources.

(Table 2). Moreover, the government should focus on dovetailing these productive and eco-friendly traditional methods into the existing modern scientific infrastructure to maintain farmland, enhance the livelihood of the farmers, and secure food security.

Sacred groves and sacred animals

A large population of the country traditionally depends on forests, which serves as the livelihood of rural households. Several indigenous communities worship nature in many parts of the NER by dedicating a part or whole forest to their local deity and/or ancestral spirit (Fig. 3c). These dedicated patches of the forest are termed sacred groves and serve as a vital source of freshwater, timber, food, fiber; besides essaying significant roles in carbon sequestration, maintaining ecological balance, conservation of soil, water, and wildlife (Tiwari et al. 2010; Kandari et al. 2014). They act as valuable gene pools for the wild, endangered, endemic, and rare species of plants and animals. Hence, these protected forest patches could be considered the last refuge for the threatened flora and fauna of different sensitive ecological zones (Khan and Tripathi 2004). NE India is one of the few regions where the sacred grove practices are still evident, even in the 21st century. The region is known for its cultural diversity, traditional knowledge, ecologically distinctiveness, and rich biological resources (Khan and Tripathi 2004). The over 150 ethnic communities with different customs and dialects of this region, with their strong cultural belief in nature and natural forces, have been instrumental in preserving and protecting the endemic flora and fauna (Khan et al. 2008). The very concept of groves being "Sacred", has added a further dimension of protection to preserving biodiversity, conserving forests, and fulfilling the SDGs. Therefore, the number of studies on systematic documentation of existing groves and their ecological diversity, particularly in NER, require a sustained increase.

A total of 101 groves have been reported in different places of Arunachal Pradesh, locally known as *Gompa* forest areas located at high altitudes and mostly conserved by Buddhist monasteries. Thirty-nine of them are in the Tawang, Twenty-four in West Kameng, Fifteen in Lohit, two in Papumpare, and a few from Siang and Lower Subansari districts of Arunachal (Khan et al. 2008; Upadhyay et al. 2019). The sacred groves are of immense ecological significance for the state and neighboring states like Assam. Sacred groves are often associated with a spring or stream, which serves as a continuous water source to the residents. The *Gompa* forest areas are considered dwelling places of ancestral souls and supernatural powers. Harming animals like tigers, toads, and wagtails are forbidden as they are believed to be traditional brothers and well-wishers of human beings. Undesirable events like deaths and famines are predicted if the pangolin (*Smutsia gigantea*), mole (*Scalopus aquaticus*), slow loris (*Nycticebus bengalensis*), hillock gibbon (*Hoolock leuconedys*), house sparrow (*Passer domesticus*), and brahminy duck (*Tadorna ferruginea*) are harmed (Murtem and Chaudhry 2014). Trees found in the groves and considered sacred include the myrobalan (*Terminalia chebula)*, banyan (*Ficus benghalensis)*, Ashoka tree (*Saraca asoca)*, wood apple or bael (*Aegle marmelos)*, and Peepal (*Ficus religiosa)* (Upadhyay et al. 2019).

The Bodo and Rabha tribes inhabiting the foothills of western Assam have traditionally maintained sacred groves known as *Than*. About forty sacred groves have also been found in the Karbi Anglong district. In the Haflong district, Madaico, usually no larger than one acre, forms the sacred groves of the Dimasa tribes of north Cachar hills. The plains of Brahmaputra valley and *Shankara deva mathas (Vaishnav places of worship)* scattered all over the state possess sacred groves (Khan et al. 2008). The killing of animals and birds during the mating season is prohibited in and around these groves. The plants like giant bamboo (*Dendrocalamus giganteus)*, wild banana (*Musa velutina)*, kumarika (*Smilaz zeylanica)*, betel nut (*Areca catechu)*, and devil's cotton (*Abroma augustum)* are considered sacred plants present in the groves (Upadhyay et al. 2019).

In Manipur, sacred groves are represented by a patch of forest land dedicated to the local deity commonly known as *Umanglai*. Locally, *Umanglai* is managed by the village head or the members of the authorized group who take up steps to protect the sacred groves. It is also believed that the deity resides in the sacred trees. Hence, the felling of trees is avoided (Khan and Tripathi 2004). A total of 365 sacred groves constituting numerous rare and endemic species of plants were reported in 2000 from Manipur. Among 166 sacred groves reported from the four valley areas of Manipur, about 58% were under the partly threatened category, 31% were threatened, and the remaining 11% were in the well protected and preserved category (Upadhyay et al. 2019). Several ecologically essential tree species with good soil nutrient retaining capabilities, such as siris (*Alibizia lebbeck)* and cluster fig (*Ficus resemosa)*, were reported from these groves (Upadhyay et al. 2019). The *Mayokpha* sacred grove is dedicated to the snakes inhabiting in and around the area. The grove also provides habitat to birds and arboreal mammals like flying foxes (*Pteropus medius*) and Rhesus monkeys (*Macaca Mulatta*) (Khan and Tripathi 2004). Trees like golden shower (*Cassia fistula)*, Toon tree (*Cedrella toona)*, heikreng *(Cettiscinua menum)*, coral tree *(Erythrina* sp.), Dandal (*Xylosma longifolia)*, fig (*Ficus* sp). are commonly conserved in most of the sacred groves. Medicinal plants like *Adhatoda vastica, Eupatorium birmaticum*, *Terminia arjuna*, *Melothria purpusilla*, and *Michilia* sp. are naturally found in this region. The *Koubru* sacred grove has immense contribution in protecting rare flora and threatened leopards. Monkeys (*Rhesus* sp.) and Flying fox are primarily conserved in the *Mongba hanba* sacred grove. Moreover, these groves play a significant part in regulating the region's microclimate and preserving the cultural heritage of the Meitei community (Khan and Tripathi 2004).

In Meghalaya, the tropical and humid sub-tropical sacred groves of Khasi Hills are locally known as *Law kyntang* or *Law lyngdoh*, while in the Jaintia Hills, they are termed *Khloo blai*. According to the local belief, the forest deity called *Ryngkew*, *Bas*, or *Labasa* resides in the sacred groves that protect the village from hardship (Tiwari et al. 2010). The size of sacred forests varies from a grove having few trees to more than 50 trees per acre. In some villages, more than one sacred forest was recorded; sacred forests are usually managed by the headman of the community (Kandari et al. 2014). Various rites and rituals are performed periodically in these forests, and activities like grazing, cutting the tree, and their branches, collecting the leaves, flowers, fruits are considered taboo (Meghalaya Biodiversity Board 2017). Based on the studies conducted on the vegetation structure and ecology, about 395 species have been reported from these groves, constituting 14% endemic flora. It was reported that at least 50 rare and endangered plant species of Meghalaya are confined to these groves. For the Khasis, a village has no identity without its sacred grove. With a forest cover of about 80 hectares, Mawphlang is regarded as one of the most important sacred groves in Meghalaya (Khan et al. 2008). There are about 450 species of trees and plants in this forest and rare species of animals and birds. The region serves as an invaluable repository for rare medicinal plants like the *Taxus baccata*, *Rhus chinensis*, *Castanea pumila*, and *Quercus glauca*.

In Mizoram, sacred groves are commonly known as *ngawpui* and range from a few hectares to a few hundred hectares in area. The sacred groves are characterized by streams, hills, plants, and trees, which provide food and natural products to the nearby villages. Religious beliefs play a pivotal role in conserving flora and fauna of the Mizo hills. The Mizos believe that the gods and goddesses inhabit the sacred groves. Cutting down of timber is strictly prohibited, but the collection of fallen leaves and various non-timber forest products (NTFP) were permitted. Hence, the genetic diversity of natural vegetation has been preserved for generations (Krishna and Amairthalingam 2014).

In Sikkim, two diverse religious communities maintain various sacred groves: Buddhist monastery (i.e., *Gumpha*) forests and Nepali *Devithan* (i.e., sacred grove, the abode of a goddess). While Sikkim's Buddhist sacred groves have received some attention, the Nepali *Devithan* has mostly gone unnoticed. The sacred groves of Sikkim are managed by lamas and mostly attached to Buddhist monasteries and known as *Gumpa* forests. The highlands of *Demojong* below the Khangchenjunga peak are the most sacred site for the Sikkim Buddhists. Any human activity here is believed to spell disaster for the region (Upadhyay et al. 2019). The state Forest Department enlisted 19 sacred groves of importance, out of which fifteen are Buddhist *Gumpa* forests and only four *Devithans*. Apart from being sites of religious worship and biodiversity conservation, *Devithans* are also symbolic of cultural association with land for the Nepalis in Sikkim. Two hundred forty-one floral species constituting 183 genera under 84 families were identified in the *Kabi* sacred grove of North Sikkim (Krishna and Amairthalingam 2014). The information available on the sacred groves of NE India and their rich biodiversity are scattered in nature. Systematic collation of information on sacred groves would be very useful for biodiversity preservation and maintaining a record of the region's natural wealth (Table 5). Hence, recent updates and proper documentation on the present status of the sacred groves are urgently required (Khan and Tripathi 2004).

Traditional health care practices and cultural belief system

Traditional health care systems and practices are widely recognized in NE India. According to Tysong (2006), rural poor in this region cannot survive without the herbal or medicinal plants, which they take as preventive or curative, for specific ailments. Traditional healers include homemakers, bonesetters, village elders, plant-based healers, and poison healers (known as *Visha vaidya*), who use vegetable, animal, and mineral substances to treat various diseases (Fig. 3d). In Meghalaya, more than 200 forest plants are used for traditional health care practices. Medicinal plants are predominantly used at the household level or self-help mode (Tynsong et al. 2006). Every village of the state possesses at least one or more traditional practitioners or *Nong ai dawai kynbat* (Hynniewta and Kumar 2008). The Khasi tribe use wild pepper or *Piper peepuloides*, egg yolk and honey to treat severe cough, while the Jaintia tribe uses the same species to treat urinary disorder and stomachache (Sajem and Gosai 2006; Tynsong et al. 2013). The Khasi and Garo tribes utilize three different wild citrus species to treat cold, headache, body ache, fever, food poisoning, and stomach disorder (Upadhaya et al. 2016). Different ethnic group residents in various parts of Arunachal Pradesh have diversified indigenous knowledge on medicinal plants and have evolved multiple ways to procure those natural resources (Tangjang et al. 2011). One example is *Catharanthus roseus* plant extract, commonly used as an anticancer drug, but the various tribal groups of Arunachal Pradesh use this plant against diabetes. The Chakma community inhabiting the northwest part of the state uses *Achyranthes aspera* to treat the urinary disorder (Tynsong et al. 2020). The Monpa tribe of Arunachal Pradesh uses the

Table 5 Different types of sacred forest/sacred groves in North East India

Sl. No.	States of NE	Local name of the sacred forest/ sacred grove	Districts covered by the Sacred groves	Plant species	References
1	Arunachal Pradesh	*Gompa Forest*	Tawang, West Kameng, Lohit, Papumpare, Siang, Lower Sibansari	*Terminalia chebula, Ficus benghalensis, Saraca asoca, Aegle marmelos, Ficus religiosa, Smutsia gigantea, Scalopus aquaticus, Nycticebus bengalensis, Hoolock leuconedys*	(Upadhyay et al. 2019)
2	Assam	*Than, Madaico*	Karbi Analog, Halflong	*Dendrocalamus giganteus, Musa velutina, Smilaz zeylanica, Areca catechu, Ehretia anacua, Abroma augustum*	(Upadhyay et al. 2019
3	Manipur	*Umanglai*	Tamenglong,	*Alibizia lebbeck, Ficus resemosa, Cassia fistula, Cedrella toona, Cettiscinua menum, Erythrina* sp.*, Xylosma longifolia, Ficus* sp.	(Khan and Tripathi 2004)
4	Meghalaya	*Mayokpha, Ngawpui,*	East Khasi hills,	*Taxus baccata, Rhus chinensis, Castanea pumila,* and *Quercus glauc*	(Khan et al. 2008)
5	Mizoram	*Recreation forest managed by Val Upa (Young Mizo association)*	Mamit	*(Data not available)*	(Tiwari et al. 2010)
6	Nagaland	*Wan*	Mon	*(Data not available)*	(Tiwari et al. 2010)
7	Sikkim	*Gumpa, Devithan*	North Sikkim,Gangtok, Yukosom, Kishangonj	*Terminalia chebula, Ficus benghalensis, Saraca asoca,*	(Upadhyay et al. 2019
8	Tripura	*Darlong sacred groves (Khawbiak)*	Unakoti	*Dipterocarpus turbinatus, Artocarpus Roxb, Begonia surculigera,*	(Darlong and Darlong 2015)

Litsea cubeba plant to cure heart diseases and stomach disorders (Namsa et al. 2011). The tea tribe of the Morigaon district of Assam uses *Drymaria cordata* plant extract to treat jaundice (Bhattacharyya et al. 2020). Different tribes and communities of NE India commonly utilize *Centella asiatica* against stomach disorders and as a brain tonic (Tynsong et al. 2020). According to Tynsong (2020), different researchers from various parts of the country reported around 2416 ethnomedicinal uses of multiple plants. The use of such plant-based indigenous knowledge provides evidence about the rich herbal flora of the region and the contribution to biodiversity conservation through their knowledge system.

Apart from plant species, various animals and their product are also widely used in NE India. Two tribes of Arunachal Pradesh, Tangsa and Wenchow, utilize the body fat of tiger, civet, hornbill, eagle, and python to treat joint, bone, and muscle pain. Both the tribes also use the bile of Bear to reduce stomache, headache, and labor pain (Jugli et al. 2020). The Biato tribe habitant in Dima Hasao, Assam, uses fermented fat of *Python molurus, Gallus molars*, and dried or fresh flesh of *Lutrogale perspicillata* to treat burn injuries (Betlu 2013). The Ao community of Nagaland uses twenty-five different vertebrate species for various treatments (Kakati et al. 2006). Singh (2011) reported eleven species of edible insects in Manipur for the treatment of multiple diseases.

Sustainable economic development, conservation of biodiversity, and cheaper health care practices can be attained by the sustainable extraction of medicinal plants. Sustainable production and trade of medicinal plants can provide resilience against various diseases, protect the indigenous community, diversify livelihood prospects, and achieve significant levels of progress in different SDGs, as mentioned in Table 2. Lack of documentation of different medicinal plant species and traditional health care practices cause the extinction of such TEK. Apart from the medicinal uses, various plant and animal species also help in weather forecasting. Singh (2011) mentioned that Meiti tribes from Manipur believe in ten plant species for weather forecasting, predicting destructive calamities, or taboos or signals for bad omens. In a given year, the side on which the flowers of the *Agava americana* are present is indicative of wind direction and lower occurrence of storms (Singh 2011). It is assumed that the high flowering of *Alacasia indica* brings a lot of difficulties and bankruptcy to a family who cultivates those flowers. They also believe that cutting Bamboo trees on Tuesday and Saturday may cause the decline of property for the family (Singh 2011). Several other plant species such as *Mangifera Indica*, *Hibiscus cannabinus*, *Brassica campestris* are also associated with different belief systems present in Manipur.

Various studies also suggested that the Chinlampianga tribal community of Mizoram can successfully forecast the weather using TEK. They believe that the roar of male bamboo partridges in the morning after sunrise indicates the possibility of rain on that day. It is also thought that rain is not expected for a while if the roots of *Articulates* sp. emerge from the soil soon after rainfall. Again, if a large number of ants are moving along a path and carrying their food, heavy rain is expected on the same day or within two to three days. Different cultural belief systems related to weather forecasting help in biodiversity conservation and adapting to climate change.

Numerous other TEKs are also developed by various indigenous groups of NE India related to seasonal and extreme weather events such as floods and drought tropical cyclones (Lefale 2010; Garay-Barayazarra and Puri 2011). Analysis and incorporation of such traditional indicators potentially enrich the existing forecasting system. To highlight the importance of the traditional forecasting system, we have divided this system into different elements as per Houde's manifestation (Table 6). However, rapid urbanization and high dependence on modern scientific methods cause a loss of traditional indicators. Therefore, more studies need to be carried out to document various TEKs associated with weather forecasting, predict natural disasters, and preserve traditional indicators.

Challenges of TEK and practices

Various TEK present in NE India shows significant potential towards sustainable utilization and management of natural resources. Though TEK is largely acknowledged globally, its acceptance and integration in the resource management policy framework are far from complete. The lack of acceptance of TEK has been defined by two terms "Inertia" and "Inflexibility" (Huntington 2000). The term "Inertia" explains the resistance of people to change because change induces people to come out of their comfort zones. People usually prefer to do work within the existing paradigm instead of adopting a new one. "Inflexibility" describes the resistance of people towards TEK and the changes associated with it. The lower levels of reliability and quantification in TEK-based systems cause the resistance and lack of acceptance of TEK (Huntington 2000). The difference in the perception towards traditional belief with time has also led to a gradual decline in practices and rituals.

The sacred groves are facing tremendous pressure due to the rapid developmental changes and increasing population density. Further, encroachment and increasing exploitation of the natural resources by the local inhabitants have also threatened flora and fauna (Khan and Tripathi 2004). These socio-economic drivers have a disastrous effect on the

Table 6 Traditional healthcare practices, weather forecasting system and sacred groves are described using Houde's manifestation

Manifestation of TEK	Sacred groves and Sacred Animal	Traditional Health Care Practices	Traditional weather forecasting System
Factual Observation	Some plant and animal species become endangered with time but are highly required to maintain the ecological balance. Conservation of such species helps to balance the ecosystem.	Knowledge about identification, classification, and utilization of various species help to innovate new medicinal drug molecule.	Traditional indicators help to inform the upcoming climate conditions. They also aware us about the upcoming natural disasters. The conservation of such traditional indicator will help in weather forecasting.
Management Systems	Various strategies such as prohibiting human intervention in sacred groves, protecting animals from hunting during mating season are considered very important for biodiversity conservation.	Various strategies related to traditional treatment processes such plant-based medicine formulation help to innovate new medicinal drugs.	Follow the traditional indicators for weather forecasting is great strategies for future.
Past and current use of environment	Long history of resource utilization and conservation is present.	Long history of resource utilization is present.	Long-term knowledge about the behavior of plant and animals in different condition are help to forecast the weather.
Ethics and Values	Ethnic groups of Northeast India considered forest, plant and animal as sacred and worshiped them. They lead simple life and thus help in conservation of landscapes.	They use medicinal plants just to cure the diseases.	No ethical value is associated with it.
Cultural Identity	Traditional people possess a strong connection with forest.	Traditional people possess a strong connection with forest.	Traditional people possess a strong connection with nature.
Cosmology	Biophysical interaction and human intervention help to determine the conservation of natural resources.	Interaction between human and nature help to maintain the ecological balance.	Ethnic group of northeast India worshiped nature.

biodiversity of the region, which is corroborated by a recent study (Ludwig and Macnaghten 2020). The loss of various key species, cardinal to the cultural identity, drives the changes in TEK. Overuse, population growth, and pressure emanating from resource use by immigrants cause environmental changes, force the indigenous community to relocate and cause a change in TEK (Tang and Gavin 2016). TEK has been profoundly affected due to the complete or partial loss of access to the traditional land and resources. Eviction of the indigenous community during the establishment of protected areas for biodiversity conservation causes the loss of access to natural resources required for indigenous livelihood (Agrawal and Ostrom 2001).

Climate change has a massive impact on TEK as the livelihood of indigenous communities is completely natural resource-dependent, and they inhabit an environmentally vulnerable area. Thus, the reckless speed of global climate change can outpace the ability of TEK to cope up with the environmental changes (Wildcat 2013; Fernández-Llamazares et al. 2015; Ludwig and Macnaghten 2020). Most natural resource managers are unaware of various methods used in social science, which impedes insights on specific data that is otherwise unreachable (Tynsong et al. 2020). The control and unequal political power over TEK research are other impediments to the unbiased implementation of TEK in sustainable development. The preservation of TEK is also affected by the loss of indigenous language, which threatens the protection, transmission, and cultural significance of TEK through narratives, songs, and telling of stories (Finn et al. 2015). The difference in language and culture between TEK holders and modern researchers could modify TEK interpretation and outcomes.

TEK can also be threatened by the reduced reliance of TEK holders on traditional livelihood practices. Introduction and integration of the market economy change livelihood practices by the exposure to alternative commodities, shift to wage labor or commercial production. The fallout from this shift is reflected in the youth of the indigenous community; they neither acquire nor transfer traditional skills to the future generation, especially as it does not come with a monetary incentive (Tang and Gavin 2016). Several studies also suggested that some TEK and practices are sustainable only at low population pressure. Consequently, an exponential population increase creates extreme pressure on land and other natural resources, making several practices unsustainable (Davies 2001).

Policy framework and recommendations for future

The large numbers of ethnic groups inhabiting different parts of NE India have developed several holistic TEK systems for the sustainable use and management of their natural resources. Thus, TEKs have become an integrating information system and underscores the various cultural adjustments required for livelihood practices at a specific local level (Tynsong et al. 2020).

The Government of India (GoI) has taken various legislative and administrative initiatives to preserve and document TEK and the Intellectual Property Right (IPR) of the indigenous people of NE. The launch of the Traditional Knowledge Digital Library (TKDL) by Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology, Department of Ayurveda, and Ministry of Health and Family Welfare, aims to prevent misuse of TEK and biopiracy (Jasmine et al. 2016). The Geographical Indication (GI) of Goods Act juxtaposed with the IPR is imperative in bringing together geographical origin and product quality to protect the products of the indigenous people. At present, just 28 products from the NE have received the GI tag till 2021; it is hoped that the number of GI tagged products will reveal a sharp increase in the near future.

In the NE region of India, flexible and evolved forest management practices are derived from TEK; concomitantly human interference and regulation in the forest is dictated by the ethical laws of sacred groves (Upadhyay et al. 2019a; Tynsong et al. 2020). These practices viewed in terms of social, cultural, and ecological dimensions are cardinal for achieving sustainability (Kim et al. 2017). Thus, the existence of sacred groves is crucial in forest management and facilitates the delineation of appropriate strategies to prevent the degradation of forests (Khumbongmayum et al. 2005). The World Bank and Millennium Ecosystem Assessment Report also addressed the importance of TEK in forest management methodologies (Bulloch 2017). In addition to the interventions related to biodiversity conservation, the Biological Diversity Act (BDA), 2002, National Biodiversity Authority (NBA), and State Biodiversity Board (SBB) were established by the GoI (Khan et al. 2008). The preparation, maintenance, and validation of the People's biodiversity register (PBR) aids in the effective translation of policies at the grassroots level. A total of 12,086 PBRs have been prepared to date in a phased manner to document various TEK and biological resources present in the NE. Besides, in-situ and ex-situ conservation programs under BDA have been initiated to target reforestation and fencing of groves, in an attempt to reduce grazing and human encroachment (Khan and Tripathi 2004). For instance, in Meghalaya, steps are being undertaken by the Ministry of Environment and Forest to promote the conservation of sacred groves through national afforestation and eco-development programs (Upadhyay et al. 2019). These steps are part of other policy interventions tools such as the Forest Rights Act. The Patent Act also help to protect and promote different TEK systems of NE India. Retrieval of TEK systems through the various provisions offered by different national and global policies, like the clean development mechanism, millennium development goals, and SDGs has been detailed in Table 2. Documentation of TEK conservation and practices are imperative, given the haphazard urbanization and industrialization in developing countries like India.

The present review focused on TEK and practices of the NE region and offered a comprehensive analysis of the six manifestations of TEK and its role in SDGs. In the context of TEK in the NE region, these vast storehouses of human wisdom have an important influence on indigenous farming practices, watershed management and ethnobotanical knowledge. Nonetheless, it is noteworthy that while the acceptance of TEK as a precursor of SDGs is significantly on the rise, acceptance and evaluation of TEK is nascent and still evolving. Therefore, new innovative approaches and extensive research on systematic documentation and their promotion should be refurbished through an advanced policy framework. There are certainly ample opportunities for developing and promoting the TEK as a precursor of SDGs. Therefore, strategic policy recommendations could target but not be limited by:

- Improvement in digital documentation of TEK and practices by developing app-based approaches for more effortless and rapid promotion.
- Development of a regional database for different SDGs and targets for optimum and sustainable socio-ecological benefits.
- Generation of GI and IPR to be based on applications of TEK and practices and customized by the Indian scientific fraternity.
- Empowerment of indigenous communities by focused dissemination and implementation of the various government initiatives like Vocal for local, Skill India and Aatmanirbhar Bharat.
- High-quality knowledge management and capacity building through scientific-communities' interactions, field-based training and capacity building of educational institutions, government and non-government agencies and local groups.
- Achievement of sustainability through TEK and practices in NE India based on localization of SDGs.
- Establishment of participatory networks involving different stakeholders along with local, regional and sectoral development.
- Undertaking the bottleneck assessment in TEK and practices in priority areas through technology enabled solutions.

The present review has meticulously detailed that TEK and practices that can be used to achieve various sustainable development targets (SDTs) under the different SDGs. The SDG India Index and Dashboard, formulated by Niti Aayog, a planning body of the GoI, monitors the progress made at the regional and national levels toward achieving SDTs and SDGs. Its first edition covered 13 SDGs, 39 SDTs, and 62 indicators, which rose to 17 Goals, 70 targets, and 115 indicators in 2020 (NITI Aayog 2021). In general, it acts as an implementation tool to assess resilience, sustainability, and collaborative efforts.

Conclusions

TEK, a diverse, dynamic and integral part of indigenous people in NE India, is inadequately linked and reflected in the SDGs, despite mass communications and education programs. Therefore, the present review attempted to delineate in depth the value and need for the conservation of TEK and the indigenous communities to achieve the SDGs. Our review outlined the manifestations and dynamics of TEK, which is critical in understanding how indigenous knowledge is positively linked with the SDGs. It revealed that the rich and diverse TEK of NE India is ecologically sensitive, and incorporating such knowledge in modern NRM may help to achieve a sustainable future. Various practices, customs, traditions, beliefs related to the indigenous farming systems, watershed management, biodiversity conservation, and ethnomedicinal therapeutic systems in NE India formed a vital part of this review. The final recommendations highlight the necessity for systematic collation, documentation and assessment of TEK, along with a sustainable policy framework for effective conservation, protection, and maintenance of TEK.

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