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Review of the food, water and biodiversity nexus in India

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ABSTRACT

Nexus research can help address issues arising at the intersection of traditionally independently treated management, policy, and research areas. While an extensive body of literature and reviews have been published on the water, food and energy nexus, biodiversity is less commonly featured in food and water nexus research, particularly in India. India hosts a large proportion of the world's biological diversity. At the same time, it is facing one of the world's highest habitat conversion rates, among others for agricultural production, as well as increasing water scarcity. Hence, the integration of biodiversity considerations into food and water nexus management and governance decisions is particularly critical in India. Here, we explore linkages at the food, water and biodiversity (FWB) nexus in India using a systematic review of peer-reviewed literature. A total of 208 nexus linkages were extracted from 55 articles and mapped using a qualitative systems mapping approach. Results show a strong interdependence between all three nexus nodes, with biodiversity exhibiting the highest number of linkages across the system (137 linkages), followed by water (131 linkages) and food (120 linkages). Our results reflect the state-of-the-art of research on biodiversity at the food-water nexus in India and highlight the importance of better understanding the linkages and tradeoffs at India's FWB nexus.

1. Introduction

Nexus research has been defined as the study of interlinkages between different subsystems or sectors within socio-ecological and other systems (Sanders and Webber, 2012). Nexus research has the ambition to highlight feedback loops, synergies and trade-offs between system elements in a holistic fashion – therefore, the concept of nexus research is closely linked to and partially rooted in systems thinking (Schlör et al., 2021; Liu et al., 2015).

Nexus studies aim to address issues arising at the intersection of traditionally independently treated management, policy, and research areas. In environmental sciences, nexus research is thought to first have fully risen to the limelight after the World Economic Forum of 2008, where the importance of considering water, energy and food linkages was officially recognized (Zhang et al., 2018). In addition, the run-up events and Rio+20 conference and resulting United Nations Sustainable Development Goals (SDGs) are thought to have played an important role in furthering nexus research (Liu et al., 2018; Hoff, 2011). As a result, an extensive body of literature and reviews have been published on the water, food and energy nexus (e.g., Biggs et al., 2015; Weitz et al., 2017; Wichelns, 2017; Vakilifard et al., 2018; Schlör et al., 2021; Rasul and Sharma, 2016).

Yet, biodiversity is rarely featured in food and water nexus research (Liu et al., 2015; Vargas et al., 2023), and has been more commonly addressed as part of dual nexus issues, such as biodiversity and food production (Iannetta et al., 2021; Godfray, 2011; Wittman et al., 2017; Glamann et al., 2017; Fischer et al., 2017) or the biodiversity climate nexus (Mooney et al., 2009; Bellard et al., 2012; Araújo and Rahbek, 2006; Willis and Bhagwat, 2009; Mashwani, 2020). Due to its wide-reaching significance for ecological, human and economic systems, biodiversity is however increasingly gaining attention in nexus considerations. For example, the ecosystem service framework emerged with the ambition to quantify and connect the various benefits people derive from ecosystems in a more holistic way (Daily, 1997; Millennium Ecosystem Assessment, 2001). Likewise, the importance of a nexus perspective for achieving SDGs has been widely recognized. Thus,

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numerous studies using a nexus approach to assess SDG linkages have been put forward (Liu et al., 2018; Scharlemann et al., 2020; Bleischwitz et al., 2018). These studies emphasized the importance of tradeoffs and synergies between different SDGs (Nilsson et al., 2016; Pradhan et al., 2017). Only recently, the Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published a scoping report for assessing the interlinkages among biodiversity, water, food, and health (Schmeller and Bridgewater, 2021). The resulting nexus assessment, to be published in 2024, will inform decision making towards policy options to achieve the post-2020 global biodiversity framework and the 2030 Agenda for Sustainable Development (llIPBES, 2021). However, developing sustainable governance options for nexus issues requires context- and scale-specific understanding of the same. There is therefore a need for national studies assessing nexus linkages, trade-offs and synergies in specific geographical and institutional contexts (Nilsson et al., 2018).

The aim of this study is to provide an overview and insights into nexus issues at the food, water and biodiversity interface in India and to visualize these linkages using a qualitative systems mapping approach (Hanger-Kopp et al., 2024). Through this exercise, we highlight key challenges, linkages and trade-offs in the FWB nexus. India is home to about 8 % of the world's biodiversity and four biodiversity hotspots (Chitale et al., 2014). As such, it is one of the world's 17 'mega--biodiverse' countries (Venkataraman and Sivaperuman, 2018). At the same time, India is among the largest food producers globally (Aditya et al., 2020), which has led to habitat and biodiversity loss (Bawa et al., 2021). India is also one of the world's most important food producers (Ramankutty et al., 2018). Agricultural expansion has also entailed increased groundwater use for irrigation and water scarcity (World Bank, 2012). For all these reasons, the integration of biodiversity considerations into food and water nexus management by considering trade-offs and linkages within this nexus and governance decisions is particularly critical in India.

2. Methods

In this study, publications addressing the FWB nexus linkages were identified through a systematic literature review, as well as additional snowballing from included sources. To select relevant literature, a search was undertaken in Scopus (Elsevier, 2022) in January-July 2022. Scopus was selected because of its broad scientific literature coverage. In addition to Scopus, key studies known by experts in the field were added to complement search results.

Only articles published after 2010 were included in the study. This is due to the fact that although the linkages between food, water and biodiversity have been recognized for a long time, the nexus terminology itself (particularly for food, water and energy) began to assume most prominence in academic and policy circles after the 2008 World Economic Forum, as well as the run up to the 2012 United Nations Conference on Sustainable Development (see Introduction). Table 1 provides a summary of the exact Boolean syntax (including search terms and exclusion criteria) used in Scopus.

In function of the number of results found in Scopus, search terms were refined to facilitate the screening process. This was mainly necessary for the food and water nexus due to the extensive body of literature on the topic. Literature was selected according to the guidelines defined in the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) statement (Moher et al., 2009). Fig. 1 depicts the literature selection workflow. Thus, a total of 55 journals and reports were analysed in-depth, most of which were empirical studies to ensure their scientific robustness.

We reviewed and analyzed the literature to illustrate insights on the food-water-biodiversity nexus, using a qualitative system mapping approach (QSM), which entails visualizing relationships through nodes and linkages (Hanger-Kopp et al., 2024). Systems mapping is one area of manifestation of systems thinking, and a way of grappling with complex challenges. Systems thinking is known support more integrative policy interventions that can bridge disciplines (Davila et al., 2021). QSM may be useful in many different ways, but in this specific instance, we use it to make nexus linkages (as implied in the academic literature) explicit and visible (Barbrook-Johnson and Penn, 2022). The QSM effort forces us to disentangle and organize linkages between nexus elements, which ultimately helps us to communicate our insights better. According to Hanger-Kopp et al. (2024), the QSM approach applied here fits the intersection of concept maps and causal diagrams.

Table 1
Summary of Scopus Boolean syntax and search terms.

Nexus issue	Boolean syntax of search terms used in Scopus	Boolean syntax of exclusion criteria
Water & biodiversity	TITLE ("water OR hydrol* OR aquatic*) AND TITLE (biodivers* OR diverse OR "species richness" OR "species composition*" OR evenness) AND TITLE-ABS-KEY (india)	NOT (marine OR coastal) AND PUBYEAR > 2010
Food & biodiversity	TITLE (agricultur* OR crop OR food OR nutrition) AND TITLE (biodivers* OR "species diversity" OR "species richness" OR "species composition*" OR evenness OR diverse) AND TITLE-ABS-KEY (india)	PUBYEAR > 2010
Food & water	TITLE ("food production" OR agricultur* OR crop) AND TITLE (water OR hydrol* OR aquatic*) AND TITLE-ABS-KEY (india)	AND PUBYEAR > 2010

Fig. 2 illustrates the different steps of this analysis, while Fig. 3 explains the terminology applied. Based on the relevant literature identified and elements and linkages extracted (step 1), nexus linkages are systematically coded (step 2). Depending on the analytical approach and scope of a study, these linkages do not necessarily represent direct causal connections, therefore step 3 explores all linkages (including intermediate and linkages that might not have been explicitly cited in literature) and disaggregates them to identify all explicit and implicit causal relationships. Step 4 involves the visualization of all (implicit and explicit) coded linkages as a systems map in kumu.io. Finally, linkages were quantified using common metrics used in Social Network Analysis, such degree centrality, i.e., the number of ingoing and outgoing connections for each nexus node and element (Wasserman and Faust, 1994) (step 5). System elements (henceforth elements) and connections between these elements (henceforth linkages), as well as the quantification of linkages (degree) were performed using the Kumu.io system mapping software (Mohr and Mohr, 2023).

Fig. 3 explains the terminology used in the systems map through an illustrative example of farmland owls reducing rodent populations in and around farmlands through predation (Ravikanth et al., 2020). Since farmland owls impact rodents, the direction of the arrow linking both elements goes from 'farmland owls' to 'rodents', meaning that the linkage is 'ingoing' for rodents and 'outgoing' for farmland owls. Additionally, because farmland owls reduce rodents, the linkage type is negative (represented by a dotted line), as depicted by a minus sign next to the arrowhead. If the sign was positive, this would have represented an increase in rodents. The size of elements' circles within the produced systems map is proportionate to the total number of ingoing and outgoing linkages for a given element. This means that the larger its circle, the more connected the element is within the entire systems map. Dotted lines represent a negative linkage, whereas solid lines represent a positive linkage between two elements.

3. Results

3.1. The food, water biodiversity nexus: overview

From the 55 data sources included in this study, 151 unique system

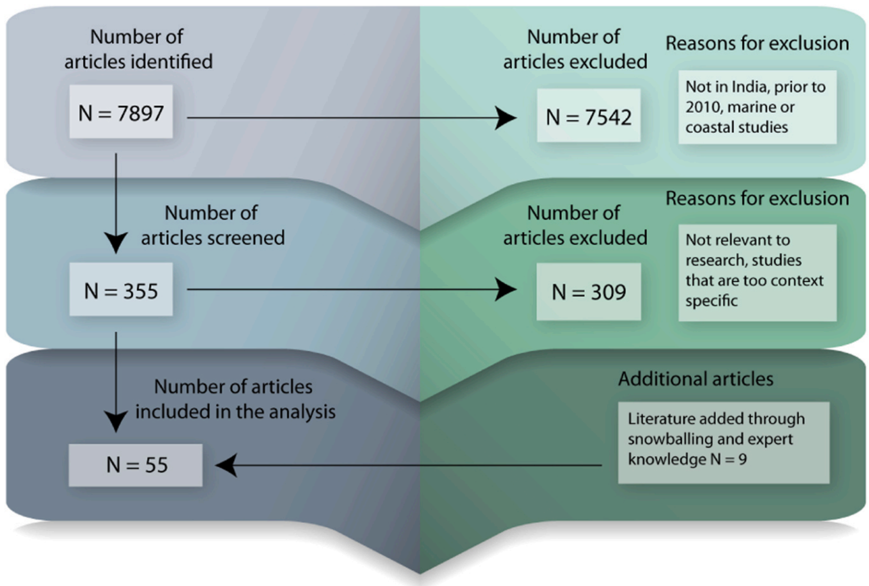

Fig. 1. Literature identification process, from the initial articles identified in Scopus (top) to the final articles included in the analysis (bottom).

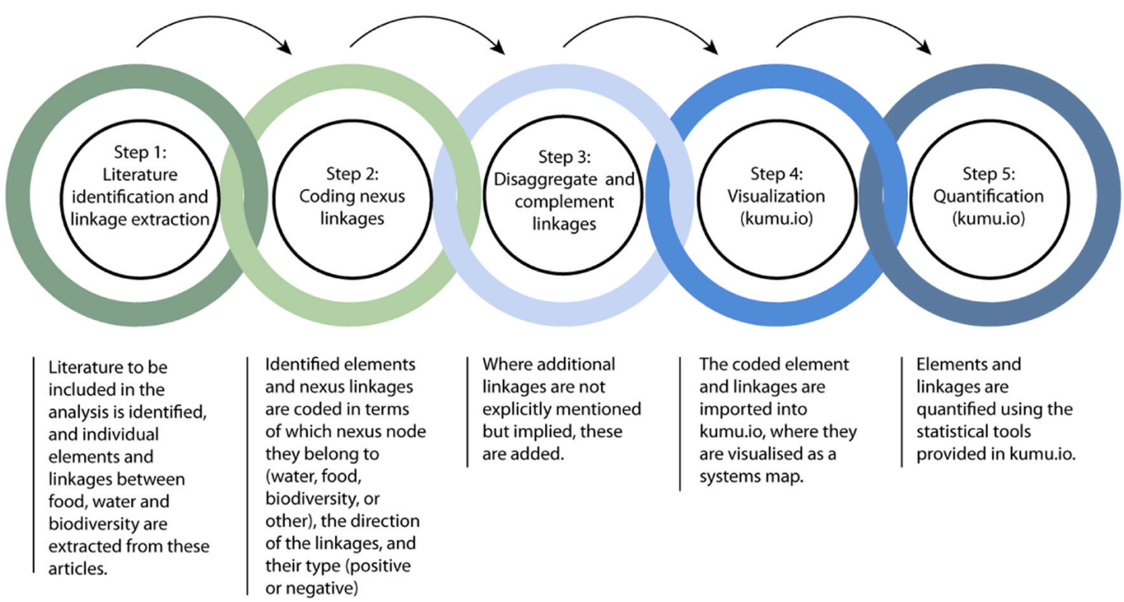

Fig. 2. The analytical process for building qualitative system maps from the literature. Adapted from Eker and Ilmola-Sheppard 2020.

elements and 208 linkages between these elements were extracted. Table 2 reports on the general distribution of these linkages, as well as their type - positive, negative or neutral (only 2 instances). 'Positive' and 'negative' indicate whether an element increases or reduces another one, rather than representing a value judgement on the desirability of an impact.

We identified mostly biodiversity elements, followed by water, food, and a small number of other nexus issues (including social, economic and health elements (N=12)). Most linkages were found between biodiversity and food, followed by water and biodiversity, and finally food and water. Most positive linkages were found between biodiversity and food (35), and the most negative linkages were found between water and biodiversity (17). In terms of reach (i.e., how far an element propagates in the system), the elements with most reach were 'agricultural land expansion', 'droughts' and 'conservation agriculture' (see Appendix A). Fig. 4 shows the entire system map created based on the reviewed literature, highlighting the diversity of elements as well as the most connected elements, which are distinguished by their size. These central elements may be indicative of research foci and areas of concern in the nexus literature, such as food security, agricultural land expansion, and freshwater biodiversity. Some elements are detached from the main map, which may indicate that they are more independent in the overall system and/or have been studied separately from more central concerns. Due to the dense nature of the full systems map produced which makes it hard to isolate individual elements on a static map, the main advantage of the kumu.io software is that the fully interactive map is openly available online here. The online map can be used to search, filter or isolate specific elements. Additionally, clicking on individual elements in the online map as well as linkages will reveal the data source used to code a given linkage.

Biodiversity was the most interconnected nexus node, with a total of 137 linkages, closely followed by water (131 linkages) and food (120 linkages) (Table 3). In terms of the direction of these linkages, a large number of outgoing linkages denotes that the nexus node is mainly

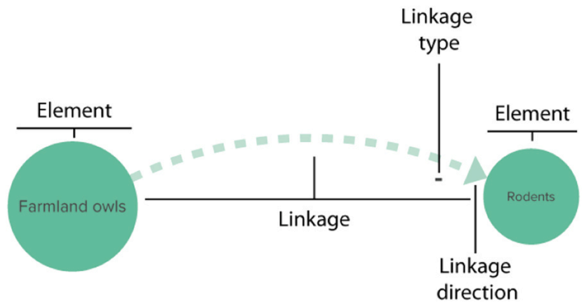

Fig. 3. Explanation of the terminology of different components in the systems map produced in kumu.io, using an annotated example from Ravikanth et al. (2020) based on their article's statement: "Owls which reside in and around farmlands have significantly contributed to managing the rodent population damaging crops"(2020:35. Sizes of circles (elements) represent the number of linkages going to and from a given element, while the thickness of lines represents the number of connections between two nodes. Dotted lines denote negative linkages, whereas solid lines represent positive linkages.

Table 2
General statistics of the linkages extracted from literature.

Nexus node	Biodiversity	Water	Food
Total unique* elements	57	41	41
	Biodiversity - food	Water - biodiversity	Water - food
Total linkages	56	39	28
Positive linkages	35	22	10
Negative linkages	21	17	18

** Social, economic and health related elements.
* Some elements (e.g., irrigation) are mentioned in several studies. Therefore, the number of unique elements is reported here.

'influencing' or impacting other nexus nodes, whereas a large number of ingoing linkages signifies that a given node is mainly 'influenced' by other nodes. We find that biodiversity presents the highest number of ingoing linkages (90), meaning that biodiversity is the most influenced by the other two nexus nodes. On the other hand, with 83 outgoing linkages, water is the largest influencer in the nexus system map (Fig. 5). While the results provide an overview of the general FWB nexus landscape, the next sub-sections explore the key elements that were part of each nexus node and how they were linked to each other. In each of the three following sub-sections, the top three most frequently cited elements and their direct in- and out-going linkages are discussed.

3.2. Water nexus issues

With a very rapidly growing population, sustainable water management is a key issue in India which is likely become increasingly critical under a changing climate (Gosain et al., 2011) and with increasing water demands (Gupta and Deshpande, 2004). Indeed, several studies have predicted that India might become one of the world's water scarcity hotspots in the future (Gosling and Arnell, 2016; Vörösmarty et al., 2000). The National Water Policy (Government of India, 2012) is the main (national) legislation governing water resources in India. Our results show that there is a clear link between water and food, and water and biodiversity. Among the water linkages extracted from literature, the most frequently cited and thus connected nexus elements are water quality (directly connected through 16 linkages), water extraction for irrigation (13 linkages) and droughts (11 linkages) (Fig. 6).

In the analysed studies, water quality was mainly impacted by agricultural practices and activities. For example, particularly during monsoon seasons, water quality was shown to decrease due to increased nutrient loads (mainly phosphates and nitrates) in Indian waterbodies (Kumar et al., 2021), in turn related to agricultural fertilizer runoff (Dubey et al., 2022). This is compounded by agricultural pesticide use, which has in many instances increased the chemical load of waterbodies, such as rivers in West Bengal (Bunting et al., 2015) or the Western Ghats (IUCN, 2011), where pesticide runoff has been linked to declines in water quality, freshwater habitat quality and biodiversity. Additionally, many industries in India discharge waste into rivers due to a lack of operational waste treatment plants (Dudgeon, 2000), further impacting water quality. With India undergoing rapid urbanization, urban sewage is also recognized as a major cause for decreasing water quality (Amerasinghe et al., 2013; Kumar et al., 2022). Inadequate wastewater treatment infrastructure has resulted in crops getting contaminated in peri-urban areas where wastewater is a primary source for irrigation (Kookana et al., 2020; Thomas et al., 2017). Water quality was also impacted by changes in water availability and distribution. Among their many socio-ecological and economic impacts, droughts were particularly associated with deteriorated water quality (Udmale et al., 2014). Likewise, changes in natural river flow and discharge due to canalization and dam constructions have further degraded water quality. For example, in the river Yamuna, water abstraction and increases in industrial effluents have drastically impacted water quality (Joshi et al., 2016). In terms of elements impacted by water quality, our results highlight the direct link between water quality and freshwater biodiversity, including fish (Joshi et al., 2016), macroinvertebrate (Khatri et al., 2021; Kumar et al., 2021) and phytoplankton diversity (Meshram et al., 2018). Indeed, good water quality leads to high diversity, and high biodiversity of certain taxonomic groups is an indicator of good water quality (Meshram et al., 2018; Khatri et al., 2021).

Water extraction for irrigation was the second most connected element and was identified as a main driver for declining groundwater availability, and as whole, water security. Indeed, a significant and increasing proportion of freshwater resources in India is used for irrigation (Bunting et al., 2015), which has led to decreases in both surface and ground water levels (Gupta et al., 2015). It is estimated that in India, about 89 % of extracted groundwater is used for irrigation (Jain et al., 2019). Water for irrigation is mainly extracted through wells, canals and tanks (Shah, 2011). Yet, groundwater irrigation is also the backbone of India's agriculture (Zaveri et al., 2016), which employs about 55 % of India's population (Jain et al., 2019). Thus, there are important implications for the country's food security. Indeed, agricultural water use represents one of India's National Water Policy's main water allocation priorities (Government of India, 2012). Yet, the Policy primarily sets focus on water as a resource and does not address biodiversity or its decline in relation to water exploitation. Yet, irrigation was also associated with decreased freshwater fish diversity and general biodiversity. It was estimated that freshwater species have declined by over 30 % from 1970 to 2003, partially as a result of water diversions for irrigation (Lakra et al., 2011). Fish and mollusk species that are particularly affected include freshwater prawns, carps, catfish and ilish (*ibidem*), whereas odonates are particularly threatened by dams, as observed in the Western Ghats (IUCN, 2011). However, water reservoirs have also evolved to be important sources of inland fisheries (Sarkar et al., 2018). Water extraction for irrigation is thus mainly influencing other elements, and was in our results only impacted by monsoon rainfall, as more rainfall leads to a lower reliance on water from irrigation (Zaveri et al., 2016).

Finally, droughts were the third most connected element. While droughts in India are largely determined by global climate patterns, such as el Niño (Kumar et al., 2013), they can have catastrophic effects on local livelihoods and are perceived to be on the rise by local farmers (Sharma and Mujumdar, 2017). Unsurprisingly, droughts were mainly driven by water scarcity (Zaveri et al., 2016), yet were an important influencer in the overall system, impacting not only food and water nexus elements, but also health-related and economic elements. As such, droughts have been linked to decreased agricultural yield and livestock production (both associated with decreased income generation) and

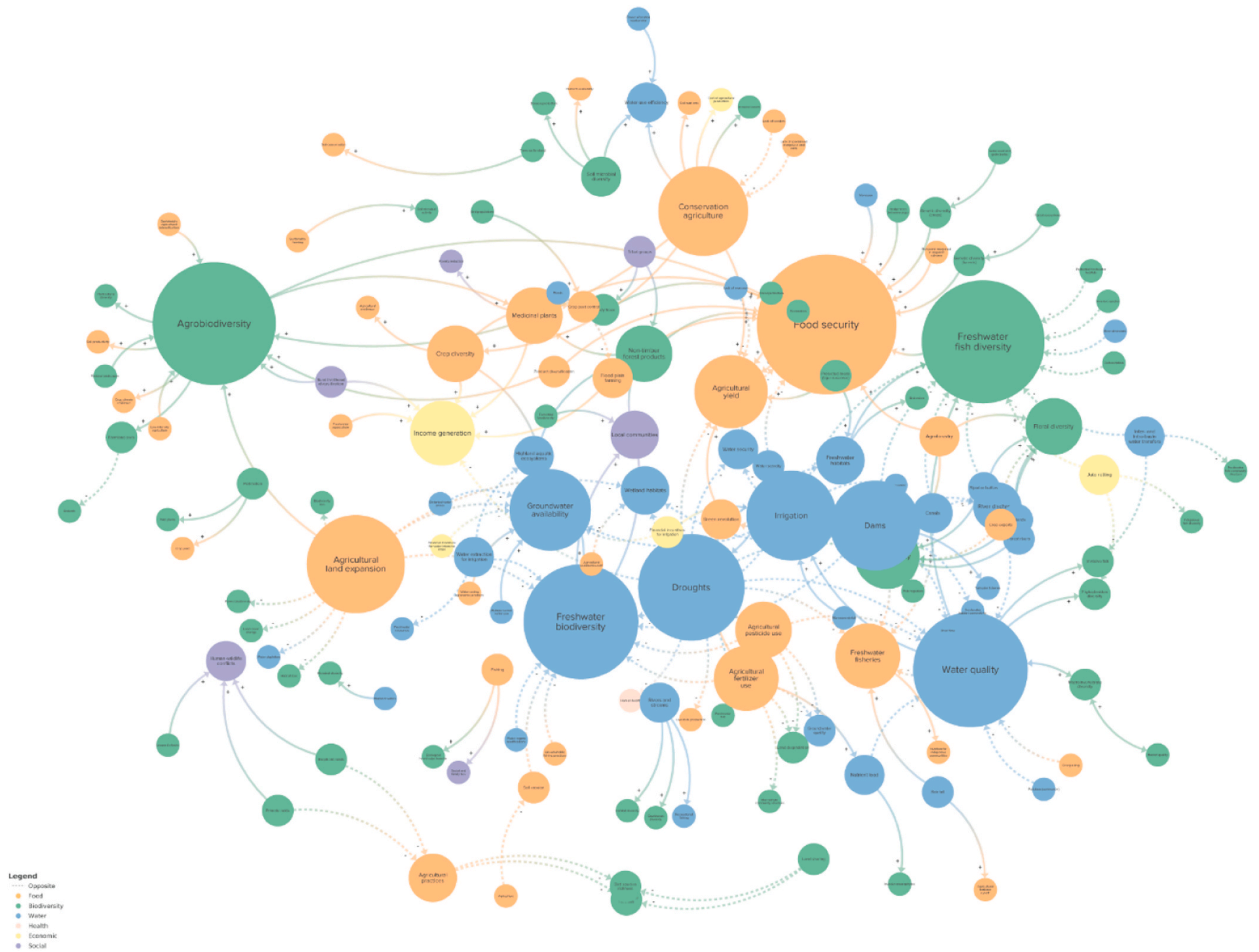

Fig. 4. Systems map of food, water and biodiversity nexus linkage in India based on literature. Sizes of circles (elements) represent the number of linkages going to and from a given element. Dotted lines denote negative linkages, whereas solid lines represent positive linkages (a full version of the map is available here).

Table 3
Number and direction of linkages between food, water and biodiversity.

Nexus node	Linkage direction	Number of linkages
Water	ingoing	48
	outgoing	83
	total	**131**
Biodiversity	ingoing	90
	outgoing	47
	total	**137**
Food	ingoing	56
	outgoing	64
	total	**120**

poor health (including mental health) by farmers in the Maharashtra State (Udmale et al., 2014). Droughts also led to environmental degradation, and are associated with decreases in faunal diversity, including freshwater fish (*ibidem*). For instance, droughts have a direct impact on the success of carp cultures in Purulia (Mishra et al., 2022) and fish spawns in the river Ganga (Das et al., 2013).

3.3. Biodiversity nexus issues

India hosts a substantial proportion of the world's biological diversity (Jenkins et al., 2013; Chitale et al., 2014; Venkataraman and Sivaperuman, 2018). At the same time, India is among the world's countries facing the highest habitat conversion rates (Watson et al., 2016) and biodiversity loss (Venter et al., 2016). It is estimated that over 40 % of the country's land is degraded, mainly due to the overuse of agrochemicals and land conversion for irrigation (Ravikanth et al., 2020). Yet, it is estimated that up to 150 million people (including marginalized communities) directly depend on biodiversity for their livelihoods (Bawa et al., 2021).

With a total of 137 linkages, results show that biodiversity is the most connected nexus node in the food, water and biodiversity nexus. We find 39 direct linkages between water and biodiversity, as well as 56 between food and biodiversity. The most connected biodiversity elements are freshwater fish diversity (directly connected through 16 linkages), agrobiodiversity (16 linkages) and freshwater biodiversity as a whole (15 linkages) (Fig. 7). It is noteworthy that these top 3 most connected biodiversity elements are in fact not only related to biodiversity, but already straddle the food and water nexus nodes. Indeed, freshwater biodiversity and fish biodiversity relate to water, while agrobiodiversity relates to food. This shows that by default, biodiversity is a highly connected nexus node that goes beyond a single sector or discipline. This is in line with the various definitions of biodiversity, placing it at the root of functioning ecosystem processes and resulting ecosystem services (Isbell et al., 2017; Harrison et al., 2014)

India has a very high freshwater fish diversity, hosting about 10 % of the global freshwater fish (Kisku et al., 2017) and over 900 different species (Joshi et al., 2016) and high endemism (Nesemann et al., 2017).

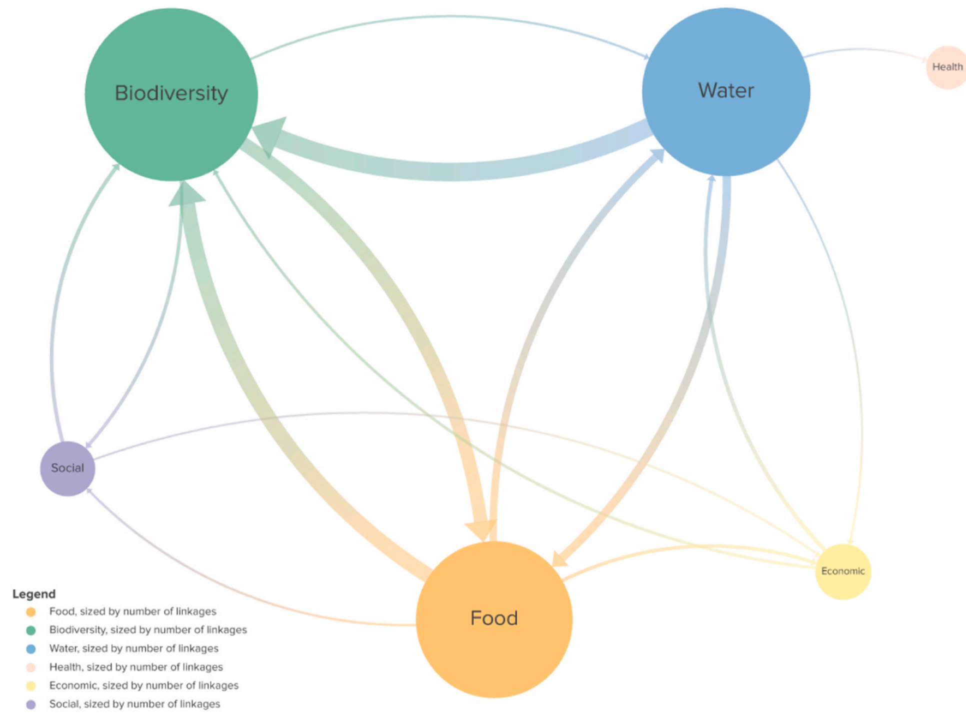

Fig. 5. Systems map of the food, water and biodiversity nexus in India based on literature. Sizes of circles (elements) represent the number of linkages going to and from a given node, while the thickness of connections represents the total number of connections between two nodes (map available here).

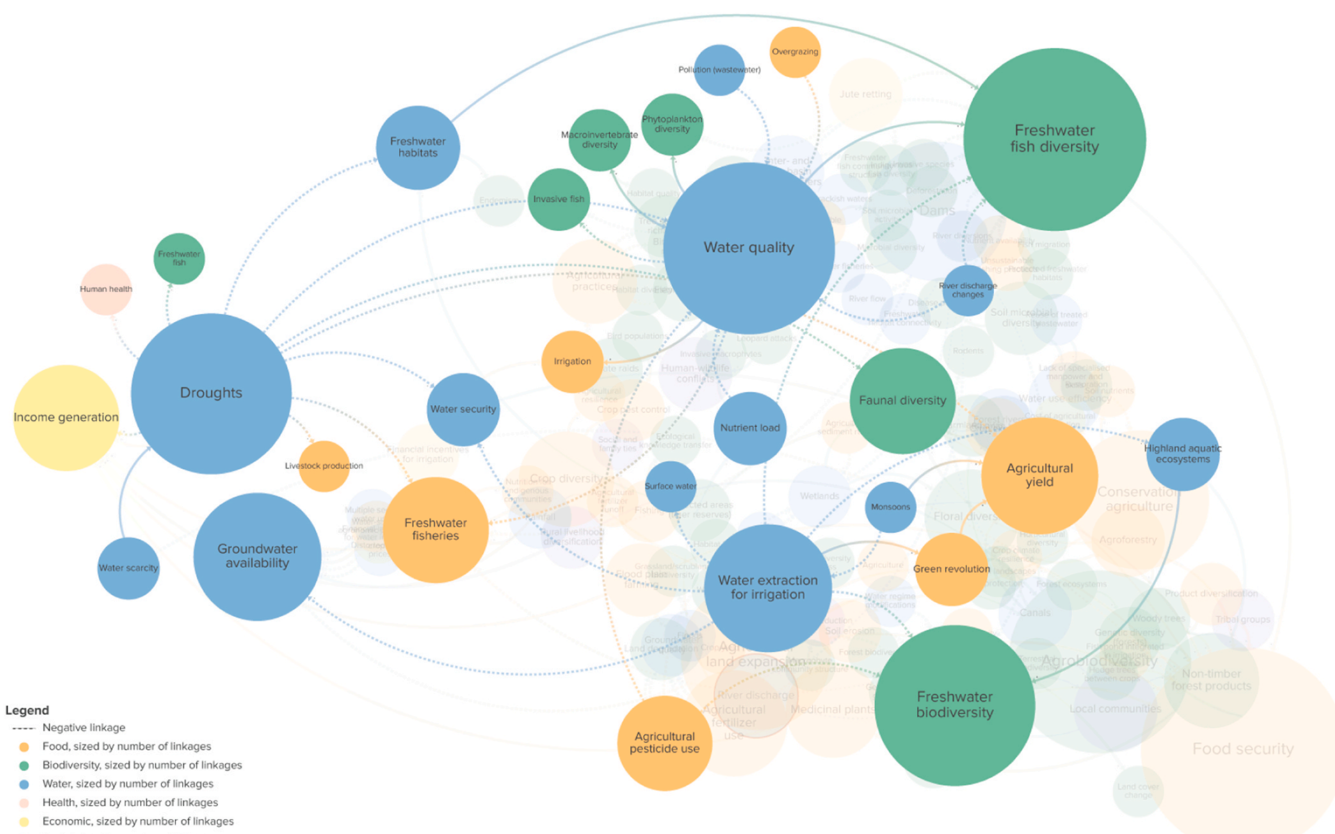

Fig. 6. Systems maps showing the ingoing and outgoing linkages for water quality, water extraction for irrigation and droughts (full version of the map available here). Sizes of circles (elements) represent the number of linkages going to and from a given element. Dotted lines indicate negative linkages and solid lines positive linkages.

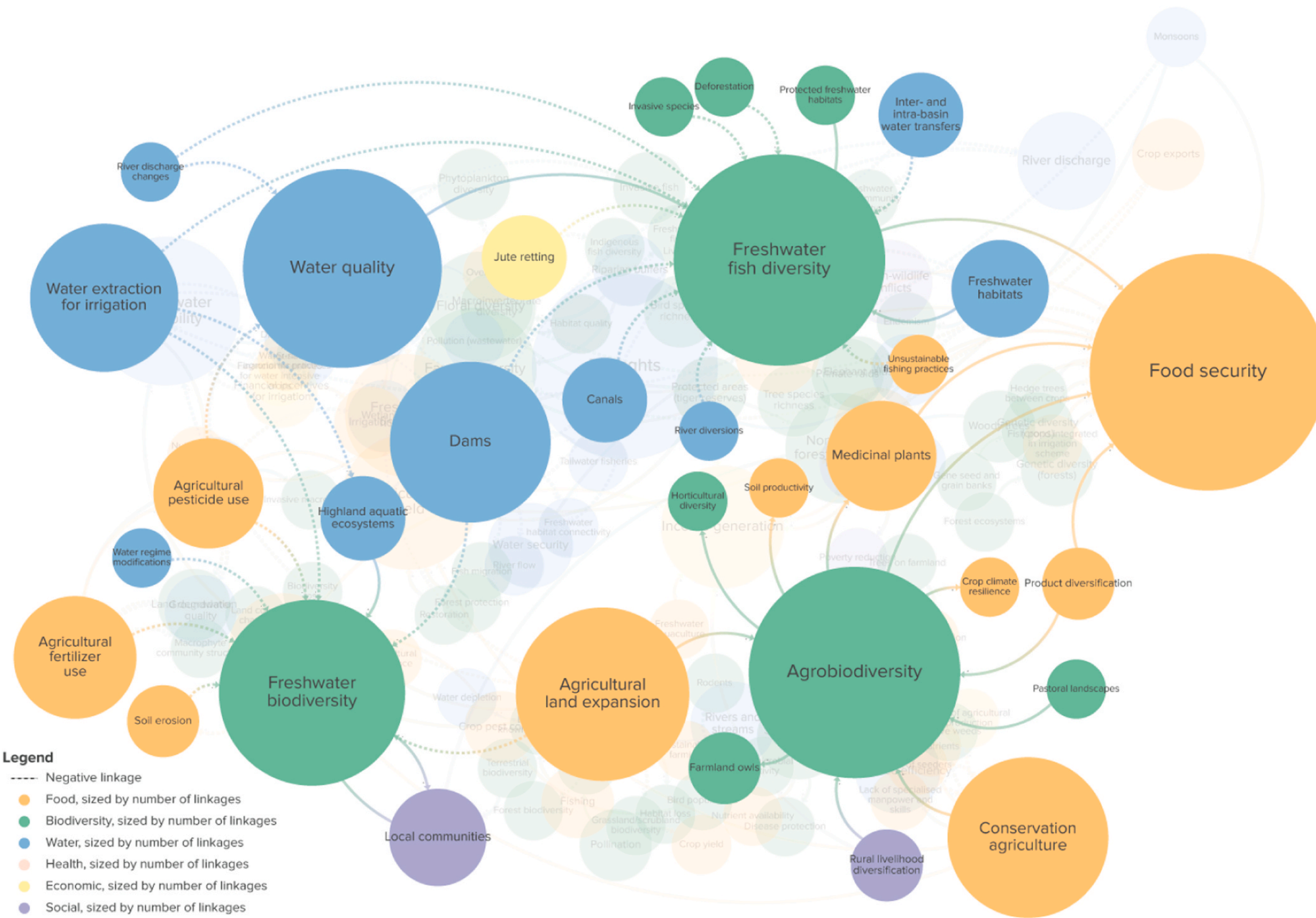

Fig. 7. Systems maps showing the ingoing and outgoing linkages for freshwater fish diversity, agrobiodiversity and freshwater biodiversity (full version of the map available here). Sizes of circles (elements) represent the number of linkages going to and from a given element. Dotted lines indicate negative linkages and solid lines positive linkages.

In the analyzed studies, freshwater fish diversity was mainly impacted by other elements. Water quality (including water turbidity, pH, dissolved oxygen and the concentration of various fertilizer by-products) was the biggest driver of freshwater fish diversity. Indeed, fish diversity depends on good water quality (Joshi et al., 2016). For example, in the Paschim Medinipur District (West Bengal), a study revealed that Community Development Blocks with the highest water quality exhibited the highest fish diversity (Kisku et al., 2017). As previously highlighted, the engineering of waterways (both for irrigation and other water management purposes) also played a key role in reduced freshwater fish diversity. Thus, the construction of dams and canals, as well as resulting inter- and intra-basin water transfers and changes in river discharge were shown to have reduced fish diversity (Lakra et al., 2011; Bunting et al., 2015; Grant et al., 2012). Equally, the loss of forests (Lakra et al., 2011) and introduction of invasive species (Bunting et al., 2015) were associated with lower fish diversity. Results also show that freshwater habitats are currently underrepresented in the national protected area network (Kumar Sarkar et al., 2013). The only element directly impacted by fish diversity is food security. Indeed, India is among the world's largest aquaculture producers (FAO, 2021). As a non-vegetarian source of protein, fish consumption and production are increasing in India, thus contributing to nutrition and food security (Barik, 2017). Freshwater fisheries are thought to support the livelihoods of over 23 million inland fishermen and fish workers in the country (Ghosh et al., 2022).

Agrobiodiversity was the second most connected biodiversity element. Agrobiodiversity is broadly defined as the diversity of life on, around or supported by agricultural land (Wood and Lenné, 1999). As many as 22 agrobiodiversity hotspots have been identified in India (Nayar et al., 2009), pointing to the importance of India in global agricultural diversity. In India, agrobiodiversity is a central source of nutrition, raw materials and soil productivity for farmers (Ravikanth et al., 2020). Besides, vegetation around farmland increases resilience to disasters, e.g., by acting as windbreakers and increasing pest control through predation (*ibid*). Agrobiodiversity is also vital for medicinal plants, such as *Terminalia chebula* (Maske et al., 2011), which are a non-negligible source of income for many small-scale farmers (Nautiyal et al., 2020). These various non-timber forest products (NTFPs) are recognized as crucial livelihood sources and include wild plants, fungi, wild fruits, nuts, edible roots, small mammals, insects, fish, honey and aforementioned medicinal plants (Pullanikkatil and Shackleton, 2019).

The reviewed studies reveal that agrobiodiversity can be increased by conservation agriculture practices (including low intensity farming or sustainable intensification) (Bunting et al., 2015; Kothari and Joy, 2017). For example, in Buxa (West Bengal), introducing multiple cropping seasons, diversifying crops (e.g., combined rice and fish cultures) and reducing agrochemical use was shown to have a positive impact on agrobiodiversity and crop resilience (Bunting et al., 2015). However, implementing measures supporting agrobiodiversity can be limited by many factors, including the lack of resources, financial and institutional support, access to knowledge and needed paradigm shifts (Bhan and Behera, 2014; Singh et al., 2023). Likewise, the co-creation of agricultural conservation options is key. Participatory crop variety selection, seed exchange and the establishment of community institutions promoting new varieties and knowledge exchange were proven to strengthen livelihoods and biodiversity in three agrobiodiversity hotspots of India (Anil Kumar et al., 2015).

The third most connected biodiversity element is freshwater biodiversity. As freshwater fish are a subset of freshwater biodiversity, the ingoing and outgoing connections are very similar to those for freshwater fish diversity, with few notable differences. For example, literature highlighted a mutual direct link between freshwater biodiversity and local communities, including the importance of aquatic resources for NTFPs and the harvesting of aquatic plants and animals (Bunting et al., 2016; Kothari and Joy, 2017). Additionally, more focus was attributed to the negative impacts of agricultural expansion (IUCN, 2011), resulting soil erosion (Bunting et al., 2015) and the use of agrochemicals (Allen et al., 2012) on freshwater biodiversity.

To conclude, biodiversity elements are the most frequent in our systems map, and the most connected. This can be explained by the central role biodiversity plays in supporting provisioning services, such as food and water (Naeem et al., 2012; Watson et al., 2019). Yet, our results only highlight few linkages between biodiversity and human well-being, which may point towards a lack of recognition of this linkage in India. The Indian National Mission on Biodiversity and Human Well-Being (NMBHWB) aims to fill this gap by integrating biodiversity, agriculture, health, bio-economy, climate change and capacity building within biodiversity science (Bawa et al., 2021).

3.4. Food nexus issues

India is among the largest food producers globally, with the agricultural sector employing over 50 % of India's workforce and remaining the country's primary food supplier (Ravikanth et al., 2020; Zaveri et al., 2016). In our nexus systems map, the most connected agricultural elements are food security (19 linkages), conservation agriculture (12 linkages) and agricultural land expansion (11 linkages) (Fig. 8). Food security is the most connected element, not only among food elements but in the entire systems map. Yet, it only presents ingoing connections, showing that it is mainly influenced and impacted by other elements in the system. An estimated 600 million Indian people directly or indirectly depend on agriculture for their livelihoods (Anil Kumar et al., 2015). Most of India's farmers are small-scale and many live in poverty (Baw et al., 2020), which means that sustainable agricultural practices are of vital importance for local livelihoods and food security.

Results show that food security is positively affected by conservation agriculture measures, such as agroforestry (Dandabathula et al., 2021), product diversification (Anil Kumar et al., 2015) or the presence of hedges and woody trees between crops (Aditya et al., 2020; Hegde et al., 2019). Several other elements related to biodiversity increased food security, many of which were mentioned in the previous section (e.g., NTFPs, agrobiodiversity and freshwater fish diversity). Additionally, our systems map reveals the importance of genetic diversity for food security. For example, a field experiment in Madhya Pradesh demonstrated that in the case of pigeonpea, crops with a higher diversity exhibit lower pod and grain damage from pests (Ambhure et al., 2014). Similarly, the genetic diversity of forest species in India has been associated with many species of food value (Bélanger and Pilling, 2019) and is particularly critical for the most vulnerable parts of the population (Anil Kumar et al., 2015). Related to this, farmers' experiential knowledge on traditional crops and farming practices as well as associated ecological processes were proven key for maintaining indigenous food sovereignty in India (Bisht et al., 2020). Yet, the qualitative and less tangible nature of such knowledge makes its formal recognition in institutional policies

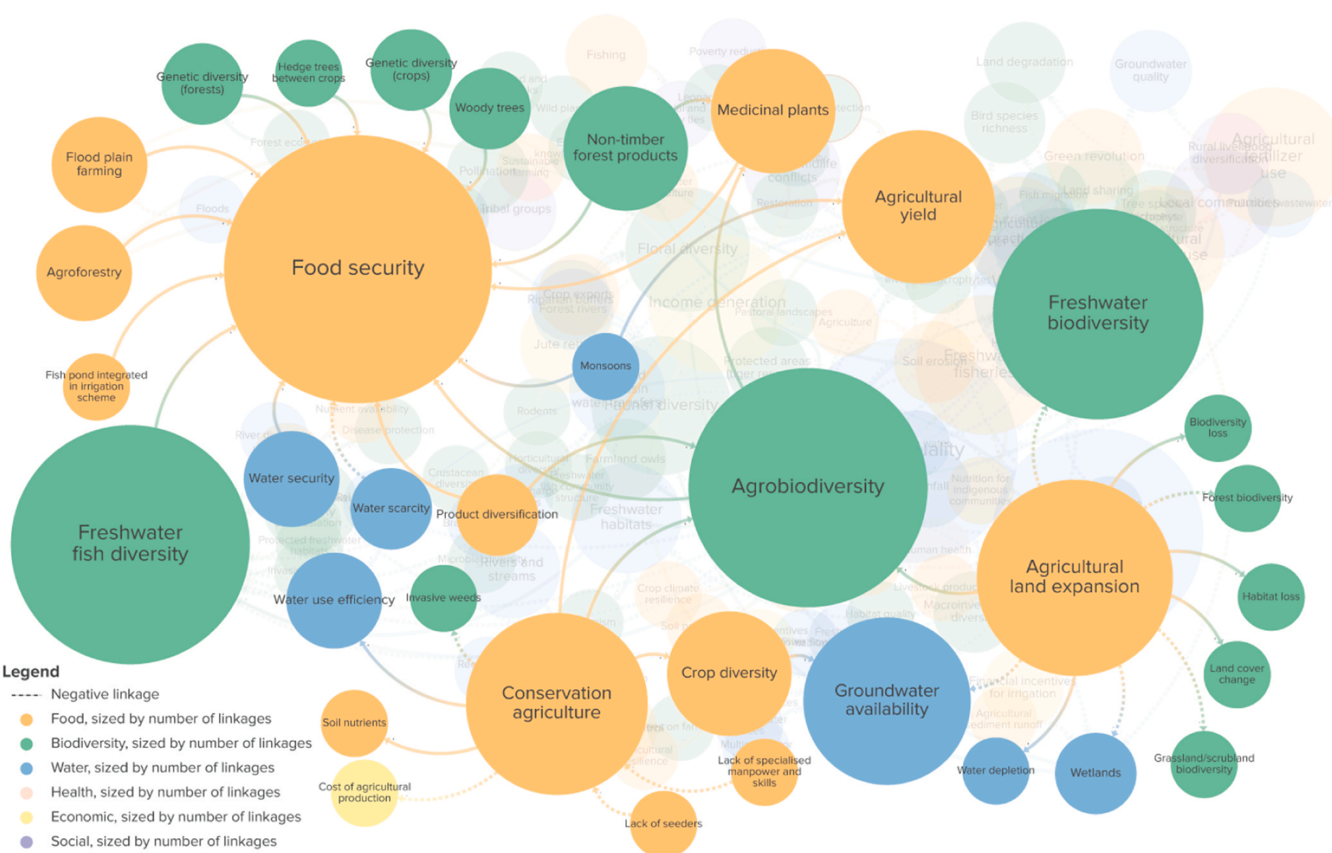

Fig. 8. Systems maps showing the ingoing and outgoing linkages for food security, conservation agriculture and agricultural land expansion (full version of the map available here). Sizes of circles (elements) represent the number of linkages going to and from a given element. Dotted lines indicate negative linkages and solid lines positive linkages.

difficult (Šūmane et al., 2018).

A further key influencer of food security is water availability and security, largely defined by monsoons in many parts of the country (Dhawan, 2017). India is the world's largest groundwater user (World Bank, 2012). Most of India's extracted groundwater is used for irrigation, without which the country's agricultural transformation (or Green Revolution) could not have been achieved (Mukherji, 2008; Quinlan et al., 2014). Government subsidies for electricity powering irrigation equipment have also led to increased water extraction – which did increase food security, yet with important tradeoffs for groundwater levels (Zaveri et al., 2016; Gulati and Pahuja, 2015). This linkage is also reflected in policy. Agriculture and food production are addressed in a number of national frameworks in India, including the 2000 National Agricultural Policy, the 2007 National Policy for Farmers, the 2001 Protection of Plant Varieties and Farmers' Rights Act and the 2002 National Seed Policy (Jacob et al., 2020). Water use is a key consideration in most of these frameworks, while biodiversity is only marginally addressed (Mondal et al., 2023; Šūmane et al., 2018; Bisht et al., 2020).

The second most connected food element is agricultural land expansion. In contrast to food security, agricultural land expansion only has outgoing connections, showing that the analyzed literature focused on the impact this element has rather than its causes. While agricultural expansion in India is associated with increased agrobiodiversity (Ravikanth et al., 2020), this has been to the detriment of numerous habitats, including wetlands (Behera et al., 2012), associated freshwater biodiversity (IUCN, 2011), forests, scrub- and grasslands (Ravikanth et al., 2020). Indeed, in their study comparing crop yields of land sharing and land sparing strategies in India, Phalan et al., 2011 show that overall, more species are negatively impacted by agriculture than benefiting from it, particularly among endemic species. As discussed above, agricultural land expansion has also greatly reduced water resources (Zaveri et al., 2016; Quinlan et al., 2014; Dhawan, 2017).

Conservation agriculture, which was already mentioned in the context of agrobiodiversity (see previous Section) was the third most connected food element. The Food and Agriculture Organization of the United Nations defines conservation agriculture as practices that promote the maintenance and conservation of soil cover and the diversification of plants (FAO, 2023) – thus increasing agrobiodiversity. Because of this close link, several of the elements connecting to and from conservation agriculture, such as crop diversity and soil nutrients, overlapped with those connecting to and from agrobiodiversity, described in the previous section. Literature also highlighted the role conservation agriculture practices, such as zero-tillage, can play in reducing invasives weeds (Bhan and Behera, 2014), fuel and herbicide costs (Malik et al., 2005) and increasing water use efficiency by up to 30 % by preserving soil water content (Gupta and Jat, 2010). However, literature also revealed potential challenges in implementing conservation agriculture measures. For example, the lack of appropriate seeders for small- and medium-scale farmers, as well as limited skills and manpower to switch to conservation agriculture practices were highlighted (Bhan and Behera, 2014).

Finally, it is noteworthy that agricultural land expansion and conservation agriculture were among the three system elements with the highest reach (0.137 and 0.123 respectively, see Appendix 1), pointing towards the wide-reaching effects of these elements throughout the entire FWB nexus.

4. Discussion

With this review, we address the need of a context-specific nexus understanding and review academic literature to explore important causal linkages at the food-water-biodiversity nexus in India. Applying a systems thinking lens, we use qualitative system mapping to illustrate our findings.

As most extracted elements pertain to biodiversity, our results make recent advancements in biodiversity and conservation research in India evident. Biodiversity was the most connected element (both with food and water), which can be explained by biodiversity representing the backbone of ecosystem processes that support water regulation and food availability. A central issue that emerged here was the safeguarding of food security in a country where agriculture is expanding and water resources are dwindling. While food elements were less frequent in the final systems map, they had a higher reach than other nexus issues, with agricultural land expansion having the highest reach. This is due to the severe impacts of agricultural expansion on water quality and use for irrigation, as well as habitat fragmentation. In the reviewed literature, particular emphasis was placed on agrobiodiversity and sustainable farming practices to address trade-offs with biodiversity and water management. Additionally, many studies focused on the impacts of river alterations on ecosystems, including the construction of dams and channels for irrigation. Thus, our findings also reveal potential conflicts and competing interests within the FWB system.

In terms of nexus pairings, food and biodiversity linkages were most frequent, followed by water and biodiversity linkages. Despite their straightforward link, water and food linkages were the least frequent. This might be explained by the timeframe chosen for including studies (post 2010), chosen based on the rise of nexus research in this period. Nevertheless, this timeframe also overlaps with a rise in studies on biodiversity (Titley et al., 2017), whereas research on water management and food production expanded earlier (Postel, 1998), which may have created a bias towards this nexus node. Despite this, the role of biodiversity in safeguarding nature's provisioning services is less systematically addressed in Indian water or food policy, as opposed to the linkage between food and water, which is traditionally more widely recognized and straightforward. This is most likely due to the complexity of the concept of biodiversity, and the indirect linkages that connect it to provisioning ecosystem services such as food and water, as highlighted in our nexus systems map. Our study therefore highlights a need for further cross-sectoral policies addressing multiple FWB nexus considerations simultaneously. 'Horizontal' coordination and decision-making spanning across different sectors is a key characteristic of polycentric governance arrangements (Ostrom, 1999), which have indeed been proposed for addressing other nexus interdependencies and their governance, e.g., in the water-energy-food (Srigiri and Dombrowsky, 2022) or energy-water nexus (Villamayor-Tomas, 2018).A related aspect is the oftentimes conflicting objectives of biodiversity conservation and economic development, which is particularly crucial in the case of India (Srivathsa et al., 2023). On the one hand, the country needs to improve the living standards of its vast and expanding population, and lift people out of poverty through sustained and long-term economic growth. On the other hand, many sectors that propel growth and employment have adverse impacts on biodiversity and environment (Jha and Bawa, 2006). This tension has resulted in complex policy choices and tradeoffs (Chopra, 2017). Yet, India has a track record of bringing in strong legal provisions to conserve biodiversity and protect the environment. Examples include the Biological Diversity Act 2002 (Parliament of India, 2002) and the Forest Conservation Act 1980 (Parliament of India, 1980). In addition, the government has constituted conservation bodies like the National Mission on Biodiversity and Human Well-Being (Bawa et al., 2021) to protect biodiversity hotspots and complex socio-ecological systems. Biodiversity conservation efforts in India have attempted to bring in community participation and ownership going beyond the traditional 'fortress conservation' strategies (Rai et al., 2021). However, the tension between the need for economic growth and environmental priorities has seen several of these efforts not reaching their desired goals (Tisdell, 2020). Critics have argued that legal provisions have been weakened to prioritize economic growth and these have not been implemented properly on the ground: for example, recent amendments to the Biological Diversity Act 2002 and the Forest Conservation Act 1980 have come under critical scrutiny and evoked strong responses from conservationists and experts (Gupta, 2023; Saxena, 2024; Chouhan, 2023). While our review provides valuable insights into key food, water and biodiversity nexus issues in India, it is not without limitations, many of which are inherent to literature reviews (Snyder, 2019). For example, our study only highlights those linkages mentioned in the included literature, at the risk of missing important (yet unpublished or omitted) nexus linkages. Since food, water and biodiversity are all broad concepts that encompass many subfields, sectors and disciplines, it is difficult to capture all nexus linkages in a comprehensive manner. Additionally, as with any literature review, the scope of the study was bound using specific search terms, with the possibility that themes outside of the FWB nexus were insufficiently covered as a result. Similarly, we cannot be fully certain that the terms reviewed covered all available studies on the topic, as authors may have used different terminology for identical or similar concepts. Further biases may have arisen by including only English language resources, while key studies might be published in local languages or not be publicly available. Moreover, terminology may often be used inconsistently, thus forcing the reviewer to make potentially arbitrary decisions when interpreting meaning.

Visualizing literature reviews using qualitative system maps is increasingly common, for example to illustrate author or thematic networks. However, we are not aware of applications where QSM has been used to structure and illustrate a literature review on nexus issues. This approach is thus an innovation, which cannot build on available literature yet is explored in this review study. The key advantage is forcing clarity on linkages by making them explicit and translating vast amounts of information into easy to grasp, graphical illustrations.

A wide variety of tools are available for such visualizations. Kumu.io is a valuable and relatively novel option as it is freely accessible and provides attractive visuals, apart from ample opportunities to deepen the analysis by adding additional layers of information. Most importantly, the resulting maps are excellent knowledge repositories that can be used and searched online. There are still certain drawbacks, as complex overview maps are difficult to navigate or on the contrary can create the illusion of an oversimplified system. There is ample room for further studies into the most effective use of QSM in nexus review efforts, specifically providing clear review protocols and guidance, but also exploring quantitative opportunities for areas with ample data availability to gain additional levels of insights.

While care was taken to include studies from different parts of India, studies will inevitably reflect sample biases, for example towards areas that are most accessible or well-studied. In particular, we note the limitations of aggregating data from a variety of contexts and scopes, which is however an inherent limitation of literature reviews (Grant and Booth, 2009). Acknowledging these limitations, our findings nonetheless show the value of a national study, which on the one hand allows to disaggregate nexus issues and highlight context-specific links, while on the other hand still requiring some level of aggregation of common nexus linkages.

Although our review captures important FWB nexus issues in India as recognized by peer-reviewed literature, further on-the-ground work is needed to validate and expand these results. Additionally, while this review serves to inform and identify potential areas of policy action at the FWB nexus, prescriptions on actual policy and practice are beyond the scope of the review, and would require the consultation of decision-makers and stakeholders through a participatory process, such as interviews. We hope to fill this gap in the fairSTREAM project, where FWB nexus issues in the Upper Bhima Basin are explored using mixed (quantitative and qualitative) methods (see Kanade et al., 2023). To develop sustainable policy options across the FWB nexus, the project aims to develop a knowledge co-production approach involving direct interactions with primary stakeholders (farmers, fishermen and forest-dependent communities) which will help further contextualize the FWB nexus,its challenges and policy options in this region.

5. Conclusion

The current study represents a first attempt at distilling some of the central issues pertaining to the FWB nexus in India. Our results emphasize that food, water and biodiversity in India are part of a highly connected system, as demonstrated by the developed systems map(s), which exhibit a dense network of nexus elements and only very few isolated elements. Additionally, extracted linkages were very complex, with individual elements often having a wide reach within the system. Thus, impacting one given element can have cascading effects through the entire FWB system. The developed systems map also highlights the numerous tradeoffs and areas of competing interests within the FWB nexus. Yet, the applied qualitative systems mapping method also represents a valuable approach for understanding wider sustainability challenges.

This has important implications for policy and practice both within and beyond India. Countries around the world have committed to achieving their national targets as part of the SDGs, and nexus approaches are increasingly considered indispensable to successfully deliver them (Estoque, 2023). The Government of India has implemented various programs and interventions and has been keeping track of and reporting progress towards SDGs (Ministry of Statistics and Programme Implementation, 2023). While efforts have been focused on tracking progress towards individual SDGs, there is still a need for empirical studies monitoring the complex interlinkages between SDGs in India, especially as the country needs to meet the twin goals of economic growth to improve livelihoods and biodiversity conservation to ensure environmental well-being, which are often conflicting. The WFB nexus system map developed in this study provides insights into key linkages between SDGs 2, 6 and 15 in India.

Balancing biodiversity with socio-economic needs will require navigating complex trade-offs and synergies within the food, water and biodiversity nexus, some of which have been highlighted in this review. As pointed out earlier, India has made strong legal enactments to enhance biodiversity conservation. An engaged civil society, supported by academic studies, also ensured that the principles of community participation are adhered to in designing policies. However, recent conservation policy amendments cast questions on how environment and biodiversity will be prioritized as India advances on a growth and development trajectory. The challenge for policymakers will be to balance these competing goals, avoid short-termism and develop a long-term vision for sustainability. Fostering inclusive collaborations among stakeholders will be critical to help achieve India's sustainability goals.

This study shows the necessity for integrated policies and cross-sectoral collaboration (characteristic of polycentric governance systems) to advance sustainable development in India. It also highlights the perils in ignoring nexus issues. To overcome silo-thinking, policies and governance structures that manage food, water or biodiversity must address nexus challenges across multiple scales, national, regional and local, including cross-scale linkages. Indeed, a more integrated systems approach is key to addressing India's growing water and food demands and enable the design of sustainable development policies and synergistic governance approaches.

CRediT authorship contribution statement

Susanne Hanger-Kopp: Funding acquisition, Project administration, Writing – original draft, Writing – review & editing. **Bejoy K. Thomas**: Funding acquisition, Writing – original draft, Writing – review & editing. **Barbará Willaarts**: Writing – original draft. **Neha Bhadbhade**: Writing – original draft, Writing – review & editing. **J.K. Joy**: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. **Juliette Crescentia Genevieve, Martin**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Radhika Kanade**: Conceptualization, Data curation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Summary metrics

Table A.1
Summary metrics of nexus elements included in the analysis

Element	Nexus node	Betweenness	Closeness	Degree	Indegree	Outdegree	Reach
Recreational fishing	water	0	0.000	1	1	0	0.007
Water quality	water	0.009	0.077	12	7	6	0.075
Macroinvertebrate diversity	biodiversity	0.001	0.054	2	2	2	0.055
Freshwater fisheries	food	0.001	0.007	6	5	1	0.014
Freshwater biodiversity	biodiversity	0.005	0.018	11	11	2	0.021
Freshwater fish diversity	biodiversity	0.001	0.007	13	12	1	0.021
Freshwater habitat connectivity	water	0	0	1	1	0	0.007
Macrophyte community structure	biodiversity	0	0	1	1	0	0.007
Nutrient load	water	0.001	0.059	3	1	2	0.062
Invasive macrophytes	biodiversity	0	0	1	1	0	0.007
Agricultural fertilizer runoff	food	0	0	1	1	0	0.007
Wetlands	water	0	0.013	2	0	2	0.021
Microbial diversity	biodiversity	0	0	1	1	0	0.007
Phytoplankton diversity	biodiversity	0	0	2	2	0	0.007
Irrigation	food	0.006	0.057	2	3	6	0.007
Food security	food	0	0	15	15	0	0.007
Income generation	economic	0	0	6	6	0	0.007
Endemism	biodiversity	0	0	1	1	0	0.007
Nutrition for indigenous communities	food	0	0	1	1	0	0.007
Highland aquatic ecosystems	water	0.000	0.028	3	1	2	0.041
Invasive fish	biodiversity	0	0	2	2	0	0.007
River discharge	water	0.001	0.057	4	2	2	0.068
Agrobiodiversity	biodiversity	0.003	0.050	13	7	6	0.068
Agricultural resilience	food	0	0	1	1	0	0.007
Non-timber forest products	biodiversity	0.004	0.030	5	3	3	0.048
Groundwater availability	water	0	0	8	8	0	0.007
Social and family ties	social	0	0	1	1	0	0.007
Ecological knowledge transfer	biodiversity	0	0	1	1	0	0.007
Soil microbial activity	biodiversity	0	0	1	1	0	0.007
Soil erosion	food	0.000	0.018	2	1	1	0.021
Poverty reduction	social	0	0	1	1	0	0.007
Medicinal plants	food	0.003	0.020	5	2	3	0.027
Faunal diversity	biodiversity	0	0	6	6	0	0.007
Floral diversity	biodiversity	0	0	5	5	0	0.007
Habitat diversity	biodiversity	0	0	1	1	0	0.007
Genetic diversity (forests)	biodiversity	0.000	0.007	2	1	1	0.014
Crustacean diversity	biodiversity	0	0	1	1	0	0.007
Agricultural yield	food	0	0	7	7	0	0.007
Freshwater habitats	water	0.000	0.017	4	2	2	0.034
Forest biodiversity	biodiversity	0	0	1	1	0	0.007
Grassland/scrubland biodiversity	biodiversity	0	0	1	1	0	0.007
Rodents	biodiversity	0	0	1	1	0	0.007
Farmland owls	biodiversity	0.000	0.007	2	1	1	0.014
Soil productivity	food	0	0	1	1	0	0.007
Crop climate resilience	food	0	0	1	1	0	0.007
Soil conservation	food	0	0	1	1	0	0.007
Disease protection	biodiversity	0	0	1	1	0	0.007
Water use efficiency	water	0	0	3	3	0	0.007
Nutrient availability	food	0	0	1	1	0	0.007
Land cover change	biodiversity	0	0	1	1	0	0.007
Water depletion	water	0	0	1	1	0	0.007
Land degradation	biodiversity	0	0	2	2	0	0.007
Biodiversity loss	biodiversity	0	0	1	1	0	0.007
Habitat loss	biodiversity	0	0	1	1	0	0.007
Woody trees	biodiversity	0.000	0.007	2	1	1	0.027
Crop yield	food	0	0	1	1	0	0.007
Wild plants	biodiversity	0	0	1	1	0	0.007
Crop pest control	food	0	0	2	2	0	0.007
Tree species richness	biodiversity	0	0	2	2	0	0.007
Bird species richness	biodiversity	0	0	2	2	0	0.007

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Table A.1 (*continued*)

Element	Nexus node	Betweenness	Closeness	Degree	Indegree	Outdegree	Reach
Genetic diversity (crops)	biodiversity	0.000	0.007	2	1	1	0.014
Tailwater fisheries	water	0	0	1	1	0	0.007
Freshwater fish community structure	biodiversity	0	0	1	1	0	0.007
Indigenous fish diversity	biodiversity	0	0	1	1	0	0.007
Surface water	water	0	0	1	1	0	0.007
Groundwater quality	water	0	0	2	2	0	0.007
Green revolution	food	0.001	0.007	3	2	1	0.014
Water security	water	0.000	0.007	3	2	1	0.014
Water extraction for irrigation	water	0	0.035	8	0	3	0.089
Cost of agricultural production	economic	0	0	1	1	0	0.007
Soil nutrients	food	0	0	1	1	0	0.007
Conservation agriculture	food	0.002	0.085	9	2	7	0.123
Invasive weeds	biodiversity	0	0	1	1	0	0.007
Crop diversity	food	0.001	0.027	5	1	4	0.034
Human-wildlife conflicts	social	0	0	3	3	0	0.007
Agricultural practices	food	0.000	0.013	4	2	2	0.021
Livestock production	food	0	0	1	1	0	0.007
Freshwater fish	biodiversity	0	0	1	1	0	0.007
Human health	health	0	0	1	1	0	0.007
Droughts	water	0.001	0.110	11	1	10	0.130
Horticultural diversity	biodiversity	0	0	1	1	0	0.007
Flood plain farming	food	0.000	0.013	3	1	2	0.021
River flow	water	0	0	1	1	0	0.007
Fish migration	biodiversity	0	0	1	1	0	0.007
Local communities	social	0.004	0.025	4	4	2	0.034
Rivers and streams	water	0	0.020	3	0	3	0.027
Agricultural pesticide use	food	0	0.081	5	0	5	0.103
Overgrazing	food	0	0.052	1	0	1	0.055
Rainfall	water	0	0.017	2	0	2	0.027
Agricultural land expansion	food	0	0.100	10	0	10	0.137
Unsustainable fishing practices	food	0	0.018	1	0	1	0.027
Dams	water	0	0.099	9	0	9	0.116
Agricultural fertilizer use	food	0	0.084	6	0	6	0.075
Agricultural sediment runoff	food	0	0.007	1	0	1	0.027
Brackish waters	water	0	0.007	1	0	1	0.014
Freshwater aquaculture	food	0	0.007	1	0	1	0.014
Habitat quality	biodiversity	0	0.039	1	1	1	0.021
Pollution (wastewater)	water	0	0.052	1	0	1	0.055
Canals	water	0	0.056	3	0	3	0.055
Rural livelihood diversification	social	0	0.038	2	0	2	0.062
Fish pond integrated in irrigation scheme	food	0	0.007	1	0	1	0.014
Fishing	food	0	0.013	2	0	2	0.021
Invasive species	biodiversity	0	0.010	1	0	1	0.027
Sustainable farming	food	0	0.007	1	0	1	0.014
Water regime modifications	water	0	0.018	1	0	1	0.021
Agriculture	food	0	0.019	1	0	1	0.021
Forest rivers	water	0	0.013	2	0	2	0.021
Agroforestry	food	0	0.020	3	0	3	0.027
Riparian buffers	water	0	0.013	2	0	2	0.021
Forest ecosystems	biodiversity	0	0.010	1	0	1	0.021
Tribal groups	social	0	0.030	2	0	2	0.041
Protected areas (tiger reserves)	biodiversity	0	0.022	2	0	2	0.034
Trees on farmland	biodiversity	0	0.007	1	0	1	0.014
Soil microbial diversity	biodiversity	0	0.020	3	0	3	0.027
Pollination	biodiversity	0	0.013	2	0	2	0.021
Bird populations	biodiversity	0	0.007	1	0	1	0.014
Hedge trees between crops	biodiversity	0	0.007	1	0	1	0.014
Land sharing	biodiversity	0	0.013	2	0	2	0.021
Forest protection	biodiversity	0	0.007	1	0	1	0.014
Restoration	biodiversity	0	0.007	1	0	1	0.014
Gene seed and grain banks	biodiversity	0	0.010	1	0	1	0.021
Product diversification	food	0	0.037	2	0	2	0.055
Inter- and intra-basin water transfers	water	0	0.023	3	0	3	0.041
River diversions	water	0	0.010	1	0	1	0.027
Deforestation	biodiversity	0	0.010	1	0	1	0.027
Jute retting	economic	0	0.023	3	0	3	0.041
Crop exports	food	0	0.013	2	0	2	0.021
Financial incentives for water intensive crops	economic	0	0.007	1	0	1	0.014
Financial incentives for irrigation	economic	0	0.042	2	0	2	0.021
Water scarcity	water	0	0.075	2	0	2	0.089
Monsoons	water			3	0	3	
Distorted water prices	water	0	0.007	1	0	1	0.014
Water-saving agronomic practices	food	0	0.007	1	0	1	0.014
Multiple sector water use	water	0	0.007	1	0	1	0.014
Lack of seeders	food	0	0.056	1	0	1	0.062
Lack of specialised manpower and skills	food	0	0.056	1	0	1	0.062

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Table A.1 (*continued*)

Element	Nexus node	Betweenness	Closeness	Degree	Indegree	Outdegree	Reach
Reuse of treated wastewater	water	0	0.007	1	0	1	0.014
Protected freshwater habitats	biodiversity	0	0.010	1	0	1	0.021
Elephant raids	biodiversity	0	0.020	2	0	2	0.034
Primate raids	biodiversity	0	0.020	2	0	2	0.034
Leopard attacks	biodiversity	0	0.007	1	0	1	0.014
Pastoral landscapes	biodiversity	0	0.034	1	0	1	0.055
Floods	water	0	0.013	1	0	1	0.027
Terrestrial biodiversity	biodiversity	0	0.021	1	0	1	0.027

Appendix B. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103826.

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