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System analysis of water-energy-food nexus of Bundelkhand region, India

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ABSTRACT

The challenges in drought-hit Bundelkhand are stemming from policy constraints and insecurity of water, energy, and food resources, which have triggered mass migration, unemployment, indebtedness, and farmer suicide. Among the surveyed households of Banda District, 21% have no electricity, 90% are using fuelwood and cow dung for cooking purposes, 70% are engaged in agriculture, per capita food consumption is very low, and 51% of the households are using less than 40 lpcd (liters per capita per day) of water. The research methodology is unique and tailored to the WEF nexus approach. It analyzes the primary data of 534 households, 33 experts (Delphi Technique), and the secondary data of 189 articles. The Causal Loop Diagrams capture the system's dynamic behavior and establishes interconnectedness of the identified control parameters using the systems approach. Major parameters for agricultural production are productivity, productive area, and cropping intensity, while major water demand comes from agriculture, industrial, and domestic use. The energy sector is identified as the most challenging in this region, and the total generation comes from solar, biogas, fossil fuels, and organic fuels. This study concludes with findings suggesting urgent actions to be taken for regional sustainability and policy recommendations at the local level.

Key words: Bundelkhand region, causal loop diagram, stakeholders' opinion, sustainable development, systems approach, water-energy-food nexus

HIGHLIGHTS

- It is the first research done in India pertaining to water-energy-food (WEF) nexus together, where their interdependency is established using the systems approach.
- The methodology used is unique, and no literature is found to use this kind of methodology in WEF research in India.
- This study is a stepping-stone and can be used as a framework for conducting future WEF Nexus research and policy planning.

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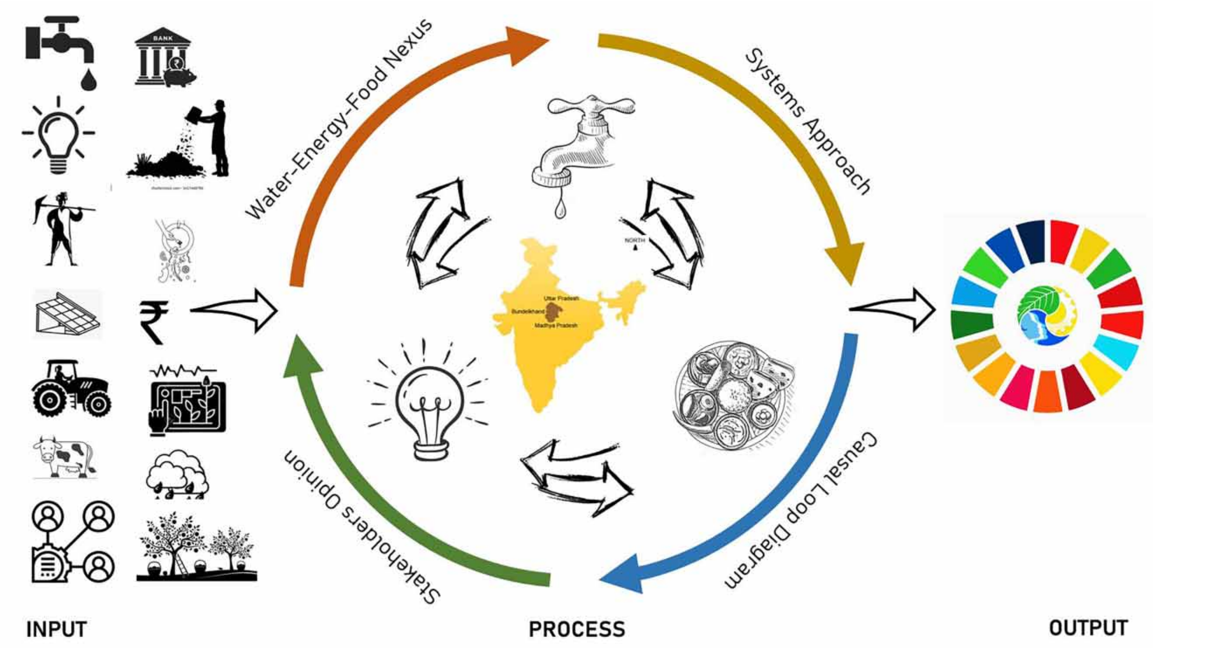
GRAPHICAL ABSTRACT



1. INTRODUCTION

The world is facing immense pressure from urbanization, economic growth, technological advancement, climate change, population growth, international trade, economic growth, expanding the discourse on security (Albrecht 2018), and globalization. In order to maintain sustainable growth, the major challenge is to manage the demand and supply of resources and ensure the security of water, energy, and food. These three components have a complex interaction with each other. In order to minimize the risk and maximize human-environment security, optimization of Water-Energy-Food (WEF) connections is required. The demands for water, energy, and food are estimated to increase by 40%, 50%, and 35%, respectively, by the year 2030 (USNIC 2012). Explicit interaction needs to be established between these three components. The nexus has yet to be officially acknowledged uniformly on an international platform because there is no clear definition of the term 'nexus', but it is internationally interpreted as a process of linking ideas and actions of different stakeholders from different sectors for achieving sustainable development (Endo 2015a, 2015b).

WEF nexus is not just about irrigation, electricity, and agriculture; it is a cross-sector collaboration to minimize trade-offs and maximize resource use efficiency to improve management outcomes. Conventional approaches provide a narrow perspective on nexus, so more interactive analytical approaches are required to enrich nexus solutions. The conceptual literature articles identified research needs, methods, data gaps, challenges and limitations, system boundaries, a new approach, WEF linkages, and innovative techniques. Few studies stated 'nexus' as a buzzword. This calls for collaborative, contextual, innovative, and implementable methods. The accessibility to resources and the need to efficiently use the declining resources have given rise to the concept of the WEF nexus to manage the resources for sustainable development. Food and water are important for human existence, while energy is essential for human development in providing infrastructure, transportation, etc. Balanced integration is required for the social, environmental, and economic issues to deal with the problem of water, energy, and food security (Rasul 2014). It is required to reduce the adverse impact on nature, ecology, biodiversity, and climate. The integrated nexus approach brings in the complex political negotiation that tries to solve the challenges such as climate uncertainties, demographic change, growing inequalities and social discontent. Therefore, the WEF nexus needs to be addressed sustainably to find the interlinkages to deal with the growing demands and critical global challenges of our time (Endo 2015a).

In India, research in WEF Nexus areas is still in the primary stage due to the absence of an umbrella policy framework, and also, these sectors are primarily considered as state subjects. Research priorities are localized, scattered, and difficult to assess (Kumar 2017). There are different ways to comprehend the nexus to understand

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the interlinkages of the sectors and identify cross-sectoral consequences (Strasser 2016). The system-based perspective of the WEF nexus explicitly recognizes the interconnected and interdependent behavior of water, energy, and food systems for mutually beneficial outcomes (Bazilian 2011; Foran 2015). Frequent drought in Bundelkhand has made the region water-scarce and poverty-stricken. It has led to mass outmigration, farmer suicides, starvation, deaths, the decline in agriculture production, domestic water shortage, and indebtedness. It has a huge social, economic, and environmental impact. In the accentuated water stress situation, people are stuck in a vicious cycle of low income, low output, and negligible saving, affecting the cycle of food and energy (Joshi 2004). As per secondary data, in this region, 76% of people still rely on kerosene as the main energy source for lighting, and 64% of the population uses fuelwood for cooking, despite having huge potential for hydro and solar energy. Major challenges and gaps are identified regarding water, food, and energy using a systematic methodology to identify the multiple interactions among the subsystems. After identifying the parameters that control the development of this area, especially in terms of water, food, and energy of the Bundelkhand region, recommendations are made based on the findings.

The purpose of this research has been to analyze the present literature on WEF Nexus to understand the interactions and to propose the conceptual framework of WEF Nexus for the Bundelkhand region by using a systems approach. The major gap identified in WEF nexus research is that the integrated approach is missing along with people's points of view along with scale and site-specific data. This became the novelty of this research because it identifies scale (district-level), multidisciplinary approach, and inclusion of stakeholders' opinions. The paper opens new vistas to develop an innovative strategy for socio-economic development in the field of planning to find a sustainable approach at the grassroots level. This research gives an insight into WEF Nexus by giving direction by summarizing the work and opening a platform for researchers to build a case for further investigation.

2. METHODOLOGY

2.1. Research method

In this research, the systems approach takes a holistic view and tries to find an optimal solution by bringing together dialogues, interviews, public and private sectors perspectives, and discussions with people at various levels (District, Urban (City), Rural (villages), household) in the hierarchy (Catalan 2018). Systems Approach is the process where sub-system-wise information can be gathered, modeled, and analyzed; to find the optimal solution from the alternative scenarios (Barrier 2002). It helps establish the interaction and interrelation between the important identified variables (the process has been explained further in the paper in section 2.1). The data for the study area profile (Banda District, Bundelkhand Region) is taken from the Government documents such as census, records, reports, and official websites. The secondary data is very recent (2002–2021) and comprise 189 articles and reports that are documents from the government, reputed global organizations, census, peer-reviewed articles, indexed journals, reports from seminars, workshops, conferences, programs, archives, and research work, documents and articles from official websites, government, organizations working on WEF security, and newspaper articles. The keywords searched for the study were water-energy-food nexus, Bundelkhand region, water security, energy security, food security, causal loop diagrams, systems approach, systems analysis, System Dynamics Technique, WEF study in India, agriculture scenario in India and Uttar Pradesh, water scenario in India and Uttar Pradesh, and energy scenario in India and Uttar Pradesh, and other searches related to water, food, energy resources at global, national, and local level. The data collected is authentic, adequate, accurate, and economical for the study, and it is the amalgamation of all three sectors that were analyzed by looking at the scope, aim, objective, and nature of the study, where all three sectors have been given equal importance. The research methodology used in this research is presented in Figure 1.

This research is based on the secondary data collected and the reconnaissance survey done by the authors. The reconnaissance survey was conducted by doing route map analysis of various districts of the Bundelkhand region, which led to site selection (Banda District) based on preliminary data analysis on resource sufficiency in terms of WEF and discussion with key stakeholders. In the initial phase of this research, the objectives were refined using preliminary data and discussion with experts and key stakeholders using the Delphi technique. There were 33 participants involved in the initial discussion and structuring: the District Magistrate of Banda District, six national experts, five international experts, three government officials, four farmers, five social workers, and nine locals. Based on the discussions, the variables were identified, and the survey schedule was finalized after

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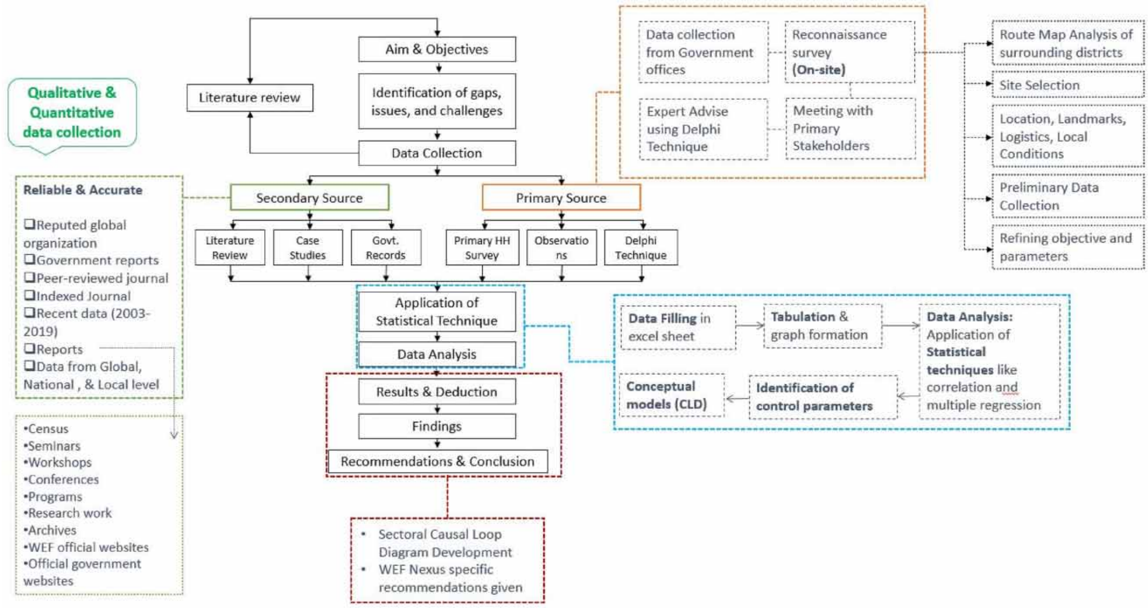

Figure 1 | Research Methodology. *Source*: By Authors.

the pilot survey. This survey schedule was later used to collect data from 534 households for the research using Multistage Stratified Random Sampling. The categorization of the study area for stratified sampling was done based on various elements like landmarks, locations, logistics, and local conditions. Identification of the control parameters was done by data analysis and application of statistical techniques like correlation and multiple regression. This paper presents the relationship between the identified WEF sectors' control parameters using Causal Loop Diagrams (based on discussion with key stakeholders and secondary data analysis). The WEF-specific results, findings, and recommendations are made using a systems approach. The current research has been done using national and local data, but the WEF systems model will be developed later and used for further study.

2.2. System analysis

System analysis is a science of identifying feasible alternatives and selecting an optimal solution which helps in decision making and policy planning. Both quantitative and qualitative analyses could be unified in this process. It can help stakeholders understand system complexities by building cause and effect relationships over time and knowing phenomena in a plethora of disciplines like urban planning, public health, natural sciences, business administration, etc. (Bureš 2017). This systematic approach is used to establish clearly defined objectives and the method and techniques are for examination and critical analysis. To make better and informed choices, a better understanding of the interdependence and interlinkage of all the subsystems should be developed to arrive at a sustainable solution out of all the alternative choices. The models developed can be constantly updated as more information becomes available by using every relevant information and extracting the best components from different scientific methods from different disciplines on which the analyses are based, unlike other decision-making tools (Biswas 1976). The complexity of dynamic systems is rooted in many system attributes ranging from non-linearity to relationships between multiple causes and their effects (McGlashan 2016).

System Dynamic Modeling requires three categories of system thinking that are elements (describes characteristics), interconnections (relations and feedback), and their purpose (Meadows 2008). Understanding the system's behavior is mandatory, along with knowledge of its agent's interaction over time and their dynamic complexities (Sweeney & Sterman 2000). To observe system behavior, both negative and positive feedback processes are hypothesized. The impact is to be understood by identifying the stock and flow relationship along with delays. Further, non-linearities must be identified to recognize the boundaries of the mental model. This process of creating the mental model was suggested by Sweeney & Sterman (2000) and is shown in

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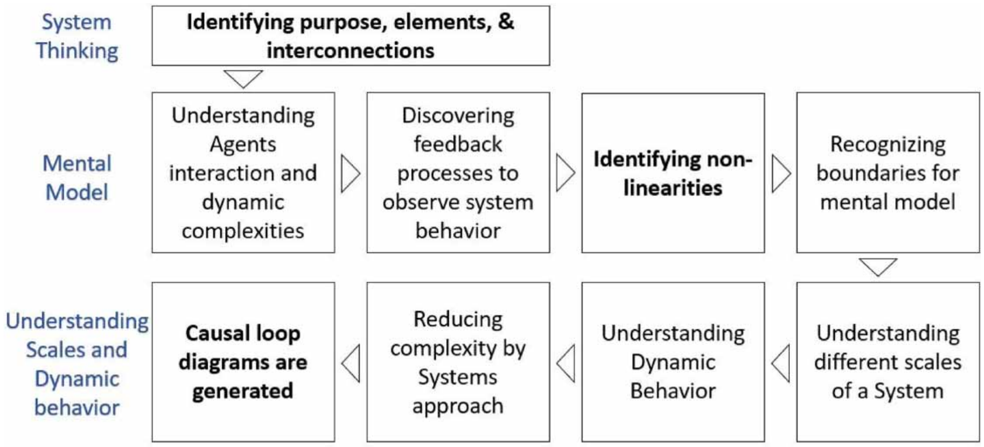

Figure 2 | Systems thinking for the formation of CLDs. *Source*: By Authors.

Figure 2. Based on the earlier framework, Stave & Hopper (2007) added two more characteristics to the findings: creating simulation models and testing policies (Stave & Hopper 2007). It is very important to understand systems at different scales and their dynamic behavior to reduce the complexities of modeling systems (Arnold & Wade 2015). On the other hand, Kim (1999) proclaims that problems can be anticipated and addressed before they arise if the consequences of the intended and unintended actions can be mapped in the form of a causal loop diagram (Kim 1999).

The System Analysis starts by defining goals and values, then leading to the WEF objectives, which are derived in such a fashion that each program helps to achieve the goals. The objectives are then converted to measurable criteria to appraise the degree of importance. The next step is to evaluate and examine alternative options, and the model will try to relate the alternative to the objectives. Due consideration will be given to resource availability, constraints to the system, environment, and technological factors. It not only helps planners in decision-making but also in prediction and planning processes. This type of modeling helps explore the consequences of various policies, test assumptions, and set different parametric relationships. Thus, one develops an appreciation of planning and decision-making situations by substituting a model in a simulated environment for experience in a real-world situation.

The model can be divided into two parts: programming and descriptive. The programming model describes the optimal policy for a given objective function. On the other hand, descriptive models try to predict possible future consequences with the help of exogenous variables and alternative analysis. Such types of models predict values for a given set of exogenous variables. Such decision-maker can choose exogenous variables, also known as policy or control variables. The optimal policy can be selected by changing policy variables. The model means making a replica of a real-world system to find solutions to real-world problems. It is used to find the relationship between different variables using mathematical expressions. In the case of WEF, it is difficult to quantify and evaluate all the real-world situations. Therefore, the model might not be the exact replica of the real world but will be fairly close to the real scenario.

Planning is a multi-objective field where the needs of society and political scenario is also added. It has caused multifarious problems and made the planning process much more complex, along with that reliable and compatible data is also missing. Objectives with multidimensional functions are not mutually exclusive but often conflicting. The conflict point is about decision-makers as there are many involved planners, politicians, academicians, and the public. WEF is a complex process, and system analysis is a new tool used for operational phases. Major changes in the WEF resources approach offer planners and civil engineers the opportunity to develop new constituencies to apply our experience and adapt our traditional tools to plan for society's changing needs. Integration of environmental sustainability with planning, regulation, and improved customer interaction is required. Population, technological and industrial advancement, residual discharge in the environment, and per capita use of resources increase with the increasing demand for a better environment and quality of life, creating a difficult dichotomy for policymakers and planners.

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2.3. Bundelkhand

2.3.1. Location

The Bundelkhand region comprises thirteen districts spread over Northern Madhya Pradesh and Southern Uttar Pradesh. It covers a geographical area of around 70,000 sq km and includes seven districts of UP and six districts of MP. It lies between 23°10′ and 26°30′ north latitude and 78°20′ and 81°40′ east longitude (Gopal n.d.). It resides in the heart of India, as shown in Figure 3.

2.3.2. Districts of Bundelkhand region

Bundelkhand comprises 13 districts: Jhansi, Lalitpur, Jalaun, Hamirpur, Mahoba, Banda, and Chitrakoot (all in UP), and Datia, Tikamgarh, Chhatarpur, Panna, Sagar, and Damoh (all in MP) (Gopal n.d.). Figure 3 shows blocks in each district.

2.3.3. Physical features of Bundelkhand

Bundelkhand is a historically and culturally rich region divided into four sub-regions: plain in the North, upland in the center and South, and Vidhyanchal plateaus in the deep South. The Northern part is more urbanized than the southern part. Jhansi and Sagar are the two largest towns in this region. Out of 13 districts, seven are part of Uttar Pradesh (UP), while six are in Madhya Pradesh (MP). The total population of the Bundelkhand region is 18.33 million, divided into two states: Uttar Pradesh has 9.68 million (52%), and Madhya Pradesh has 8.65 million (47%). The total area of the Bundelkhand region is 63,619.135 km^2 (Census 2011).

This research is focused on Bundelkhand-UP due to this region's political and regional division. The socio-economic data of Bundelkhand-UP is represented in Figure 4. A reconnaissance survey of the area was conducted, where meetings and discussions were held with key stakeholders like the District Magistrate, farmers,

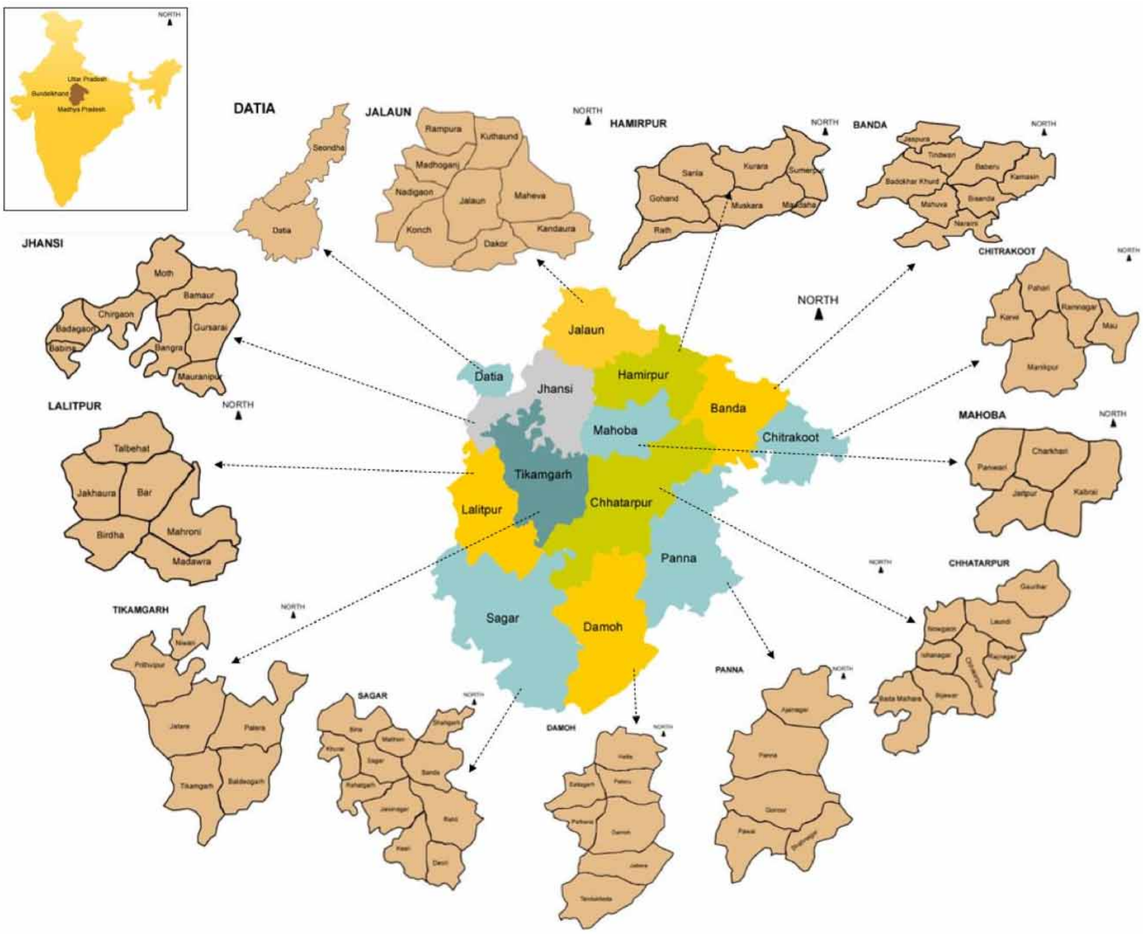

Figure 3 | Districts in Bundelkhand with block boundaries. *Source*: (SeedFoundation 2007), Bundelkhandinfo.org.

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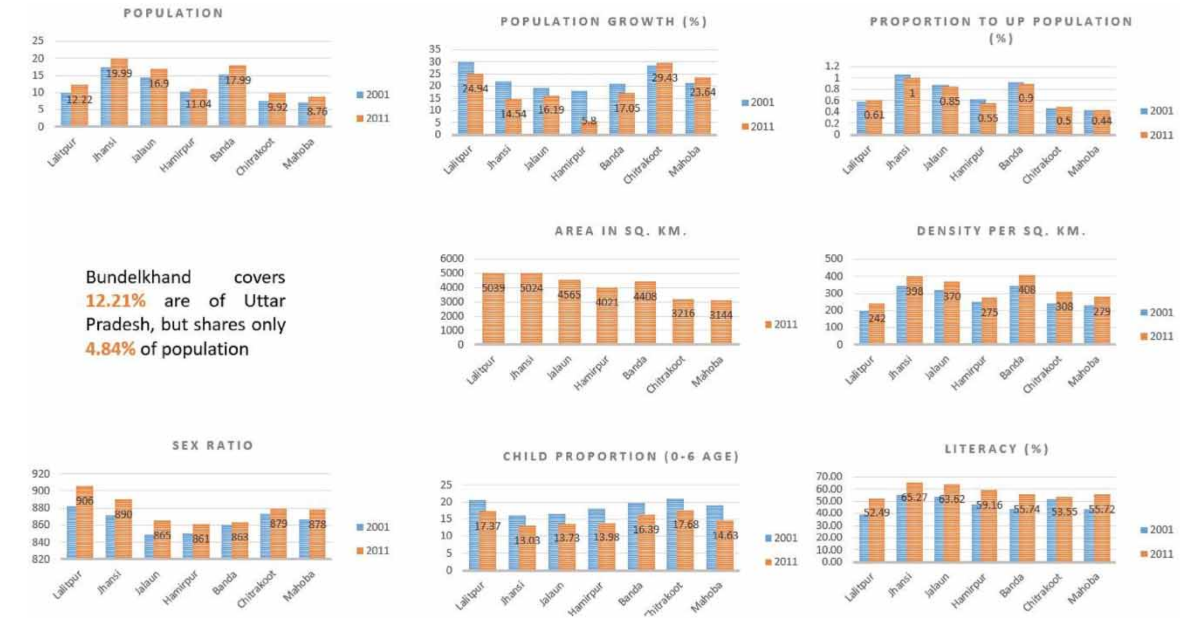

Figure 4 | Socio-Economic data of Bundelkhand (UP). *Source*: By Authors, (Census 2011).

self-employed workers, and local leaders in the fields of water, energy, and agriculture. After analyzing government reports and census data, Banda was identified as the most backward district out of all districts in Bundelkhand-UP, and according to the literature, no research has been done in this area. District Banda has been selected as the study area for conducting the survey. The data will later be used for analysis and modeling for this research, based on which policy planning recommendations will be made regarding WEF Nexus. The results can be extrapolated to the other district of the Bundelkhand region that lies in UP state as they share the same socio-political and geographical features.

2.3.4. Banda district profile

Banda district lies at an elevation of 127 m above sea level. In 2001, population of Banda was 1,537,334 which increased to 1,799,410 in 2011. Banda is divided into four tehsils: Atarra, Baberu, Banda, Naraini, and 694 villages. Banda district had a population density of 408 person per km^2 in 2011, which has increased from 345 person per km^2 in 2001. The area of the district is 4,408 km^2. The district is predominantly rural in character, and in this district, only 15% of the population lives in the urban area. The district layout presenting Community Development Blocks (CDBs) and features of the Banda District are presented in Figure 5. The survey data is collected from one municipal council and eight CDBs, namely Jaspura, Tindwari, Badokhar Khurd, Baberu, Kamasin, Mahua, Bisanda, and Naraini.

3. RESULTS AND DISCUSSIONS

3.1. System analysis of water, energy, and food security

A causal loop diagram can be defined as a 'causal loop diagram (CLD) and is a qualitative method for visualizing how different variables in a system are interrelated and how they influence each other to create system dynamics' (Columbia 2016). Principal feedback loops in the system are identified through the causal loop diagram, and it also generates behavior over time (Sterman 2010). A feedback loop relates the causality of two or more variables. The relationship is either positive or negative. In a positive relationship, if one increases, the other also increases, or if one decreases, the other also decreases. In a negative relationship, the variables are related to each other inversely. If there are an even number of negative relationships in a loop, it becomes positive; while the total number of negative relationships is in odd numbers, then the loop remains negative. Positive feedback loops generate growth, i.e., reinforcing, and negative feedback loops are goal-seeking (Bala 2014). The causal loop diagrams have been developed for food security (Figure 6), water security (Figure 7), and energy security (Figure 8) based on literature and field surveys.

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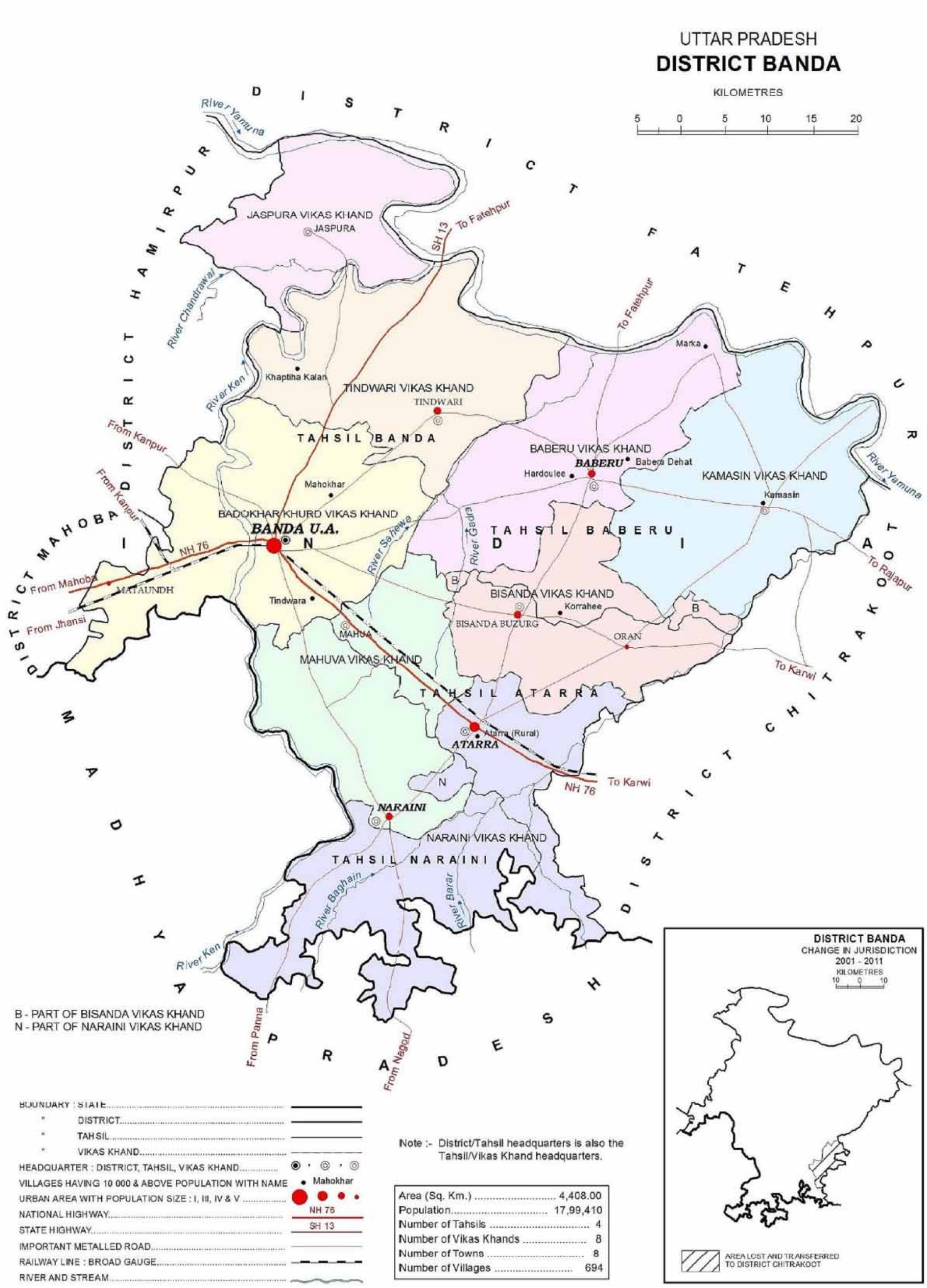

Figure 5 | Banda District layout and features. *Source*: (Census 2011).

The World Economic Forum (2011) defines water security in the context of trade and politics: 'Water security is the gossamer that links together the web of food, energy, climate, economic growth, and human security challenges that the world economy faces over the next two decades.' (WEF 2011). The UN Advisory Group on Energy and Climate Change (United Nations 2010) defines energy security as 'access to clean, reliable and affordable energy services for cooking and heating, lighting, communications, and productive uses.' (United Nations 2010). Food security is defined by FAO (2003) as 'Food Security is a situation that exists when all people at all times have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences for an active and healthy life.' (FAO 2003).

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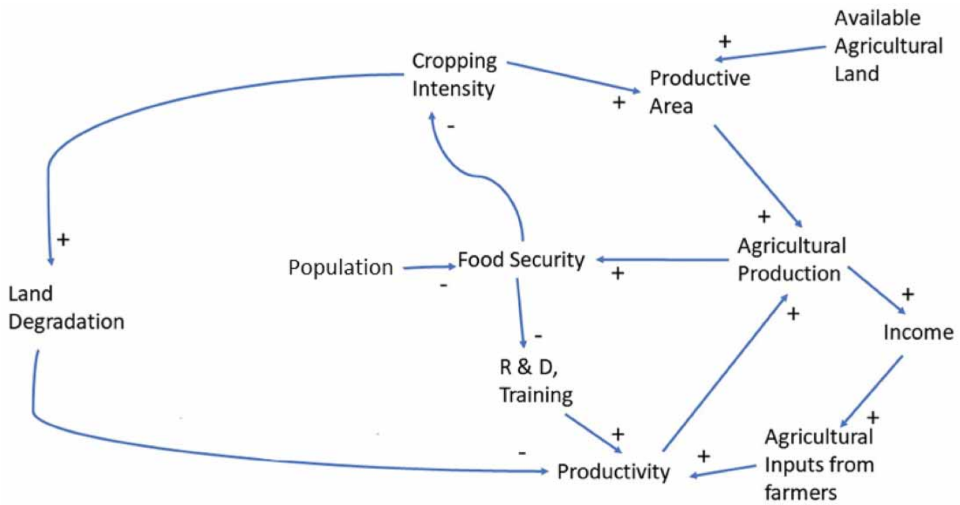

Figure 6 | Causal loop diagram for food security. *Source*: By Authors.

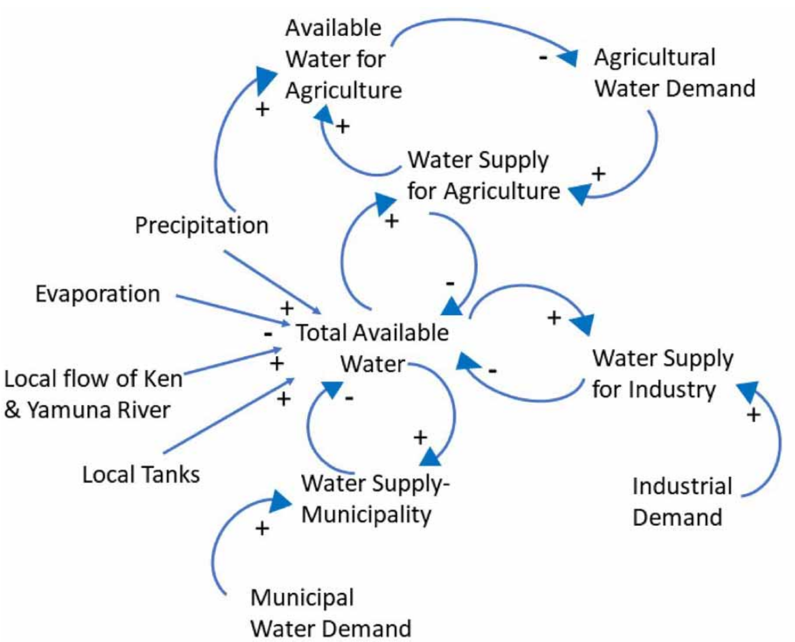

Figure 7 | Causal loop diagram for food security. *Source*: By Authors.

3.1.1. Causal loop diagram for food security

$$\textit{Agricultural production} = \textit{agricultural productivity} \times \textit{productive area} \times \textit{cropping intensity} \quad (1)$$

Agricultural production will increase if the productive agricultural land increases, as shown in Figure 6. To increase the productivity training of farmers and field workers, research in the field of agriculture and inputs from farmers is important. Equation (1) refers to increased productivity, which leads to increased agricultural production. In turn, it will increase the income of farmers, enabling them to use better inputs in agricultural fields. Agricultural production directly depends on agricultural productivity, suitable crop area for production, and cropping intensity of the crops grown. Cropping intensity degrades the land quality due to increased multiple cropping that reduces productivity. The productivity of the land can be regenerated by keeping land fallow for a period of time. Productivity increases by researching in the field of agriculture by introducing new seed varieties, new cropping techniques, less use of pesticides, improved farming knowledge, and optimal farm management practices. It

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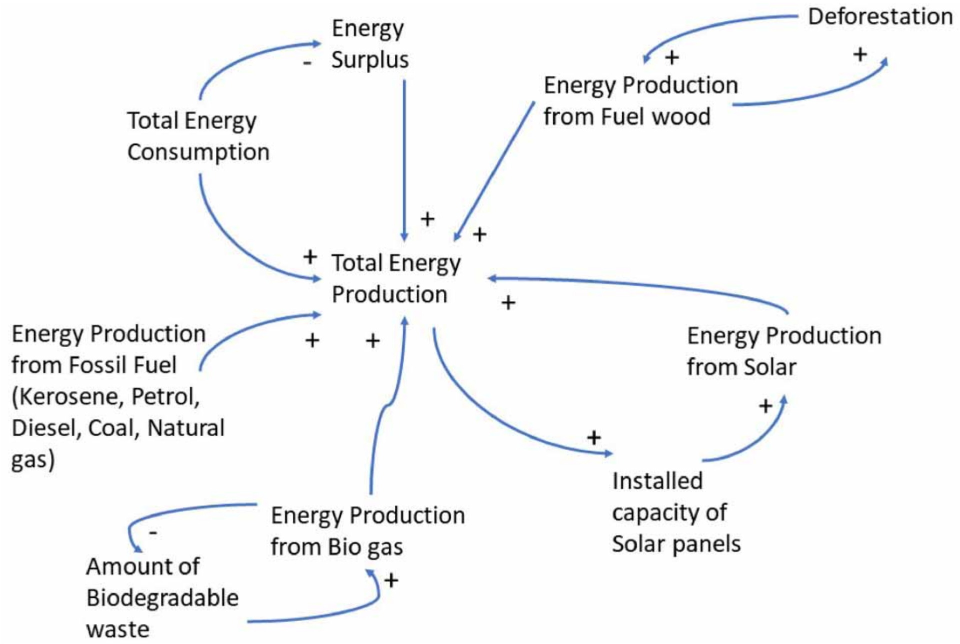

Figure 8 | Causal loop diagram for food security. *Source*: By Authors.

can be introduced to field workers and farmers and made them aware through training, implementing participatory methods, learning new techniques, and experimental methods reduce the yield gap. The requirement of crop production is based on population, growth rate, and per capita consumption. Therefore, the variables in the causal loop diagram in Figure 6 account for ensuring food security.

3.1.2. Causal loop diagram for water security

$$\begin{aligned} \textit{Total Available Water} &= \textit{Precipitation} + \textit{Local flow of Rivers} + \textit{Local tanks} \\ &\quad - (\textit{total water demand} + \textit{Evaporation}) \end{aligned} \tag{2}$$

$$\begin{aligned} \textit{Total water demand} &= \textit{Agricultural Water Demand} + \textit{Industrial Demand} \\ &\quad + \textit{Municipal Water Demand} \end{aligned} \tag{3}$$

Futurearth (2018) identifies water as a central element in producing food and energy (Futurearth 2018). Equation (2) suggests that in the Banda district, variables of total available water are total precipitation, the local flow of river Ken and the Yamuna flowing inside the boundaries of the district Banda, and local tanks that provide water directly and recharge groundwater. Total water demand depends upon the summation of agricultural water demand, industrial water demand, and municipal water demand, as shown in Equation (3). There is a negative loop between total available water and water supply for agriculture; as the water supply for agriculture increases, the total available water will decrease; but if total available water is more, the amount of water supply for agriculture will increase. It is similar in the case of industrial and municipal water demand loops. Precipitation and evaporation account as natural variables for total available, as shown in Figure 7. Local tanks in Banda are a major source of water along with surface water and groundwater, but the condition of these tanks is depleting fast, and Banda being a semi-arid region, refurbishment of local tanks is a major requirement. Many small and medium farmers are adopting tank irrigation techniques for agricultural activities as it is more sustainable and more apt for Banda according to the climatic conditions. Water recharge is a major requirement for this area for sustainability and water sufficiency (for drinking and irrigation usage). Rapid water depletion in this region leads to crop failure due to the timely unavailability of water, resulting in agricultural debts. Many of the farmers cannot take the burden and commit suicide. In the survey, it has been identified that even though the Bundelkhand region lies in the central part of India, the industrialists are not investing much here due to insufficient

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access to water resources. Therefore, proper planning and water resource management are required by analyzing the interaction and integration of the variables.

3.1.3. Causal loop diagram for energy security

$$\begin{aligned} \text{Total Energy Production} &= \text{Energy Production from Solar} + \text{Energy production from Bio Gas} \\ &\quad + \text{Energy Production from Fossil Fuels} + \text{Energy Production from Fuel Wood} \end{aligned} \tag{4}$$

$$\text{Energy Surplus} = \text{Total Energy Produced} - \text{Total Energy Consumed} \tag{5}$$

In the Bundelkhand region, 76.3% of people still rely on kerosene as the main source of lighting, and 64.4% of the population uses fuelwood for cooking. District Banda has a huge potential for hydro energy as river Ken and the Yamuna flows through the district and also encompasses the huge potential for solar energy as the region lies in central India that receives a sufficient amount of sunlight throughout the year. As per Equation (4), total energy production comprises solar energy, biogas, fuelwood, and fossil fuel (kerosene, petrol, diesel, coal, and natural gas). Mostly, energy used in the Banda district is produced from fossil fuel and fuelwood, while a very less amount of energy used is produced from solar and biogas. According to the causal loop diagram in Figure 8, if the amount of biodegradable waste increases, energy production from biogas will also increase, while the increase in energy production from biogas will decrease the quantity of biodegradable waste. There is a positive loop between the amount of fuelwood and deforestation; an increase in the amount of energy produced from fuelwood will increase deforestation and vice-versa. The energy surplus of the region can be calculated by subtracting total energy consumed from total energy produced as per Equation (5). Energy security can be calculated from Equations (4) and (5) and can be obtained by proper management of energy production and hydro and solar energy use.

3.2. Discussions

The fast-growing world faces rapid economic development causing climate change, population growth, migration, technological advancement, discourse in WEF security, and international trade. It is causing disproportionate socio-economic development and exploitation of natural resources. A systematic and integrated approach is required, so the WEF nexus is a way forward. The solutions are required at the local level to curb the WEF crisis. Nexus needs to be clearly defined to maximize resource utilization and reduce the trade-offs. Most of the studies on nexus are done in silos, so studies are conducted on one or two-sector and not all three. Studies need to be done that include all three sectors that cover both qualitative and quantitative aspects. This study includes all three sectors that cover parameters from stakeholders' points of view. Causal loop diagrams need to be developed to understand the cause-and-effect relationship and recognize the role of different variables in achieving water-energy-food security. To optimize the maximum use of resources, nexus-related site-specific variables must be identified, and their interactions and inter-dependencies must be researched at the grassroots level.

4. FINDINGS AND CONCLUSION

4.1. Findings

In this study, it has been established that Bundelkhand is one of the most backward regions of India pertaining to WEF resources. CLDs of the Banda district of the Bundelkhand region are evolved with regard to WEF Nexus using a systems approach. The analysis suggests

1. The major parameters for agricultural production are productivity, productive area, and cropping intensity. In the Banda district, 70% of the surveyed population is engaged in agriculture sectors; yet the per capita food consumption of Banda is low compared to the state's and nation's average. It shows that the area is facing poverty and food insecurity. Food security can be improved with the optimal use of pesticides, fertilizers, and seeds, along with enhanced farming techniques, research, and management practices.
2. The major demand for water comes from agriculture, industrial, and domestic use, while the availability of water in Banda is from precipitation, local rivers (Ken and Yamuna), and tanks. Regarding water usage in households, 51% of households used less than 40 lpcd (liter per capita per day), meaning there is water scarcity. Water depletion leads to crop failure, indebtedness, timely water unavailability, farmers' suicides, and

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lack of investment. Water security can be achieved by adopting tank irrigation which is apt for this region and for groundwater recharge. Properly planned water resource management is required for the sustainable development of this region.

3. Total energy generation comes from solar, biogas, fossil fuels, and organic fuels. In Banda District, the major energy source used for cooking is organic fuels like fuel wood, cow dung, and agricultural waste, as 90% of the surveyed households use it. In comparison, 71% of the surveyed households have an LPG connection, but not all use it. The major energy source for lighting is fossil fuels, as 77% of the surveyed households use government-supplied electricity, while the startling finding is that 21% of the households still have no electricity. In case of a power cut, 46% of households still use kerosene lamps. There is barely any use of solar energy and biogas. Using organic fuel like fuelwood leads to deforestation and deterioration of the health of females who use it for cooking purposes. Energy security can be achieved by utilizing appropriate technology, like improved biomass cooking stoves, etc., for biodegradable waste, organic fuel, and biomass. Along with the 100% electricity coverage, proper management of energy production using solar and hydro energy is the need of the hour as this region has huge potential for the same.

The nexus system defines the major flows within and between water, energy, and food systems. It suggests energy is used for desalination of water and pumping water for irrigation in the water subsystem, while it is used for harvesting and processing in the food subsystem. Water is used for the extraction process of fossil fuels and to produce biofuels in the energy subsystem, while it is used for agriculture, forest produce, fisheries, and livestock in the food subsystem. The agricultural produce is used as biomass input for the generation of biofuels in the energy subsystem, while it helps to maintain water flow into oceans and recharges groundwater in the water subsystem. Water is the most important input for agricultural operations and the entire supply chain. Activities on efficient water resource management for crops produce a shift to low water consuming crops, training programmes, micro-financing, farm mechanization, virtual water, and food imports were identified in the water-food nexus. In agricultural operations, energy is required for various operations, including pumping water, water distribution, operation of farm equipment like tractors, generators, harvesting machines, processing agricultural output, transporting output, etc. Water will be required to generate biofuels and hydropower in the energy field. Water storage, wastewater management, and food storage are some other activities in which energy is required. Water is used as a coolant in food storage, which is required for food security. Energy and water are the most important sector for the development of an area, while food and water are considered basic human rights. The interdependence of these sectors on each other is very high, and one cannot survive without the help of the others.

4.2. Conclusion

The key understanding of this study is that resources are sufficient but not efficient. The cross-sector approach is required to achieve WEF security at the grassroots level. A dynamic approach has been used by evolving causal loop diagrams of WEF resources to investigate the system's dynamic properties, feedback, non-linearity, and interactions. Further, a significant modeling technique is required to identify the replica of a real-life scenario. The systems approach is essential to ensure sustainable solutions for Bundelkhand region, where WEF will act as a catalyst; it will also help identify alternative policies for long and short-term goals. WEF Nexus progress and gaps have been identified in this study. Variables have been identified to develop causal loop diagrams to understand the interactions between variables and attain WEF security at the local level using the given research methodology. Current scenarios, historical trends, present literature, and experts' and stakeholders' opinion are being considered while developing the model. The proposed causal loop diagrams are efficiently used for developing policy suggestions and improving the policymaker's decisions. The interaction between all three sectors, water, energy, and food, has been established. The study has been concluded by addressing the subsystems individually and all subsystems together as a system as a whole simultaneously. The study shows the local level outcomes (with regards to causal loop diagrams and identified control parameters) but can be used and replicated at different scales in and out of India. The dynamics identified here will be applicable in future studies. To maximize the system's performance, sectoral planning must be complemented with integrated planning. Social, economic, and environmental development is required simultaneously for the sustainable development of a region.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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