System analysis of Water-Energy-Food Nexus of Bundelkhand Region

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Bundelkhand lies in the central part of India comprise of thirteen districts that lie in two states. It is a drought-hit region, which is mainly because of the policy constraints. Currently, it is facing challenges stemming from groundwater depletion and inadequate water flow, which in turn have triggered mass migration, farmer suicide, unemployment, and indebtedness. In order to optimize the agricultural output, this research is done in the context of Water-Energy-Food (WEF) Nexus to understand the interaction and integration among the sub-systems for the sustainable development of this region. A system based approach is used to identify the interdependency and interconnectedness of WEF System. A System Dynamics approach is used, to develop a framework of the feedback processes. The dynamic behavior of the system is captured in the form of stock-flow diagrams and causal loop diagrams of key indicators. This study is concluded with policy recommendations based on findings.

Keywords: Water-Energy-Food Nexus, System Dynamics, Causal loop diagram, Bundelkhand Region

1. INTRODUCTION

The world is facing the immense amount of pressure of urbanization, economic growth, technological advancement, climate change, population growth, international trade, economic growth, expanding the discourse on security(Tamee R Albrecht, 2018) and globalization. In order to maintain sustainable growth, the major challenge is to manage the demand and supply of resources and to ensure the security of water, energy, and food. These three resources have a complex interaction among 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 percent, 50 per cent and 35 per cent respectively by the year 2030(USNIC, 2012). Explicit interaction needs to be established between these three sectors. The nexus has yet to be officially acknowledged uniformly at an international platform because there is no clear definition of the term ‘nexus’, but it is internationally interpreted as a process to link ideas and actions of different stakeholders from different sectors for achieving sustainable development (Aiko Endoa, 2015).

WEF nexus is not just about irrigation, electricity, and agriculture; it is a cross-sector collaboration to minimize trade-off and maximize resource use efficiency to improve management outcomes (Scott, 2016). Conventional approaches provide a narrow perspective on nexus and so more analytical approaches are required to enrich nexus solutions. Research needs, methods used and data gaps were identified from the conceptual articles, while challenges and
limitation, 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 has given rise to the concept of water-energy–food nexus to manage the resources for sustainable development. Food and water is important for human existence, while energy is essential for human development. The 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, urbanization, growing inequalities and social discontent. Therefore, addressing the WEF nexus in a sustainable manner, in order to find the interlinkages to deal with the growing demands is a critical global challenge of our time (Aiko Endo, 2015).

In India, research in WEF Nexus areas is still in primary stage due to the absence of umbrella policy framework and also these sectors are primarily considered as state subjects; also, research priorities are localized, scattered and difficult to assess (Subodh Kumar, 2017). There are different ways to comprehend the nexus to understand the inter-linkages of the sectors and to identify cross-sectoral consequences (Lucia de Strasser, 2016). The system-based perspective of WEF nexus explicitly recognizes interconnected and independent behavior of water, energy and food system for mutually beneficial outcomes (Morgan Bazilian, 2011) (Foran, 2015). Frequent drought in Bundelkhand has not only made the region water-scarce but also poverty-stricken. This has led to mass outmigration, farmer suicides, starvation, deaths, and the decline in agriculture production, drinking water shortage and indebtedness. It has a huge social, economic, and environmental impact. The accentuated water stress situation, people are stuck in a vicious cycle of low income, low output, and negligible saving, which in turn affects the cycle of food and energy. In this region, 76.3% of people still rely on Kerosene as the main source of energy for lighting and 64.4% of the population use fuelwood for cooking, in spite of having huge potential for hydro and solar energy. Major challenges and gaps are identified in terms of water, food, and energy by using a systematic methodology to identify the multiple interactions among the subsystems. After identification of the parameters, that control the development of this area especially in terms of water, food, and energy of Bundelkhand region, the recommendations will be made based on the findings. 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.

2. METHODOLOGY
This research is based on the secondary data collected and reconnaissance survey done by the investigator. The data is reliable and accurate, as it has been collected from the reports by highly reputed global organizations working on water-energy-food nexus, government reports; peer-reviewed and indexed journal articles. The data is very recent (2003-2019). The data collected is suitable and adequate for the study, as it is the amalgamation of all three sectors were analyzed by looking at the scope, aim, objective and nature of the study, where all three sectors have been given equal importance. Causal Loop Diagrams have been created using the reference of various documents of the seminar, workshops, conferences, programs, research work, reports, and archives of WEF organization. The current research has been done by using the data from national level to local level, but model will be developed which will be used for further study.
The purpose of this research has been to analyze the literature present on WEF Nexus to understand the interactions and to propose the conceptual framework of WEF Nexus for the Bundelkhand region by using system approach. The interaction and inter-relation between the several important variables identified through literature. This research gives an insight on Water-Energy-Food Nexus by giving the investigator the direction to work upon by summarizing the work and opens a platform for researchers to build a case for further investigation. The data for the study area profile is taken from the census, Government Records, Government Reports, and Official Government Websites. The secondary data used is authentic and therefore, it is faster, economical and efficient by saving time and energy.

3. BUNDELKHAND

3.1 Location
Bundelkhand is spread over southern Uttar Pradesh (UP) and northern Madhya Pradesh (MP), between 23\(^{\circ}\)10' and 26\(^{\circ}\)30' north latitude and 78\(^{\circ}\)20' and 81\(^{\circ}\)40' east longitude. The region covers a geographical area of around 70,000 sq km and includes seven districts of UP and six districts of MP. (Ashok Gopal) It resides in the heart of India as shown in figure 1.

3.2 Districts Of Bundelkhand
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) (Ashok Gopal). Figure 2 shows block in each district.

![Figure 1 Location of Bundelkhand](#)

*Source: (SeedFoundation, 2007)*

![Figure 2 Districts in Bundelkhand with block boundaries](#)

*Source: Bundelkhandinfo.org*
3.3 Physical Features Of Bundelkhand

Bundelkhand is a historically and culturally rich region and is divided into four sub-regions: plain in the North, upland in centre and South, and Vidhyanchal plateaus in deep south. Northern part is more urbanised than southern part and Jhansi and Sagar are the two largest towns of this region. Out of 13 districts, seven districts are part of Uttar Pradesh, while six districts lies in Madhya Pradesh. Total population of Bundelkhand region is 183.35 lakhs which is divided in two states that are Uttar Pradesh have 96.82 lakhs (52.81%) and Madhya Pradesh have 86.53 lakhs (47.19%). Total area of Bundelkhand region is 63619.135 sq. km. in which UP shares only 46.24% of Bundelkhand regions area, while MP shares 53.76%. Table 6 shows distribution of population and area across the districts of Bundelkhand. (Census, 2011). UP Bundelkhand enjoys good railway connectivity. The Ken-Betwa river interlinking project has been proposed in this region and plan has been prepared by National Water Development Agency under Ministry of Water Resources.

Due to political and regional division of this region, this research has been focused on Bundelkhand UP. The socio-economic data of Bundelkhand UP is represented in figure 3. A reconnaissance survey of the area was done by the author, where meetings and discussions were held with key stakeholders like District magistrate, farmers, self employed workers in field of water and agriculture and local leaders. After analysis of government reports and census data, Banda was identified as the most backward district out of all districts in Bundelkhand UP and according to literature not research has been done in this area. District Banda has been selected as district for conduct the survey and the data will later be used for analysis and modelling for this research, based on which policy planning recommendations will be made with regards to WEF Nexus. The key features of all districts are same and this research is area-specific and therefore, the recommendation can be applied to the whole region of Bundelkhand UP.

Figure 3 Socio Economic data of Bundelkhand (UP)
Source: By Authors, (Census, 2011)
3.4 Banda Profile

Banda district stands at an elevation of 127m above sea level. In 2001, population of Banda was 15,37,334 which increased to 17,99,410 in 2011. Banda is divided into four tehsils namely Atarra, Baberu, Banda and Naraini and 694 number of villages. Banda district has population density of 408 person per sq. km in 2011, which has increased from 345 person per sq. km in 2001. The area of the district is 4408 sq. km. The district is predominantly rural in character and in Banda, only 15.32 per cent of the population lives in urban area. The tehsil of Banda is subdivided into Banda Nagar Palika Parishad, Tindwari Nagar Panchayat and Mataundh Nagar Panchayat Atarra tehsil is subdivided into Atarra Nagar Palika Parishad, Bisanda Buzurg Nagar Panchayat and Oran Nagar Panchayat. The hierarchy is shown in figure 4.

Figure 4 Banda District layout and features
Source: (Census, 2011), District Census Handbook

Figure 5 The hierarchy of Banda District
Source: By authors
4. 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 can be unified in this process. It can help stakeholder in understand system complexities by building cause and effect relationship over time and also in 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 is for examination and critical analysis. In order to make more better and informed choices, a better understanding of inter-dependence and inter-linkage 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 extract 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. (J McGlashan, 2016)

The 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 then converted to measurable criteria to appraise the degree of importance. The next step is to evaluate and examine alternative options. The model will try to relate the alternative with 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 to explore the consequences of various policies, to test assumptions and to set different parametric relationships. Thus, one develops an appreciation of planning and decision-making situations by substituting 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 is to describe 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 alternatives analysis. Such types of models predict values for a given set of exogenous variables. Such type of 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, with an aim 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 situation. 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-objectives field where the needs of society and political scenario is also added. This 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 being about decision maker as there are so many people involved planners, politicians, academicians, and public. WEF is a complex process, system analysis is a new tool used for operational phases. Major changes in WEF resources approach offering the opportunity for planners and civil engineers to develop new constituencies for which to apply our experience as well as to 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, per capita use of resources is increasing with the increasing demand of better environment and better quality of life; creating a difficult dichotomy for policy makers and planners.

5. SYSTEM ANALYSIS OF WATER SECURITY, ENERGY SECURITY AND FOOD SECURITY

Causal loop diagram can be defined as “A causal loop diagram (CLD) 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 causal loop diagram and it also generates behaviour over time (Sterman, 2010). A feedback loop relates causality of two or more variables. The relationship is either positive or negative. In a positive relationship, if one increase other also increases or if one decreases other also decreases. In a negative relationship, the variables related to each other inversely. If there are even negative relationship in a loop, it become positive; while the total number of negative relationship is in odd numbers then loop remains negative. Positive feedback loops generate growth i.e. re-enforcing and negative feedback loops are goal seeking (B K Bala, 2014). The causal loop diagrams have been developed on food security (figure 6), water security (figure 7) and energy security (figure 8) based on literature and field survey.

5.1 Causal Loop Diagram for Food Security

\[ \text{Agricultural production} = \text{agricultural productivity} \times \text{productive area} \times \text{cropping intensity} \] (1)

Agricultural production will increase if the productive agricultural land will increase as shown in figure 6. In order to increase the productivity training of farmers, field workers, research in field on agriculture and inputs from farmers is important. Increase in productivity will increase the agricultural production which in turn will increase the income of farmer that will enable them to use better inputs in agricultural fields according to equation 1. The agricultural production
directly depends on agricultural productivity, suitable land area for production and cropping intensity of the crops grown. Cropping intensity degrades the land quality due to potential multiple cropping and crop diversification that reduces the productivity. Productivity of the land can be regenerated by keeping land fallow for a period of time. The productivity increases by doing research in the field of agriculture by introducing new seed varieties, new cropping techniques, less use of pesticides and improved farming knowledge, it can be introduced to field workers and farmers and make them aware through training. Implementation of participatory methods, learning about new techniques and experimental methods reduces yield gap and act as a multiplier for agricultural productivity. Requirement of crops is based on population, growth rate and per capita consumption. Therefore, the variables in the causal loop diagram in figure 5 accounts to ensure food security.

5.2 Causal Loop Diagram for Water Security

![Causal Loop Diagram for Water Security](source)

**Total Available Water** = **Precipitation** + **Local flow of Rivers** + **Local tanks** – (**total water demand** + **Evaporation**)  

(2)

**Total water demand** = **Agricultural Water Demand** + **Industrial Demand** + **Municipal Water Demand**  

(3)

Future earth 2018 identifies water as a central element for production of food and energy (Futurearth, 2018). Equation 2 suggests that in district Banda, variables of total available water are total precipitation, local flow of river Ken and Yamuna flowing inside the boundaries of the district Banda and Local tanks which provides water directly and also recharges ground water. Total water demand depends upon 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 because is water supply for agriculture will increase, total available water will decrease; while if total available water is more the amount water supply for agriculture will increase and it is similar in case of industrial water demand loop and municipal water demand loop. The natural variables that account for total available water are precipitation and evaporation as shown in figure 7. Local tanks in Banda are a major source of water along with surface water and ground water, 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 technique for irrigation as it is more sustainable and more apt for Banda according to the climatic conditions. Water recharge is an important function for this area not only for sustainability point of view but also for providing sufficient water for drinking and irrigation. As in this region, water is depleting at very fast pace which is leading to crop failure because of unavailability of water timely and it turn leads to agricultural debts on farmer and many of them cannot take the burden and commit suicide. In survey, it has been identified that though Bundelkhand region lies in central part of India, yet the industries are not investing here due to insufficient access to water resources. Therefore, proper planning and water resource management is required looking at the interaction and integration of the variables.

5.3 Causal Loop Diagram for Energy Security

![Figure 8 Causal Loop Diagram for Energy Security](image)

Source: By Authors


(4)

Energy Surplus = Total Energy Produced – Total Energy Consumed  

(5)

In Bundelkhand region, 76.3 percent of people still rely on Kerosene as the main source for lighting and 64.4 percent of the population use fuel-wood for cooking. District Banda has a huge
potential hydro energy as river Ken and Yamuna flows through the district and also, encompasses huge potential for solar energy as the region lies in central India that receives sufficient amount of sunlight throughout the year. As per equation 4, total energy production comprises of Solar energy, Bio gas, Fuel wood and Fossil fuel (Kerosene, Petrol, Diesel, Coal, Natural Gas). Mostly, energy used in Banda district is produced from fossil fuel and fuel wood, while very less amount of energy used is produced from solar and bio gas. According to causal loop diagram in figure 8, if amount if biodegradable waste will increase, energy production from bio gas will also; while increase in energy production from bio gas will decrease quantity of biodegradable waste. There is a positive loop between amount of fuel wood and deforestation; increase in amount of energy produced from fuel wood will increase deforestation and vice-versa. 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 equation 4 and 5 and can be obtained by proper management of energy production and use of hydro and solar energy.

6. FINDINGS

The fast-growing world facing 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, and so water-energy-food nexus is a way forward. The solutions are required at the local level in order to curb the water-energy-food crisis. Nexus needs to be clearly defined in order to maximize the resource utilization and to reduce the trade offs. Most of the studies on nexus is 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. Causal loop diagram needs to be developed to understand the cause and effect relationship and recognizing the role of different variables in achieving the Water- Energy- Food Security. To optimize the maximum use of resources, nexus related site specific variables needs to be identified and their interactions and inter-dependencies needs to be researched at grassroots level.

7. CONCLUSION

There is a need to address the subsystems in both as a part of large system and small subsystem at the same time. Cross-sector approach is required to achieve water-energy-food security at grassroots level. A dynamic approach is required to investigate the dynamic properties, feedbacks, non-linearity and interactions of the system. A significant modeling technique is required to identify the replica of real life scenario. The System Dynamics Technique is essential to ensure sustainable solution for Bundelkhand Region when WEF will act as catalyst, it will also help identify alternative policies for long and short term goals using system approach. WEF Nexus progress and gaps have been identified in this study. On the basis of literature study and reconnaissance survey variables have been recognized to develop causal loop diagram to understand interaction between variables and to attain WEF Security at local level. Current scenario and human interventions are being considered while developing the model. The dynamics identified here will be application in the future study. To maximize the system’s performance, sectoral planning must be complemented with integrated planning. Social, economic and environmental development is required simultaneously for sustainable development of a region. The proposed diagram will be developed in model systematically and will be efficiently used for developing policy suggestions and improving policy-makers decision.
Bibliography


