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Article

Quantifying and Linking Sustainable Land - Water - Energy - Food Nexus Resources and Livelihoods of Local Community in Ethiopia

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Abstract: The sustainable management of Land - Water - Energy - Food (LWEF) nexus requires an environmental characterization that allows the comparison of complex interlinkages between nexus resources and livelihoods. This complexity makes this characterization difficult coupled with limited study in quantifying sustainability of LWEF nexus and its linkage with livelihood. Therefore, the present study aimed to investigate the link between sustainable LWEF nexus and livelihoods. We used analytical hierarchy process and pairwise comparison matrix in combination with weighting model. The result of composite LWEF nexus index was 0.083 representing, low sustainability. This could be linked with nexus resources consumption, use, and management. From the analysis of the weight of land, water, energy and food nexus resources, the highest weight was observed for food. The focus of on food production only shows no clear synergy on provisioning, supporting or regulating nexus resources to address livelihoods. The result further showed that LWEF nexus resources have strong correlation with livelihoods. This was evidenced by social ($r \geq 0.8$, $P<0.01$), natural ($r \geq 0.3$, $P<0.05$) and physical ($r \geq 0.6$, $P<0.01$) livelihood indicators showed strong positive correlation with LWEF nexus resources. From this results, it was observed that managing nexus resources not only provide a significant contribution to achieve sustainable LWEF nexus, but also be effective for enhancing livelihood through food security. This could be attained by strong evidence based policy to ensure sustainable use of nexus resources. The results provided by this study would serve as the foundation for future study, policy formulation and implementation.

Keywords: Local Community, Livelihoods, Sustainability, Land-Water-Energy-Food, Nexus, Indicator

1. Introduction

Land, water, energy, and food (LWEF) are natural resources vital for sustaining life on earth [1, 2], and also important for people wellbeing and economic activities [3]. Globally more than 1 billion people suffer from water, energy and food insecurity, and also correspondingly from amplifying land degradation [4, 5]. This could be due to population growth, urbanization, rising economy and consequent change in consumption patterns, and climate change, which pose pressure on those four resources [6, 7]. Thus, the issue of LWEF security is a big obstacle for global sustainable development [8-10].

Effective natural resource management via nexus approach is required for the sustainable use of LWEF nexus resource [1]. These resources are vital natural resources needed to solve critical global issues of hunger, improving health and building a sustainable and desirable economy. Due to interlinkage between them, the exploitation of one often sets the prerequisite of the abundances of another, therefore, a possible systemic approach to minimize trade-offs and maximize synergies were needed [11, 12]. The importance of systemic approaches in the management and governance of natural

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resources and food systems has been recognized, due to increasing demands for services and growing desires for higher living standards.

The progress towards water, energy, and food (WEF) nexus have motivated many discussions on how to manage these interlinked resources [13] and broadened to also include other resources or disciplines, such as soil, land use, climate, waste, ecosystems, health, and others, forming an even more multi-dimensional and multidisciplinary concept [14]. Despite the progress in recent years, there remain many challenges in scientific research in adding land as part of the WEF nexus system in small geographical scale [15]. The scientific challenges are primarily related to data, information and knowledge gaps on the these four nexus resources interlinkage [16, 17].

This concern suggest the need for a possible assessment system which is based on the concept of sustainable natural resource indicator [18]. A sustainability indicator can be defined as a measurable aspect of environmental, economic, or social systems that is useful for monitoring changes in system characteristics relevant to the continuation of human and environmental well-being [19-21]. Sustainability indicators tend to be the most suitable for providing valuable initial assessment, which necessitates for decision-making from grass root level [22, 23].

The relationship between nexus resource and livelihoods is said to be a symbiotic relationship in a form of a vicious cycle, due to ability to affect one another [24]. So far, ample empirical studies conducted on the link between individual nexus resources and livelihoods, however, studies linking LWEF nexus and livelihood are barely conducted at the study area to analyze the interlink between sustainable LWEF nexus and livelihoods. Therefore, this study specifically seeks to (i) identify LWEF nexus and livelihoods indicators; (ii) analyze sustainability of LWEF nexus and its contribution for livelihoods improvement; (iii) assess the livelihoods strategies and its sensitivity with sustainable LWEF nexus. The findings from this study will add up to the literature on the subject area and provides foundation for future studies, policy formulation and implementation in the study area and beyond.

2. Materials and Methods

2.1 Description of Research Sites

The study was conducted in the Rift Valley Basin in Ethiopia. The Rift Valley Basin, which passes the southern part of the Main Ethiopian Rift, covers an area of about 0.04 % of the country and extends to the south from the upper catchments of the Awash Basin to the Kenyan border, to the extreme south of Chew Bahir. This Basin lies both in the Oromia and Southern Nation, Nationality and People Regional States. As outlined in the Integrated Development Master Plan Study (2010), the basin is characterized by under development, widespread poverty and severe land degradation.

The Gidabo Watershed is part of Rift Valley Basin, and also called Ethiopian Rift runs through Ethiopia in the southwest direction from the Afar Triple Junction [25]. This area is characterized by wide topography and climatic variation ranging from humid in the highland to semi-arid [26]. It is situated between 6^0 9′ 4′′ to $6^0$56′ 4′′N latitude and 37^0 55′ to 38^0 35′′E longitude, covering an area that is approximately 3549 km^2 (Figure 1). The maximum and minimum altitudes are about 3213m.a.s. l and 1171 m.a.s.l respectively.

The unique characteristics of the watershed are associated mainly with the results of faulting and volcanism associated with rifting process [27]. As a result, the typical rift morphology is well developed which clearly show the upper and lower parts which drain to the common outlet (Figure 1).

The population in the watershed has nearly doubled over the last two decades from 593,157 to over 1.5M [25]. Increased population in the basin and the socio-economic developments have put pressure on land that consequently declined water and food potential in the watershed [28].

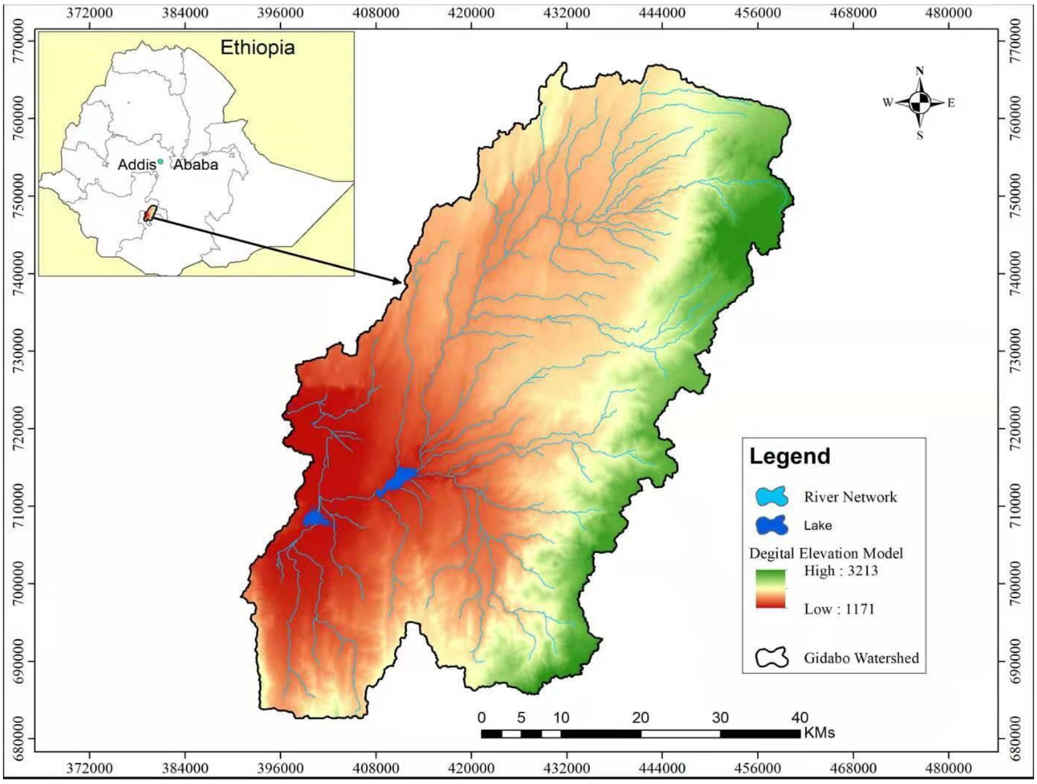

Figure 1:Map of the case study area

Land, water, energy and food nexus resources are all crucial contributors to food security. As a result of growing resource scarcity, the inter-connectedness of these sectors has become more apparent, as evidenced by growing tradeoffs. Proactive analysis of the current consumption, use and management of LWEF nexus resources are required to holistically assess and promote the best management option that co-balance benefits across LWEF nexus resources as highlighted by WoldeYohannes, Cotter [29].

2.2 Establishment of LWEF nexus indicator and sub-indicators

Indicators are becoming increasingly important for communicating information to policy makers and stakeholders, as well as for assessing the environmental performance and progress in general [30]. Nowadays, it is believed that composite indicators have been used for quality of life and environment through providing information on the status of the economic, social and environmental component to reduce the number of measurements necessary to give descriptions of an indicator [31, 32].

It is known that clear indicators are the basis of any effective monitoring, evaluation system and data obtaining system [21]. Since, this study is based on local cases one of the challenges in performing this study is obtaining sufficient data and information relevant to our study. In order to track the way in which LWEF nexus and livelihood links and its progress towards reaching certain goals the researcher need to measure this change using literature and key informants having enough knowledge in the area to select and develop indicators.

In order to develop indicators in Table 1, we used the following four stepwise procedures to define the indicator variable; (1) Collecting ideas to perform this we compiled all ideas from key informants without judging them, then we organized the ideas into group to categorize as relating to specific individual objectives and analytical questions. (2) Structure and refine ideas, in this steps we further structured and consolidated the ideas to sort out the relevant ones by referring the work of other researchers/organization or using previously developed sets of indicator. Additionally, this steps helped to remove unnecessary indicator and to merge those having similarity. (3) Formulating indicators to make sure that selected indicator in both meaningful and measurable,

we consider specific measurable attainable realistic and timely (SMART) techniques to formulate the indicators that showed what results were likely to be reached within what target group, and in what time frame. (4) Selection of indicator, the assembled indicators through step 1-3 which were many, however, this step focus on indicators quality which is more important than their number, therefore, we set priorities to have a small but meaningful set of indicators.

Following above methods we prioritized the criteria and set indicators for LWEF nexus resources (Table 1). Table 1 indicates the most important LWEF nexus indicators identified from literatures. After designing those indicators, the study used approach of the Analytic Hierarchy Process 3. Results

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Nexus component	Indicators	Descriptions	Sources
Land	Land capability (LI1)	Land capability is the ability of land to support a given land use without causing damage. Its assessment considers the specific requirements of the land use and the risks of degradation associated with the land use	[33-37]
	Land suitability (LI2)	Land capability assessments are a first step in assessing land suitability for a given use. Suitability considers other factors such as economics, infrastructure requirements, labor access, water and energy access, conflicting and complementary land uses, and the policy framework.	
	Land productivity (LI3)	The productivity of land is determined by its natural qualities and fertility. This indicates all lands are not equally fertile, which makes some locations are very fertile and have very good agricultural productivity, whereas some patches are non-productive.	
Water	Access (WI1)	Global water resources are facing increasing pressure from rapidly growing demands and climate change, which affect access to water. Thus, sustainable water management is a key global concern intricately linked to many livelihoods worldwide	[38-42]
	Safety (WI2)	Unsafe water is one of the world's largest health and environmental problems, particularly for poorest in the world. It also exacerbates malnutrition.	
	Affordability(WI3)	The physical availability of water is becoming a serious challenge, and its absence generate commensurate impacts on the livelihoods and human wellbeing.	
Energy	Adequate Supply to demand (EI1)	About 40% of the global population relies on traditional use of biomass for cooking and heating their houses. This both directly and indirectly linked with environmental disturbances.	[38, 43, 44]

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	Physical Availability (EI2)	Today lack of physical availability of energy, simultaneously affect environmental quality and growth of socio-economic activity	
Food	Availability (FI1)	Refers to the physical existence of food, whether from the household's own farm, garden production, and/or from domestic and international markets	[18, 22, 37, 45, 46]
	Access (FI2)	Refers to the resource's individual has at hand to obtain appropriate foods for a nutritious diet.	
	Utilization (FI3)	Refers to the actual food that is consumed by individuals; how it is stored, prepared, and consumed. And also, what nutritional benefits the individual drives from consumption.	
	Stability (FI4)	Refers to the temporal dimension, or time-frame of food security.	

(AHP), and the pairwise comparison matrix (PCM) to provide weight for individual indicator and to normalize the indicators and establish composite indicators index.

The AHP is a structured technique, which is helpful in solving indicators selection problems involving multi-criteria and multi-alternatives [47]. Furthermore, the hierarchical structure used in formulating the AHP model can enable all members of the evaluation team to visualize the problems systematically in terms of relevant criteria [32]. In a sense, the AHP method may be useful for selecting indicators because of the characteristics of indicator selection process.

The PCM is a technique which has been widely used to tackle the subjective and objective judgements about qualitative or quantitative criteria in multi-criteria decision making, especially in the AHP [48]. The preference relations in the PCMs are filled in by the decision maker's judgments, and presented using different measurement scales such as ratio scale. The importance of criteria and the ranking of alternatives are often judged through the priority weights derived from a PCM, thus many prioritization approaches have been proposed to derive the priority weights from PCM.

The AHP supports creation of weights based on expert's judgments structured in a pair wise comparison matrix by applying Saaty's scale of intensities importance [49]. The tool for data collection for AHP was presented in Microsoft excel, and respondents were asked to rank the 12 comparison matrices. Then, through further calculation, weightings for criteria and indicators within each criterion was computed (Table 2). Mabhaudhi, Nhamo [46] explained that the full description of how the AHP and PCM normalization works.

Table 2. Table 2: PCM and weight for the LWEF nexus indicators

Indicators	LI1	LI2	LI3	WI1	WI2	WI3	EI1	EI2	FI1	FI2	FI3	FI4	Weight
LI1	1												0.042
LI2	3	1											0.050
LI3	3	2	1										0.066
WI1	2	2	2	1									0.069
WI2	1	1	1/2	1/2	1								0.041
WI3	4	4	3	3	6	1							0.149
EI1	2	2	1	1	4	½	1						0.069
EI2	2	1	2	1	4	1/3	2	1					0.075
FI1	1	1	1	½	3	1/3	1	1	1				0.058
FI2	2	2	1	1	3	1	1	2	2	1			0.096
FI3	2	1	3	3	2	2	2	3	3	1/3	1		0.150
FI4	1	3	1	2	1	1/2	3	1	2	1	5	1	0.135

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The computation of each weight, indices, consistence ratio (CR) and consistence index (CI) were computed as follows; before calculating CR, we computed CI using the formula;

$CI = \omega - \frac{n}{n-1}$, where n represents the number of indicators in our case 12 and ω represent the eigenvalue obtained from the weight value of indicator using stata 14, for our case ω = 1.176. Therefore,

$CI = \omega - \frac{n}{n-1}$, $1.176 - \frac{12}{12-1} = 1.176 - 1.09 = 0.086$

According to Meixner, Haas [48], Random Index (RI) calculated for criteria from n=1-15,provided their RI value hence our criteria (indicator) as 12, therefore, it corresponding RI=1.54.

$$CR = \frac{CI}{RI} = \frac{0.086}{1.54} = 0.0556, equal\ to\ 0.056$$

Compared with study conducted by Mabhaudhi, Nhamo [46], we considered land as additional nexus resources which can be explained by land suitability, capability and productivity were considered as identified indicators. The identified indicators were normalized by applying the indicator weight normalization, and used to compute the LWEF index by adding the weighted normalized indicators.

2.3 Sustainable livelihoods indicators

It is crucial to consider nexus resources security for various livelihood indicators through computing indices to evaluate their role in Sustainable Livelihoods (SL). Sustainable livelihoods Framework (SLF) has been considered and it has been found that the good indicators that provide a complete picture of all the relevant aspects of sustainable livelihoods in a transparent and easily understandable way [50, 51].

Sustainability is an important qualifier to Department for International Development (DFID) view of livelihoods because it implies that progress in poverty reduction is lasting, rather than fleeting [52]. For detail on sustainable livelihoods approach, the five main livelihoods component adopted and explained from [53].

Therefore, the current study adopted the DFID SLF to characterize the livelihoods indicators [54]. The five basic components of livelihood show the variation in people's access to assets. A single physical livelihood component can generate multiple benefits. For example, if someone has secured access to land (natural capital), they may also be well-endowed with financial capital, as they are able to use the land not only for direct productive activities but also as collateral for loans. This helps to develop different sub-livelihoods indicator. Table 3 depicts the basic component of sustainable livelihoods indicators for the current study which were categorized under five main and 23 sub livelihood categories.

The importance of evaluating livelihoods from basic human aspects (i.e., land, water, energy and food) enhances local community understanding towards the management and use of limited nexus resources and to better link with their livelihoods.

Table 3: Component of sustainable livelihood indicators

Livelihoods component	Indicators	Descriptions	Sources
Social	Social interaction (SC1) Knowledge sharing(SC2) Community wellbeing(SC3) Income generation(SC4) Perceived benefits(SC5) Community acceptances(SC6)	Those indicators refer to, household's connections in social network, and the trust, reciprocity, and Resources sharing qualities of those connections.	[3, 12, 30, 46, 51, 52, 55-59]
Human	Health(HC1) Labor productivity(HC2) Level of education(HC3) Access to information(HC4) Use of traditional knowledge (HC5)	Refers to the livelihood knowledge and capabilities possessed by individuals, in addition to the intangible character traits and health status that determine how effectively individuals apply their knowledge to livelihoods activity.	
Physical	Natural resources mg't(PC1) Ecosystem conservation(PC2) Community wellbeing (PC3) Human intervention on Env't (PC4)	It refers the physical economic infrastructure along with the household's productive and other assets that enable the household to pursue its livelihoods	
Financial	Organization & institutions (FC1) Market availability(FC2) Infrastructure(FC3) Financial services (FC4)	Refers financial resources that are available to the household and include assets held as store of value.	
Natural	Human intervention on Env't (NC1) Area of crop production(NC2) Water and aquatic resource(NC 3) Tree and forest products(NC4)	Refers the physical environment and natural resources stocks that can be controlled by the household and used to expand or enhance livelihoods.	

The importance of evaluating livelihoods from basic human aspects (i.e., land, water, energy and food) enhances local community understanding towards the management and use of limited nexus resources and to better link with their livelihoods.

Most researchers have proposed various methods and evaluation of index system to assess the sustainability of WEF nexus in global, national and regional basis [60-63]. Combining the livelihood indicators helps to measure the interaction between five main livelihoods indicators [54]. We used the following equation to standardize the sub indicators;

$$K_i = \frac{xi - \bar{x}}{s} \quad (1)$$

where K_i is sub-indicator, x_i corresponds to the i^{th} measurement of SL indicator variable, $\bar{x}$ is the average value of x_i and s is the standard deviation. As a result, we write livelihood component (Lc).

$$Lc = \sum w_i K_i \quad (2)$$

where Lc the estimated value of the livelihood indicators $(0 \le i \le 4)$ in relation to LWEF nexus, w_i indicates the weight for the i[th] observation and K_i represents the normalized value of indicator for the i[th] observation.

In this paper, we used weighting model (WM) concept to combine the weight of LWEF nexus and livelihoods indicators indices selected from literature as explained in Table 1 and 2. This model helps to determine an index system that could evaluate LWEF system to associate with sustainable livelihoods using weights of individual indicator which helps to develop composite indicator value and the resulting ranking (Yang et al., 2018). There are studies conducted on exploring WEF nexus sustainability [46, 64, 65]. However, our study tries to link sustainability of nexus resources and livelihoods which have not been studied so far from small geographical units in Ethiopia, particularly in Gidabo watershed. This provides some degree of novelty to the current work.

2.4 Sample size determination and Sampling Technique

The data on LWEF nexus resources and livelihood indicators for the study were sourced from both secondary and primary sources. The primary sources involved the combination of structured interviews with local community and key informants. The survey was conducted within four-month period from July 2019 to October 2019 following two approaches. First, we made expert interview (N=50) and focus group discussion with experienced expert from natural resources, agriculture, water and energy sector to characterize the sub-indicators for LWEF and livelihood Table 1 and 2. Particularly, the identification of indicators helps for household to easily categorize which livelihood indicators linked with LWEF nexus resources. Second, a structured questionnaire was administered to 434 farmer household heads (N=434). The structured questionnaire mainly focused on assessing the importance of the proposed LWEF nexus indicators for sustainable livelihood indicators (SLI) using Likert scale (0-4, where 0=Not Important; 1=Slightly Important, 2=Moderately Important, 3=Important, 4=Very Important) was adopted for this study.

Based on the weight of indicators, we further used logistic regression to describe the causal relationship between LWEF nexus indicators (i.e. independent variable N) and livelihoods indicators (i.e. dependent variable δ). When using the logistic regression, we need to make an algebraic explanation to arrive at our usual linear regression equation. The logistic regression is given by:

$$\delta = \beta_0 + \sum_{i=0}^{n} \beta_i N_i \quad (3)$$

where δ is probability, β_O is the constants, and $\beta_i \, (i = 1, 2, \dots, n)$ is the regression coefficients. In our case the dependent variables (δ) is not continuous, and converted to probability ratio (ω) of livelihoods indicators and computed as;

$$\ln(\omega) = ln\left(\frac{\delta}{1-\delta}\right) \quad (4)$$

where ln= natural logarithm, and ω is called logit (δ), leads to the following equations;

$$Logit(\delta) = \beta_o + \sum_{i=1}^{n} \beta_i N_i \quad (5)$$

where $\beta_O + \sum_{i=1}^{n} \beta_i N_i$ is familiar equation for regression line. Knowing regression equation helps to calculate expected probability from a given values of N_i theoretically. From this equation (5) is changed to:

$$\omega = \frac{\delta}{1-\delta} = exp\left(\beta_o + \sum_{i=1}^{n} \beta_i N_i\right) \quad (6)$$

To rearrange the equation, the opposite of natural logarithm(exp) is considered since we need to estimate the probability of livelihoods indicators. This can be explained with the change in units' value of N_i . Finally, elasticity of probability was determined from the derivatives equation of (6) as from equation 7 below;

$$\omega = exp\left(\beta_j + \beta_o + \sum_{i=1}^{n} \beta_i N_i\right) = \omega exp\,(\beta_j) \quad (7)$$

where $\exp(\beta_j)$ is the elasticity probability, it changes with the unit increases and decreases in nexus resources (N_i). It shows how main livelihoods indicators are sensitive with respect to land, water, energy and food nexus indicators. In this analysis sensitivity measure the effect of changing in nexus resources in the livelihoods indicators. This means that the probability of LWEF nexus resources increase by $\exp(\beta_j)$ increase or decrease the livelihoods by one unit change based on the regression coefficient. From the regression coefficient computed student t-test was applied to test which nexus resources comparably influential using mathematical equation;

$$N_O = \frac{\beta_i}{\sqrt{\delta^2 + C_{nn}}} \quad (8)$$

Where N_o is nexus resources with $k - m - l$ degree of freedom, with k being the total number of samples and m the number of terms in the model, β_i is the regression coefficients, the term C_{nn} is the n^th diagonal elements of the data matrix, and $\delta^2 = \sqrt{\frac{SSE}{m-k}}$.

All statistical analysis was done in Stata 14 (StataCorp LP, 4905 Lakeway Drive, College Station, TX 77845, USA).

3. Result and Discussion

3.1 Pairwise comparison matrix for land-water-energy and food nexus indicators

Human well-being, poverty reduction and sustainable development are largely dependent on land, water, energy and food resources. These vital resources are projected to have demand exceeding supply in the nearest future due to population growth and migration, economic development, international trade, urbanization, diversifying diets, cultural and technological changes, as well as climate variability and change [66]. These necessitate sustainability of basic nexus resources, which can be assessed by performing the LWEF nexus indicator using PCM.

Table 4 presents the result of PCM of the four nexus resources indicators. The comparison of indicators with itself is one. The symmetrical characteristics of the matrix is explained by considering the lower half the triangle, since the remaining cells are the reciprocals of the lower triangle. According to Saaty [49], the relationships are established using a scale ranging from 1 to 9 and their reciprocals. The result shows that the indicators with the highest weights are the food utilization, water affordability, food stability and access to food (Table 2). This indicates how the percentage of food and water nexus component predict the livelihoods dependences compared with others. Table 4 indicates the CR for the LWEF nexus is 0.056, a value lower than 0.10 which shows the weights calculated are consistent enough to construct an index as reported by Mabhaudhi, Nhamo [46].

Table 4: Normalized pairwise comparison, Consistence ratio and composite index for LWEF nexus resources in the study area

Indicators	LI1	LI2	LI3	WI1	WI2	WI3	EI1	EI2	FI1	FI2	FI3	FI4	**Indices**
LI1	0.04	0.02	0.02	0.03	0.06	0.05	0.03	0.04	0.03	0.08	0.05	0.06	0.042
LI2	0.13	0.05	0.03	0.03	0.06	0.04	0.03	0.04	0.03	0.08	0.05	0.04	0.050
LI3	0.13	0.10	0.06	0.03	0.06	0.05	0.13	0.04	0.03	0.08	0.03	0.06	0.066
WI1	0.08	0.10	0.12	0.07	0.06	0.05	0.03	0.02	0.13	0.08	0.03	0.06	0.069
WI2	0.04	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.05	0.05	0.13	0.041
WI3	0.17	0.20	0.18	0.21	0.19	0.14	0.13	0.22	0.19	0.08	0.05	0.04	0.149
EI1	0.08	0.10	0.06	0.07	0.13	0.07	0.06	0.04	0.03	0.08	0.05	0.06	0.069
EI2	0.08	0.05	0.12	0.07	0.13	0.05	0.13	0.07	0.03	0.08	0.03	0.06	0.075
FI1	0.04	0.05	0.06	0.03	0.09	0.05	0.06	0.07	0.06	0.08	0.03	0.06	0.058
FI2	0.08	0.10	0.06	0.07	0.09	0.14	0.06	0.15	0.13	0.15	0.09	0.03	0.096
FI3	0.08	0.05	0.18	0.21	0.06	0.28	0.13	0.22	0.19	0.05	0.09	0.25	0.150
FI4	0.04	0.15	0.06	0.14	0.03	0.07	0.19	0.07	0.13	0.15	0.46	0.13	0.135
													∑=1
								CR= 0.056					
							Composite LWEF nexus index						**0.083**

3.2 Land-Water-Energy- Food (LWEF) nexus composite indices

AHP is a widely used method for indicator performance evaluation [47, 67], presumably because it elucidates preference information from the decision makers in a manner which they find easy to understand [68]. The basic step was undertaken by the pairwise comparison to determine the relationship among WEF nexus components in the study area.

It shows AHP helps to formulate and analyze sustainability indicators [41]. Our study utilizes LWEF nexus indicators outlined in Table 1 and overlay the transparent and clearly defined weighted criteria which used in importance index scenario. The idea behind composite LWEF nexus index is to aggregate indicators about the sustainability aspects and then provides an easy to understand scoring system to determine sustainability.

LWEF nexus composite index for the study region is 0.083 (Table 4), which implies shows low index [46, 67]. For example, study conducted by Mabhaudhi, Nhamo [46], on the WEF nexus integrated index for South Africa was 0.145 and categorized as low index revealing unsustainable performance of resources utilization and management, which is consistent with our finding. It is known that the case study area is more likely dominated by agriculture based livelihoods, but the expansion of non-agriculture based industries demanding for more land, water and energy are managed friendly in environmentally sustainable way to the extent that natural resource levels are improving rather than deteriorating.

The sustainability index is used to simplify the complex decision making process that will help the stakeholders to come with more sustainable solution [21]. Identifying of these indices is crucial since, LWEF nexus index computed from indicators are strongly linked with the livelihoods of local community.

The regional performance of natural resources index is not yet designed, which could lead to nexus resources trade-off. However, there has been wide ranging support for individual and sectorial based management of nexus resources. Lack of managing those interlinked resources in joint way creates a tension in sustaining and supplying sufficient basic resources for human well-being.

The result of low composite index for LWEF shows lack of management of nexus resources in integrated approach, while food production merely considered as core element, as also reported by Mabhaudhi, Nhamo [46]. This is also evidenced by the highest normalized weight of food indicators (Table 2), which shows that land has been overlooked to be part of nexus resources component, while it affects overall performance of nexus resources. For example, Ethiopia has the potential for arable land and water sources [23], however millions of people still suffer from food and water insecurity, and inadequate of modern energy supply.

Ethiopia depends on hydropower as the main sources of energy, in which food production and energy compete for the same water resources. Similarly, agriculture is a source of economy for over 80% of population, major means of livelihood for over 80 % of population, this indicates strong dependence of livelihoods on land, water and energy for food production with varied level of consumption. However, agriculture is seriously challenged by human-induced factors, which pose pressure in the transformation of rural livelihoods, which need sustainable natural resource management. Nevertheless, the current unsustainability of LWEF nexus resources shows that, the sectorial based nexus resource management and practices indeed significantly impacts both resources and the livelihoods.

3.3 Land-Water-Energy-Food nexus analytical livelihoods framework

Local communities, especially the rural poor in the developing world, depend directly on all or part of nexus resources for their livelihood [56]. Therefore, understanding and consensus building are necessary to identify, create and utilize nexus approach in order to reduce trade-off. Current study identified twenty-three sustainable livelihoods indicators which are linked with land, water, energy and food nexus resources (Table 3).

Table 5 shows from the social livelihoods indicators the community acceptances ranked as the most important indicators compared with others. This indicates that, the community acceptance of LWEF nexus resources as a source of livelihoods can be considered from multipurpose utilization of nexus resources for multiple sources of their livelihoods.

Table 5: Community based livelihoods indicators weight and rank in relation to LWEF nexus

Main livelihoods component	Sub-Indicators	Average weight of indicators	Rank
	Social interaction	0.176	3
Social	Knowledge sharing	0.122	4
	Community wellbeing	0.244	2
	Income generation	0.130	5
	Perceived benefits	0.079	6
	Community acceptances	0.250	1
Human	Health	0.300	1
	Labor productivity	0.245	2
	Level of education	0.214	3
	Access to information	0.131	4
	Use of traditional knowledge	0.109	5
Physical	Natural resources mg't	0.170	3
	Ecosystem conservation	0.223	2
	Community wellbeing	0.452	1
	Human intervention on Env't	0.155	4
Financial	Organization & institutions	0.255	2
	Market availability	0.230	3
	Infrastructure	0.287	1
	Financial services	0.228	4
Natural	Human intervention on Env't	0.067	4
	Area of crop production	0.307	2
	Water and aquatic resource	0.319	1
	Tree and forest products	0.306	3

Unsustainability of LWEF nexus, in this study (0.083), shows vulnerability of local community for social livelihoods insecurity. To address these challenges, shift from individual nexus resources management are the natural stage for the sustainable LWEF nexus in relation to local community.

From the human livelihood component, health is ranked as the most important indicators linked with sustainable LWEF (Table 5). The demand for food production steadily increases with population growth and all of this happens in the light of changing livelihoods, while millions of people do not have access to nutritious food that guarantees a healthy and active life. This is strongly linked with lack of productive land, water and energy sources. Ringler, Bhaduri [1] depicted that, rising food prices, and the recurrence of extreme weather events are pushing more people into poverty and hunger, compromising human health and well-being. Likely, other indicators such as labor productivity, level of education, and knowledge sharing through information also depend on distribution and use of nexus resource.

Physical component of livelihoods indicators includes four indicators (Table 5). The community well-being and ecosystem conservation ranked the first and the second, respectively. This implies that community based nexus resources management has been widely taken as a strategy that aims to conserve LWEF, while simultaneously enhancing livelihoods of local community.

Decentralizing management of nexus resources to local communities improves household's access to and management of nexus resources [15]. Thus, LWEF nexus upkeep as a tool to enhance nexus resources insecurity and resilience for sustainable livelihoods and ecosystem conservation. Therefore, the concept of nexus resources management should be viewed as longsighted and includes humankinds' harmonious and gradual modification of all ecosystem. LWEF nexus are complex multifunctional systems, which need a mosaic of four nexus resources to be properly utilized to increase social, physical, human, financial and natural livelihoods.

3.4 Comparison and validation of LWEF nexus and livelihoods

To compare and validate how LWEF nexus affects livelihoods, the impact of nexus resources indices was evaluated using regression analysis. Before regression analysis, the association between the composite weight of both LWEF nexus and livelihood indicators are computed by correlation analysis (Table 6).

The correlation coefficients between livelihoods and LWEF nexus indicator indicates that the social livelihoods indicators (SLI) have strong significant positive correlation ($r \geq 0.80$, $P < 0.01$) with land indicator (Table 6). This implies land is social resources upon which people draw in pursuit of their livelihood objectives and have significant contribution for sustainable livelihood. In addition, it has significant positive correlation with LWEF nexus indicators ($r \geq 0.30$, $P > 0.05$). This result suggests that the social livelihood indicators are directly depend on land as a sources of WEF nexus (Table 6).

This result is in relation with finding of Laspidou, Mellios [14], who reported that livelihoods and natural resources have direct correlation with social livelihoods indicators.

The natural livelihoods indicators had positive correlation ($r \geq 0.30$, $P < 0.05$) with water and energy indicators (Table 6). This result shows natural capital is very important to those who derive all or part of their livelihoods from resource-based activities (farming, fishing, gathering in forests, irrigation water dependent and others). Likewise, physical livelihoods indicators have strong significant positive correlation with energy ($r \geq 0.60$, $P < 0.01$), pinpointing that infrastructure consists of changes to the physical environment that help people to meet their basic needs and to be more productive. In general, the relationships between LWEF nexus and livelihoods indicators play an important role in the overall performance of livelihoods of local community.

The regression coefficients of land ($\beta = 0.82^{**}$, $P < 0.01$) and food ($\beta = 0.01^{*}$, $P < 0.05$) indices imply that, land and food have a significant positive effect on the composite social livelihood indicators (Table 7). Comparably, the effect of land is slightly stronger than that of food indicators. This ensures that sustainable land use management enhances food security and also promotes biodiversity conservation, in agreement with the finding of Hurni, Abate [69]. However, the current study reveals the low sustainable composite index of LWEF, (0.083) (Table 4) is an indication of unsustainable land use, which leads to the vulnerability of livelihood of the local community.

Table 7: Statistical analysis and testing of livelihoods indicators with respect to LWEF nexus

Main Livelihoods indicators	Nexus resources			
	Land	Water	Energy	Food
Social	0.8175**	0.5463	-0.0635	0.0114*
	(0.2834)	(0.02676)	(0.02549)	(0.2538)
Human	0.06873	-0.0909*	-0.1572	0.5534*
	(0.03604)	(0.03405)	(0.3243)	(0.3223)
Physical	0.1391**	0.0317	0.1896	-0.6042*
	(0.02718)	(0.0325)	(0.2445)	0.2430)
Financial	0.0969*	-0.0433	-0.1335	0.3073
	(0.0436)	(0.0411)	(0.3923)	(0.3899)
Natural	0.3523**	0.1047**	-0.0579	0.2028
	(0.0277)	(0.0262)	(0.2497)	(0.2482)
Constants	6.3296*	12.939**	-0.9016	13.369**
	(2.7217)	(3.4625)	(2.6109)	(4.1992)

The composite water index significantly affects human livelihoods indicators (β= -0.09, P<0.05). Human capital is required in order to make good uses of limited water resources which helps for the achievement positive livelihood outcome. The negative coefficient value of water index indicates a single unit change in water management have a negative impact on the livelihoods performance. Chen, Han [70], stated that water is the critical resources which underpins all social and economic activity.

Table 7 shows, land (β= 0.14, P<0.01) and food (β= -0.60, P<0.05) nexus indicators have significant effects on the physical livelihoods indicators. This implies that land indicators significantly improve the community well-being and ecosystem conservation (Table 5**)**, while the food indicators reduce physical indicators performance. This shows that the performance of land capability, suitability and productivity and food production has increased or decreased through the method of adjusting the physical livelihoods indicators, such as physical economic infrastructure that enable the household to pursue its livelihoods.

Table 7 shows that food as nexus component indicators (β= 0.5534, P< 0.05), which significantly affects the health, labor productivity and education, indeed major indicators of human livelihoods with maximum weight and rank.

Table 7 shows, land (β= 0.1391, P<0.01) and food (β= -0.6042, P<0.05) nexus indicators have significant effects on the physical livelihoods indicators. This implies that land indicators significantly improve the community wellbeing and ecosystem conservation, while the food indicators reduce physical indicators performance. This shows that the performance of land capability, suitability and productivity and food production has increased or decreased through the method of adjusting the physical livelihoods indicators, such as physical economic infrastructure that enable the household to pursue its livelihoods.

The coefficients of the land (β= 0.35, P<0.01) and water (β =0.10, P<0.01), indicates that both nexus resources have positive influence on the natural livelihoods indicators (Table 7). This implies land and water are key environmental services in which food is produced from as a natural capital**.** Thus, the livelihoods of local community are strongly linked with the nexus resources components. Therefore, to overcome the current unsustainability of nexus resources, there is a need for paradigm shift from business as usual to nexus resource management approach which needs to start from grass root level.

With the exception of all nexus resources, understanding energy as part of nexus resources is very critical. Since, energy availability and access would have a wide range of positive externalities on various dimension of human welfare. However, the impact of modern energy on sustainable livelihoods is less known. Therefore, due to the potential dependences of local community on traditional energy sources they fail to consider energy as nexus component. This pose unintended pressure on the environment.

This shows the need of sustainable management of LWEF nexus as an important analytical tool for transforming livelihoods. With this, the idea of nexus resources sustainability has received wider attention, however weighting, ranking and linking with the livelihoods will be the most important to predict the range of acceptable nexus resources impacts and community coping strategies.

3.5 Analysis of overall LWEF nexus Performance in Livelihoods

Sensitivity analysis of nexus resources in resources scarce areas has helped local communities to achieve their goal of improved livelihoods. The sensitivity analysis computed using additional regression to analyze the influence of each composite nexus resources indicators on livelihoods.

Table 8 indicates the sensitivity analysis for LWEF nexus and five main livelihoods indicators, the sensitivity judgment scale was adopted from Hosmer and Lemeshow [71]. The result show that, the probability of livelihoods, particularly social component increases by 89.1% if nexus resources, i.e. food increased by 1.00 % (Table 8).

This implies increased food production could enhance social livelihoods indicator. In addition, human, financial and physical livelihoods components show the same trends. This indicates that all the livelihoods indicators have the probability to be influenced by food availability, access, utilization and stability. Likely, the probability of natural livelihoods increases by 69.20% if food increases by one unit. This suggests that the ability of households to undertake the production of food is strongly associated with their access to natural livelihood component i.e. farmland.

The probability of a unit increases in water as one nexus resources increases the social, human and financial component of livelihoods by 79.90, 69.60 and 69.10% respectively (Table 8). This pinpoints that water is the critical nexus resources which underpins all social and economic activity since clean, healthy and sustainable water supply strongly linked with the livelihoods of local communities.

In general, the overall sensitivity analysis indicates that the probability of livelihoods dependences in the four nexus resources is greater than 50% in the study area. This indicates the current unsustainable condition of nexus resources which is 0.083 will have more than 50% of livelihoods vulnerability and need serious stakeholder intervention in the area.

In order to measure the extent of nexus resources sustainability indicators and its impact on the livelihoods of local community, we performed the spider web analysis. Figure 2a shows the proximity between land and livelihoods indicator. It depicts that social and financial livelihoods indicators are closer to land nexus component more than either physical, human or natural indicators. This indicates that land is a social capital in which household can invest with the expectation of future flow of benefits, and acts as financial sources, since it has predictable value when liquidated and exchanged.

Water sustainability indicators is a basic condition for obtaining good social indicators (Figure 2b), Plummer and Slaymaker [72], suggested that water supply and sanitation links with sustainability and prevailing condition of pro-poor economic growth. In addition, high availability, supply and access to water allows the population to cope with livelihoods shocks and stress to achieve basic social indicators.

In relation to food and livelihoods indicators, the food nexus component is most linked with human, physical and financial livelihoods (Figure 2d). This reveals that the livelihoods of local community are the most vulnerable to the adverse effect of food security.

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After understanding the individual nexus resources effects on livelihoods, we figured out the weighted average of nexus resources impact on livelihood (Figure 2e). It shows, human, physical and financial livelihoods are highly sensitive for sustainability of LWEF nexus resources. Pimentel, Whitecraft [2] reported that evidence on benefits of LWEF system management will

Table 8: Sensitivity estimation of LWEF nexus to livelihoods components

	Nexus resources			
Livelihoods	Land	Water	Food	Energy
Social component	0.705	0.799	0.891	0.794
Human component	0.778	0.696	0.781	0.698
Financial component	0.673	0.691	0.776	0.683
Physical component	0.678	0.696	0.751	0.688
Natural component	0.637	0.656	0.692	0.648

reduce costs and increases benefits for both human and nature, however a deeper understanding of the complex dynamics of these system, and their feedback mechanism are yet to be developed by scholars. This made significant contribution to nexus resources degradation which leads to vulnerability of local community.

Under such consequence, the rural poor community bare to the effect of uncoordinated management of nexus resources. This is due to lack of nexus concept emphasis on natural resources, and integrated management of sectors to be demand driven. Therefore, there is a need for paradigm shift from rigid and sectorial based nexus resources management for economic development and livelihoods improvement.

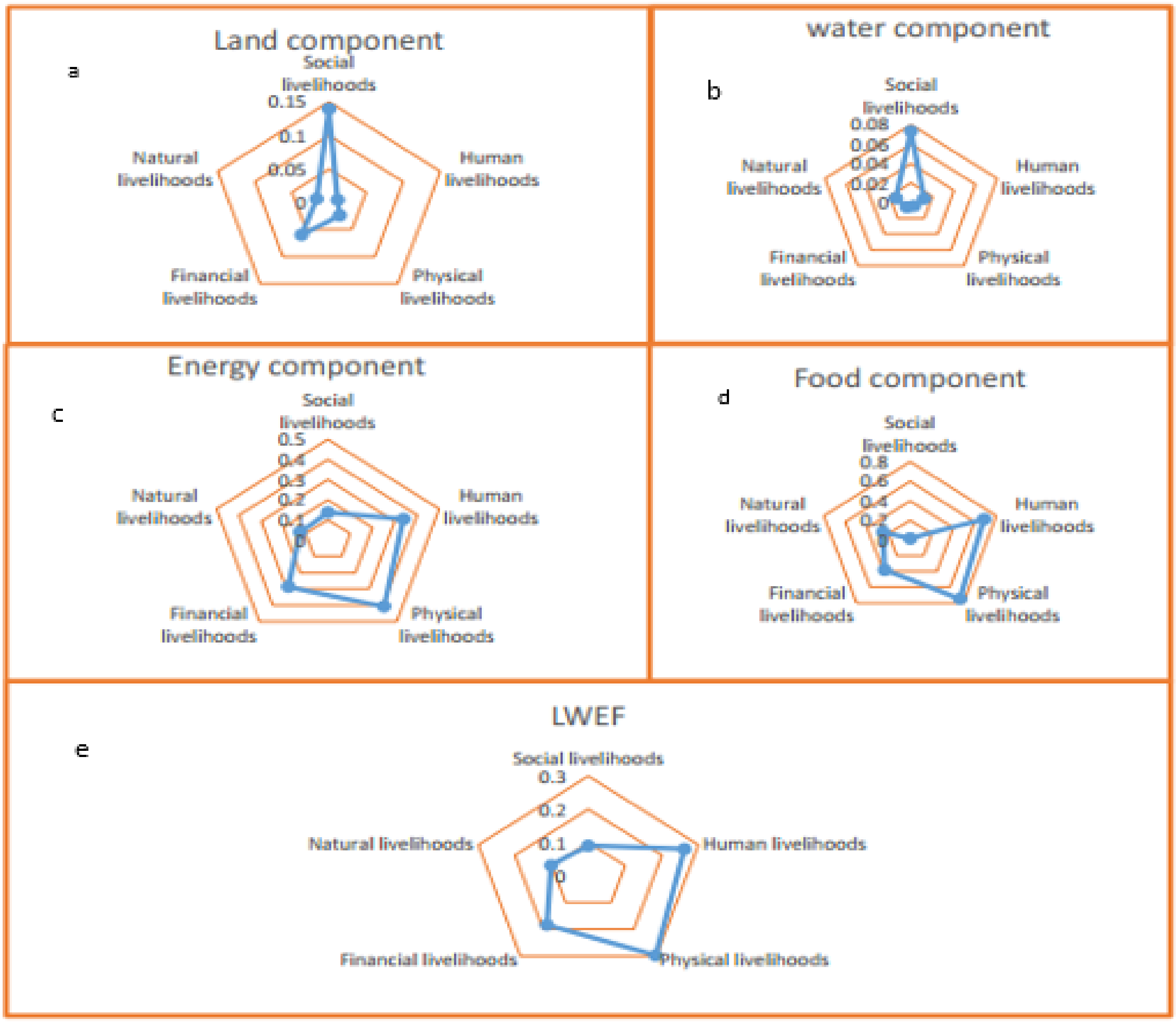

Figure 2: The spider web showing the weight of change of LWEF nexus resources indicators on livelihoods indicators.

4. Food First Verses Sustainable Livelihood Approach

Rapid population's growth, land degradation and, climatic variability are factors affecting increasing demand of water, energy and food for smallholder farmers [73], and this makes food production slow thereby declining productivity.

Food production without keeping the causal impact of land use, water and energy indeed significantly affects the total amounts of food produced, as well as related ecosystem disturbances. All the nexus resources are linked with the livelihoods of local community with varying extent (Figure 2). This indicates lack of understanding and trade-off among nexus resources and continues to have undesirable impacts on the livelihoods.

Approaches that focuses narrowly on one component of the LWEF nexus without paying attention to its synergies risks major unintended consequences [45]. For example, lack of energy in rural area, make local community to depend on forest tress, shrub wood and crop biomass as a sources of fire wood, which is becoming as silent degradation factors [74].

Therefore, singular approach, i.e. food centered approach cannot sustain livelihoods of local community, because cascading failures in one system may occur in other [46]. Since, failures in land use management lead to increase risk of failures in food productions and hydrological variability. This study discovered that the livelihoods of local community in

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the study area has been decreasing due to over dependence on fragmented land and rain-fed agriculture. This demonstrates that agricultural productivity without proper land use management and use of water and energy sources as inputs potentially affect food production.

Apparently, there is no effective identification of LWEF nexus resources sustainability to inform local community on resources variability events so that they can plan for coping and adapting to events. As shown in Table 4, the composite nexus resources index 0.083, conveyed to have adequate impacts on social, human, physical, financial and natural livelihoods indicators. The result shows the need for site specific planning, coordination and monitoring of nexus resources, is vitally important particularly for developing country like Ethiopia. Because, in the last four decades, the country has undergone dynamic land use change, which remarkably affecting water, energy and food systems. Individual focus on food production, may have impact in individual area of land, water and energy. However, the close relationships, interaction, and interdependences among these resources are usually not taken into consideration. Yet solving one challenge in managing one resources often creates challenge for other resources, therefore the better solution is managing nexus resources collectively using nexus approach.

5. Policy Implication

Understanding LWEF nexus sustainability necessitates a readily accessible institutional structure and make-up to build integrated policy. Issues on how to promote potential synergies and trade-off exists among nexus resources pose great challenge to natural resource management. Studies on LWEF nexus have found some useful measure to deal with nexus resources trade-off [6, 13]. As an example, land use change in expense of food production results in conflict between irrigation water and hydropower [5]. These seek policy that sustainably intensify food production and poverty reduction measure, which has profound implication for unique environmental management.

Policy is the main driving force for sustainable natural resources. In fact, food security and growing demand of nexus resources result in unsustainable use and management of nexus resources, which needs critical policy intervention. In order to address such issues, a range of policy measure could be investigated to safeguard and enhance LWEF nexus. These could involve regulation of land use change, reduction of inefficient use of water, expansion of alternative energy sources, reduction of biomass energy sources and use of technology-based approach. These efficiently resonate with sustainable livelihoods. Indeed, application of integrated management of nexus resources in line with livelihoods ensure environmental security. This above findings highlight implication for the sustainability of LWEF nexus resources in the context of food security.

Lastly but not the least, sustainability of LWEF nexus resources needs synergies in policy formulation when considerably food security links with livelihoods strategy. Local communities are often vulnerable to social, human, physical, financial and natural component of livelihoods to develop sustainable livelihoods strategy, the nexus approach has become useful tool for selecting and adopting site specific policy measure to enhance human-environment relation. These provide a strong evidence base for decision makers to ensure sustainable use of land, water, energy and food security for livelihoods.

6. Conclusions

Sustainability of LWEF nexus resources becoming a critical resource in global, national, regional and local scale, in particular. To address these challenges, in this paper we present quantification and linkage analysis for sustainable LWEF nexus resources and livelihoods. Using a case study design, we generated qualitative data through focus groups and interviews with households and key informants representing a broad cross-section of actors, including participant from land use, agriculture, water and energy sector.

It was found that LWEF nexus composite index for the study region is 0.083 indicating low index. This implies there is unsustainable consumption, use and management of nexus resources in the study area in which exploitation levels came to exceed resources' natural regeneration. Such overexploitation ultimately threatens the livelihoods and wellbeing of people who depend on these resources, and jeopardizes the health of overall environment.

Also LWEF nexus resources had positive correlation with livelihoods, thus social ($r \geq 0.8$, $P<0.01$), natural ($r \geq 0.3$, $P<0.05$) and physical ($r \geq 0.6$, $P<0.01$). Additionally, this study highlight that in the study area focusing on one nexus component have been encouraging in the majority of sector, i.e. food production for sustainable livelihood. In summary, the findings in this study imply that sustainable nexus resources can enhance livelihoods sustainability. Thus, government and non-governmental organization need to adopt collaborative resource management measures to improve the current nexus resources insecurity. This could be attained by strong evidence based policy to ensure sustainable use of nexus resources. In addition, the results provided by this study would serve as the foundation for future study, policy formulation and implementation.

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