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Assessment of rural livelihoods, health and wellbeing in Vhembe District Municipality, South Africa and Narok County, Kenya: A water-energy-food nexus perspective

Christina M. Botai [a,*], Joel O. Botai [b,c,d,**], Henerica Tazvinga [a], Miriam Murambadoro [a], Luxon Nhamo [c,e], Katlego P. Ncongwane [a], Michael G. Mengistu [a,c], Nosipho Zwane [a,b], Eric Wamiti [f], Silvester Mpandeli [e,h], Masinde Muthoni [d], Tafadzwanashe Mabhaudhi [c,g]

[a] South African Weather Service, Private Bag X097, Pretoria 0001, South Africa
[b] Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Hatfield, Pretoria 0028, South Africa
[c] Centre for Transformative Agricultural and Food Systems, School of Agriculture, Earth and Environmental Sciences, University of KwaZulu Natal, Pietermaritzburg 3209, South Africa
[d] Department of Information Technology, Central University of Technology, Free State Bloemfontein 9300, South Africa
[e] Water Research Commission of South Africa (WRC), Lynnwood Manor, Pretoria 0081, South Africa
[f] Kenya Water Institute, P.O. Box, Nairobi 60013–00200, Kenya
[g] Centre on Climate Change and Planetary Health, London School of Hygiene & Tropical Medicine, London, UK
[h] Faculty of Science, Engineering and Agriculture, University of Venda, Thohoyandou 0950, South Africa

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ABSTRACT

The Water-Energy-Food (WEF) nexus has become an integral component duly suited to enable sustainable development and an important tool to achieve and sustain various socioeconomic and environmental outcomes, including the 2030 Agenda for Sustainable Development Goals. The WEF nexus has become increasingly important in recent years as it can holistically address humankind's current triple challenges, including resource depletion, environmental degradation, and population growth. Socioeconomic factors such as increased population, economic development, and climate change patterns frequently induce unprecedented pressure on WEF resources. From the various climate change model simulations, the climate is likely to increase in the future, exacerbating the demand of the population to access the WEF resources and services. For effective resource planning and decision-making, the availability of WEF resources must be assessed under ongoing climate change. In this regard, this study assessed rural livelihoods, health, and wellbeing indicators within the WEF nexus framework in Vhembe District Municipality (VDM), South Africa, and Narok County, Kenya. The premise was to determine the drivers of livelihood changes by applying the analytic hierarchy process (AHP), a Multi-Criteria Decision-Making to understand the causal linkages between the WEF nexus resources and the sustainable livelihood indicators. Data collected from the literature review, questionnaire/group discussions, and field visit engagements were used to formulate and develop a matrix of indicators to assess livelihoods, health, and wellbeing. A correlation analysis based on the AHP was used to determine the linkages between WEF resources and sustainable livelihood indicators. The multivariate analysis used the correlation matrix to capture the pairwise degrees of relationship between WEF resources and sustainable livelihood indicators in the two study areas. The results show that the resources for sustainable livelihoods in VDM are more sustainable than those in Narok County. The Consistency Ratio values for Narok County and VDM were 0.046 and 0.067, respectively. The resulting composite index (0.143) classified both study sites under the lowly sustainable category. The results are important for informing policy formulation that guides timely interventions to balance socio-ecological systems.

* Corresponding author.
** Corresponding author at: Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Hatfield, Pretoria 0028, South Africa.
E-mail addresses: Christina.Botai@weathersa.co.za (C.M. Botai), u20820292@up.ac.za (J.O. Botai).

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1. Introduction

Water, energy, and food are complex resources with inextricable interdependences (IUCN ROWA, 2019). This is because the three resources are interlinked in an influential manner. Any change in one, coupled with climate- and social-related changes, also triggers stresses in the other two resources (Nhamo et al., 2018), particularly in energy-intensive, water-scarce, and food-deficient regions (IUCN ROWA, 2019). Understanding the complex and dynamic relationship between water, energy, and food and achieving effective sustainable resource management requires an integrated and systems approach like nexus planning. The nexus approach integrates and facilitates cross-sectoral management and governance, manages trade-offs, and enhances synergies between the three resources, considering the economic, social, and environmental factors related to them (Leck et al., 2015).

The Water-Energy-Food (WEF) nexus is now recognised as an integrated and transformative approach used in three-dimensional aspects to understand the dynamic processes and interrelationships between water, energy, and food for effective resource planning and management in an era of climate change (Nhamo et al., 2020a). In this regard, the first dimension of the WEF nexus approach (e.g., analytical tools and models) addresses interlinkages amongst the WEF resources based on qualitative and quantitative methods; the second dimension (e.g., a conceptual framework) streamlines understanding of WEF interlinkages, thereby promoting coherence in policy and decision-making processes, as well as highlighting the trade-offs and synergies between the three sectors; whereas the third dimension (a discourse) of the WEF nexus promotes cross-sectoral governance and cooperation (Albrecht et al., 2018; Nhamo et al., 2020a). In addition, considering that the security of the three resources is regarded as essential for sustainable development, the WEF nexus approach is also used to monitor the performance of Sustainable Development Goal (SDG) indicators related to human development and resource security) (Stephan et al., 2018), which have been set to strengthen the world's economic, environmental, and social sectors. The WEF nexus approach aids efforts towards (1) resource efficiency, (2) policy integration, (3) sustainability, (4) economic efficiency, (5) adaptation and resilience, (6) human and resource security, and (7) quality of environment and ecosystem services.

While the SDGs span a wide spectrum of themes and issues, the main goals that are directly linked to the WEF nexus paradigm are:

- Food security (SDG 2) is the goal of ending hunger by attaining food security, improving diet, and supporting sustainable agriculture.
- Good health and wellbeing (SDG 3) – ensure healthy lives and promote wellbeing for all age groups.
- Sustainable water management (SDG 6) – ensure availability and sustainable management of water and sanitation for all.
- Affordable and clean energy (SDG 7) – ensure access to affordable, reliable, sustainable and modern energy for all.
- Climate action (SDG 13) – take urgent action to combat climate change and its impacts.

Therefore, the WEF nexus tool is essential to evaluate and monitor the performance of these SDGs as linked to livelihoods, human health and wellbeing, and the sustainable production of the WEF resources. According to Krantz (2001), a livelihood can be described as the ability to obtain basic needs such as food, water, energy, and clothing. Tools such as the sustainable livelihoods framework can thus be integrated into studies that seek to understand the WEF at the community or household level. This is possible through an assessment of how people use their capabilities and assets (natural, physical, social, human, and financial) to sustain themselves and the shocks and stresses (risks) to their livelihoods (Carney, 2003). The approach also highlights the different conceptualisations of wellbeing and the different levels of vulnerability (De Satge, 2002). Furthermore, it provides avenues that can be used to develop interventions to optimize current and identify new sustainable livelihood strategies that are resilient to shocks and stresses.

Various definitions of wellbeing have been reported in the literature; however, none are unanimously accepted (Brown and Westaway, 2011). However, Alkire and Foster (2011), and Loveridge et al. (2020) argue that the concept of wellbeing entails multidimensional development, building on an understanding of what people need to participate and flourish in society. The scarcity of WEF resources, directly and indirectly, impacts human health, wellbeing, and livelihoods, particularly in rural communities. As a result, the WEF nexus becomes central to discussions regarding the development and subsequent monitoring of the related SDGs. Nonetheless, the assessment of these goals is often hampered by challenges, particularly in rural areas where it is difficult to access food, electricity, fuel, and sanitation.

The United Nations has been working towards setting new goals and targets for the post-2015 agenda aimed at achieving the long-term sustainable development of human society, thus including sustainable water use, energy use, and agricultural practices and promoting more inclusive economic development (United Nations, 2014). The organization recognises that eradicating poverty, adopting circular transformation, and sustaining and managing the natural resource base are the basic requirements for sustainable development. Currently, socio-economic factors such as population growth, economic development and the widely used linear economy model are causing unprecedented stress on the WEF resources. With climate change and population growth compounding resource depletion, demand for WEF resources will outstrip supply as we exceed planetary boundaries from the perspective of resource utilisation. Consequently, assessing the availability of WEF resources under climate change is essential for policy and decision-making to mitigate deficiencies in the three sectors.

Using the WEF nexus method, this study assessed rural livelihoods, human health, and wellbeing in the selected sites of the Vhembe District Municipality (VDM), Limpopo and Narok County, Mara River basins in South Africa and Kenya, respectively. It further assessed the availability of the WEF resources under climate change and variability to provide informed resource planning and decision-making. Furthermore, the study seeks to understand the dynamics and differences in the sustainability and management of WEF resources in the two distinct regions with different environmental, socio-economic, and cultural factors, thereby comprehending how access and use of WEF resources impact livelihoods. Correlation analysis was applied to examine the relationship between WEF resources and sustainable livelihood indicators. While the two study sites are distinct and located in different regions of Africa, both sites exhibit features that appear interesting to study within the WEF nexus frame. For instance, in East Africa, Narok County, Kenya, is interesting because of many activities, such as farming (livestock and crop), hydro-power station, forest, and game reserves. Similarly, the community in VDM in the southern Africa is rich in indigenous knowledge systems, and farming is mostly practiced under constrained water resources. The agricultural sector forms the fundamental dynamic and livelihood sustainable sector in both study sites. Generally, Narok County and Vhembe district share socio-economic (dis-)similarities and environmental challenges, including demographic compositions and skewed income distribution leading to significant unemployment, poverty, and inequality (Magombeyi et al., 2016; KNBS, 2019). Owing to the (dis-)similar features shared by Narok County and VDM, the two make ideal sites for investigating the connection and interaction of WEF resources and the uptake of renewable resources.

The main goal of the present study was to apply the WEF nexus framework to assess rural livelihoods, health, and wellbeing. The specific objectives formulated to help achieve the main goal include: a) determine the drivers of livelihood changes, b) undertake a literature review of the WEF nexus resources across the study sites, and c) use the Analytic Hierarchy Process (AHP), a Multi-Criteria Decision-Making (MCDM) framework to determine the causal linkages between the WEF nexus resources and the sustainable livelihood indicators. Overall, the present study makes two distinct scientific and practical contributions. From the scientific perspective, the results provide evidence and impetus to the methodology of integrating sustainable livelihoods within the WEF nexus framework. In this way, the results broaden the body of empirical evidence on the WEF nexus-livelihoods research domain. From a practical perspective, the linkages between the WEF nexus and the livelihood components could inform the revision or

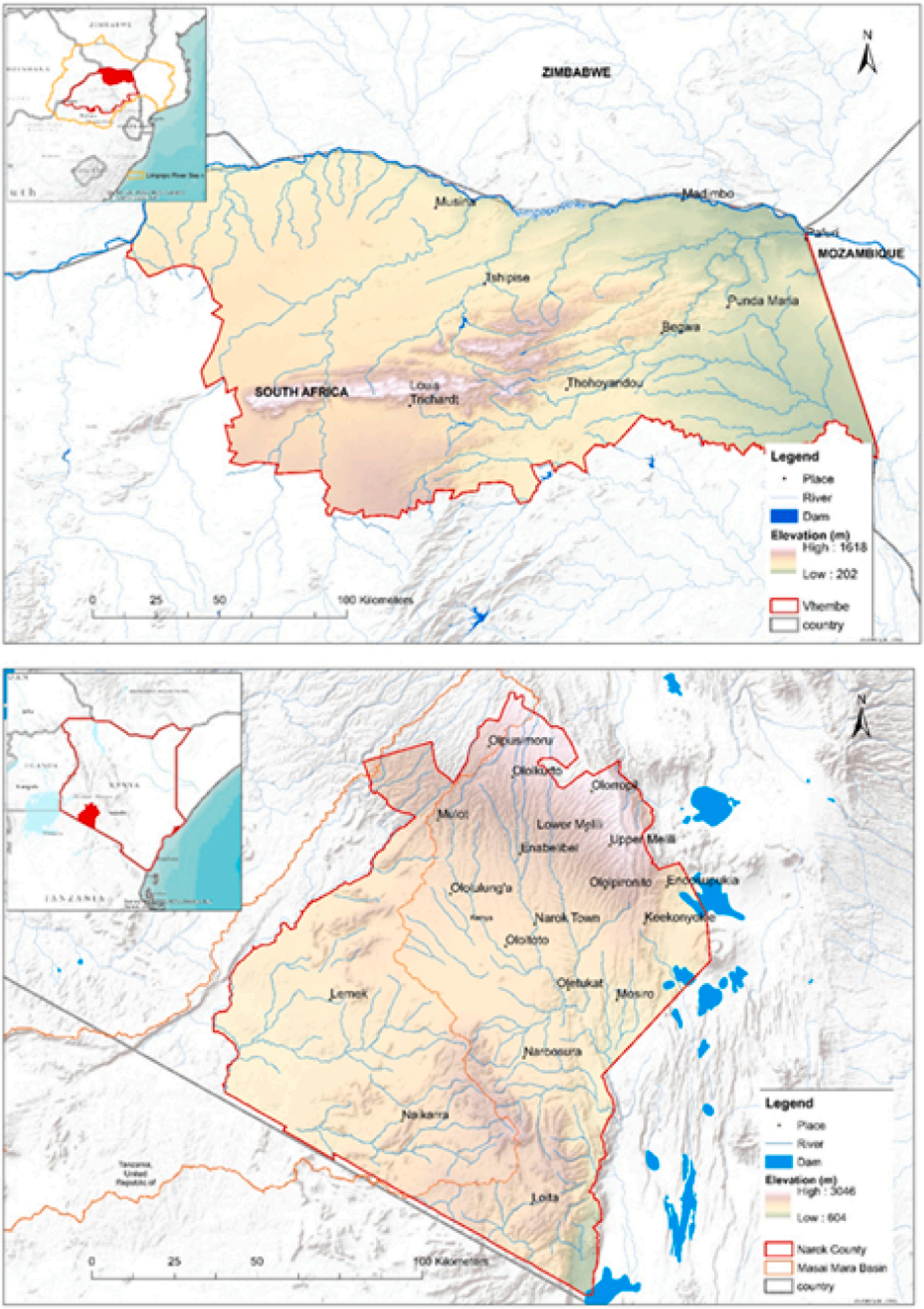

Fig. 1. Study sites: the top panel is the VDM in South Africa, and the bottom panel is the Narok County in Kenya.

formulation of new policy instruments vital for maintaining the balance between society and environment interrelations, especially in a changing environment.

2. Materials and methods

2.1. Study areas

The Vhembe District Municipality and Narok County (Fig. 1) were selected as the study sites for South Africa and Kenya, respectively. The VDM falls within the Limpopo Water Management Area and forms part of the Limpopo River Basin shared with Botswana, Zimbabwe, and Mozambique. The district falls within the subtropical climate, with a mean annual rainfall of 500 mm between October and March. Temperatures in VDM often reach a maximum of up to 40°C and a minimum of 10°C. The district also experiences recurrent floods, fires, and droughts, especially in Thulamela and Musina Local Municipality, which are semi-arid (Vhembe District Municipality. 2019). The area also has a high malaria prevalence; hence, health aspects will be integrated into the WEF nexus assessment to support communities and initiatives to mitigate the impacts of malaria.

Most rural areas in VDM experience frequent shortages of reliable water resources, with the community relying on unclean open water sources such as rivers, dams, and groundwater resources. Additionally, water security in the district is threatened by the expansion of mining activities that use a large proportion of the water. Other water challenges in the district include poor water quality, drying up of groundwater, limited funding for new and maintenance of water infrastructure, theft, and vandalism. About 66 % of households have access to electricity, while the rest rely on wood and other affordable energy sources. Most households in the district depend on rain-fed agriculture for their livelihoods (Kom et al., 2020), whilst some small farming cooperatives depend on rivers in the Limpopo catchment for irrigation.

Narok County covers parts of the Mau Forest Catchment Basin (MFCB), including the Mau Water Tower, also known as the Mau Forest or Mau Forest Complex. The Kenyan study site is part of the Mara River sub-basin in the west/southwest and the Ewaso Ng'iro South sub-basin in the north, central, and east of the delineated study area. Agricultural activities in Narok County include livestock rearing, maize and sorghum production, tea plantations, and dairy farming. Narok County has one of the highest rainfall amounts in Kenya, with mean annual rainfall averaging 750 mm, occurring from November to December (i.e., short rains season) and March to May (i.e., long rains season). Nonetheless, some areas in the higher altitude areas and the western parts of the study area on the Mau Forest Escarpment receive rainfall above 1000 mm per annum. Rainfall in the area is characterised by inter-annual and decadal rainfall variability, with frequent droughts occurring every 5–7 years influenced by the El Nino Southern Oscillation. Similarly, temperature increases as altitude decreases, with drier and warmer temperatures occurring in the northeast areas of the study area (USAID, 2019).

In Narok County, water quality and quantity have declined in recent years. This has been attributed to, among other things, rapid population growth, pollution, changes in land use and land cover as well as loss of biodiversity as evidenced by a sharp increase in the area covered by grassland and severe decline in forest cover, which enhances the water tower's ability to replenish springs and rivers (KWTA. 2015; 2016). Like the VDM site, rain-fed agriculture dominates Narok County, with households growing crops such as maize, onions, and legumes and commercial farmers growing similar crops, such as sunflower and cabbage. Energy supply in Narok is mainly from hydro-power plants, e.g., the Sondu-Miriu hydro-power plant on the Sondu River; however, some households have no access to grid electricity and use charcoal, solar, kerosene, and firewood. The use of charcoal and firewood has resulted in widespread deforestation.

2.2. Data collection and analysis

Data used in this study was collected by using a combination of quantitative and qualitative approaches. These methods are imperative since key stakeholders, including researchers, are given a chance to offer comprehensive and insightful information about WEF resources and the implications of inadequate and limited accessibility of such resources—which serve as the foundation for sustainable livelihood. In particular, data were collected using pertinent literature reviews, questionnaires/focused group discussions, and observations collected during field visits. Generally, data associated with the WEF nexus is technical and complicated (Adom et al., 2022). Hence, its collection requires the involvement of sources with professional experience and knowledge of the WEF systems within the study site. In this regard, purposive sampling, a technique that involves the selection of stakeholders and participants based on their roles (e.g., managers, decision-makers, scientific researchers and advisers, or community leaders), as well as their knowledge and experiences of water, energy and food systems and pertinent issues relating to livelihood, health and wellbeing of the societies in both Narok and VDM was applied. Consequently, the selected stakeholders and participants included farmers, government officials, academic institutions, professional bodies, community-based organizations, private water, energy, food production bodies, and local communities. About 120 participants in each study site contributed towards the physical engagements, and approximately 50 respondents participated in the online survey.

The WEF nexus literature review was conducted to select sustainable livelihoods and health and wellbeing indicators for each study site. These indicators were identified and refined to produce a small set of keywords that embody the interactions among the WEF nexus resources and their impact on rural livelihoods (Pahl-Wostl, 2019; Abubakar, 2021; Wolde et al., 2022). The selected indicators were adopted in the current study as they support monitoring, evaluation, and sustainable use of WEF resources to achieve SDGs such as 2, 3, 6, 7, and 13. These indicators, given in Table 1, were used to develop a questionnaire for the online survey and in-person group discussions. The questionnaire comprised the following parts: a) effects of population growth and urbanization; b) participants' perception of climate change and the relevant disasters; c) poverty and unemployment; and d) weak governance systems. The response to the survey was structured using a scale of 1 – 5, where 1 – Strongly Disagree; 2 – Disagree; 3 – Neither Agree nor

Table 1
Sustainable livelihood, human health, and wellbeing metrics.

Drivers of livelihood changes	Subjective Indicators
Population growth and urbanisation	• Population growth rate • Rate of urbanisation and migration • Land use and land-use change • Land productivity • The proportion of water used per sector • Access to sanitation
Climate change	• Climate risks and associated impacts (Changes in weather and climate variables such as rainfall and temperature) • Exposure and sensitivity to risks • The proportion of rainfed agriculture
Poverty and unemployment	• Poverty levels • Unemployment levels • Accessibility and affordability of nutritious food • Malnutrition and mortality • Food insecurity
Weak Governance Systems	• Poor resource planning and management • Existing policies and other policy instruments • Supportive government institutions and structures • Wellbeing and governance • Access to Water-Energy-Food resources • Access to clean drinking water at the household level • Water quality

Disagree; 4 – Agree, and 5 – Strongly Agree. During focused group discussion and interviews with key informants, the participants highlighted some of the complex interlinkages between nexus components, what and how climate hazards had affected them, and how they cope, including the role of indigenous knowledge in understanding changes in weather and climate and recommendations on what can be done to support climate change adaptation as well as water, energy, and food security in the study sites.

2.2.1. Calculation and normalisation of water-energy-food and livelihood indices

The responses from the survey and information gathered during group discussions and field visits were grouped based on relevancy, and a set of indicators for WEF, sustainable livelihood, human health, and wellbeing were developed. The analytic hierarchy process (AHP), a Multi-Criteria Decision-Making (MCDM) framework proposed by Saaty, (1977); (1987); (1990); (2016), and the pairwise comparison matrix (PCM) technique were used to analyse the data. According to Kumar et al. (2017) and references therein, the AHP technique is the most known MCDM technique used to structure and solve complex management decision issues, including selecting indicators relating to multi-criteria and multi-alternatives. This structural tool is achieved through pairwise comparisons, a process that facilitates the comparison of two indicators using Saaty's scale (Baswaraj et al., 2018). In this study, the PC matrix analysis in the AHP was carried out using the methodology described in Nhamo et al. (2019). Theoretically, it is assumed that a PCM in AHP is represented by a matrix given in Eq. 1,

$$A = [a_{ij}]_{n\times n} \tag{1}$$

In Eq. 1, the entry a_{ij} for $i, j = 1, 2, 3, \ldots, n$, expresses the expert's subjective knowledge or judgement based on the associated intensity of a compared entity i over another compared entity, j.

The eigenvector method is used to derive priority vector $w = (w_1, w_2, w_3, \ldots, w_n)$ from the PCM matrix A (Eq. 1). The PCM estimates the priority ranking in the AHP, where each element is evaluated with the rest of all other elements at a specific hierarchical level. Consequently, the maximum value, λ, and its corresponding vector w are calculated using the following Eq. 2 (Nhamo et al., 2019),

$$Aw = \lambda w \tag{2}$$

Applying Saaty's scaling rations (as reported by e.g., Baswaraj et al., 2018), a PCM matrix A of n criteria with elements a_{ij}can be determined in the order of $n \times n$. This is a reciprocal matrix and can be expressed as,

$$a_{ij} = \frac{1}{a_{ij}} \tag{3}$$

The generated matrix is normalised as a matrix b with elements b_{ij} and can be expressed as

$$b_{ij} = \frac{a_{ij}}{\sum_{j=1} n a_{ij}} \tag{4}$$

The weights are calculated using Eq. (5)

$$w_i = \frac{\sum_{j=1} n b_{ij}}{\sum_{i=1} n \sum_{j=1} n b_{ij}}, \quad i, j = 1, \quad 2, \quad 3, \ldots, \quad n \tag{5}$$

The integrated composite index is expressed as the weighted average of the indices. This index represents an indicator of the general performance of resource management within a system of interest. On the other hand, the consistency ratio CR which is a key component of a PCM is often expressed in terms of the Consistency Index (hereafter CI), and Random Index (RI) as follows,

$$CR = \frac{CI}{RI} \tag{6}$$

In Eq. (6), CI is expressed as

$$CI = \gamma - \frac{n}{n-1} \tag{7}$$

In Eq. (7), γ corresponds to the main eigenvalue, whereas n represents the number of criteria/sub-criteria in each PCM. Detailed information on the computation of the PCM can be found in Nhamo et al. (2018) and Mabhaudhi et al. (2019).

In the current research study, a matrix comprising the developed indicators was established, where individual indicators were intercompared and assigned a value based on the AHP within the (MCDM framework. The AHP was utilized to integrate and build numerical correlations among the WEF nexus indicators (including drivers of livelihood changes) and calculate indices. As reported in Mabhaudhi et al. (2019) and Nhamo et al. (2020b), the AHP comparison matrix is calculated by comparing two indicators at a time using Saaty's scale (Saaty, 1977), with the PC matrix scale ranging from the lowest of 1/9 up to 9. In this case, a range of one to nine signifies a significant connection, whereas a range of 1/3–1/9 represents a minor relationship. A score of nine implies that the row element is nine times more significant than the column factor. A score of 1/9, on the other hand, suggests that the row indication is 1/9 less relevant than the column indicator. When both the column and row indicators are equally important, they are given a rating of 1. The PCM was used to construct numerical correlations between the indicators. Only pairwise respondents whose CR of up to 10 % was used to generate the pairwise comparison matrix. The scaling in Table 2 was used to classify the performance of WEF nexus indicators in the two study areas. The spider diagrams were generated to assess the performance of the sustainable livelihood metrics. In addition, the linkages between the sustainable livelihood indicators and the WEF resources were independently assessed for each indicator of the WEF components.

Correlation analysis was undertaken to determine how the WEF resources are linked to sustainable livelihood indicators. In multivariate analysis, a correlation matrix can capture the pairwise degrees of relationship between, for instance, in this study, the WEF resources and sustainable livelihood indicators (Pham-Gia and Choulakian, 2014). For this purpose, the association between the WEF nexus and sustainable livelihoods constructs was computed using their respective composite weights based on Pearson correlation.

3. Results and discussion

3.1. Comparative analysis of sustainable livelihood indicators

This study provides the impact of climate change using specific climate-sustainable indicators related to the water, energy, and agriculture sectors. Tables 3 and 4 show the pairwise comparison matrix formulated using selected sustainable climate indicators based on local knowledge gathered during stakeholders' engagement/questionnaire administration in Narok County and VDM, respectively. The climate sustainable indicators comprised of 1) population and urbanisation - En1; 2) Climate Change - En2; 3) Risks-vulnerability - R1x; 4) Exposure-sensitivity - R2x; 5) wellbeing & governance - I; 6) Health-water quality - H1; and 7) Health-Malnutrition - H2. Following Nhamo et al. (2020b), the diagonal indicators are assigned the value of 1.00 to represent values

Table 2
WEF nexus indicators performance classification categories. (Nhamo et al., 2020b).

Indicator	Unsustainable	Marginally sustainable	Moderately sustainable	Highly sustainable
WEF Nexus composite index	0–0.09	0.1–0.2	0.3–0.6	0.7–1

Table 3
Pairwise comparison matrix of sustainable livelihood, health, and wellbeing indicators for Narok County. Definition of abbreviations: En1 – population & urbanisation; En2 – Climate Change; R1x – Risks-vulnerability; R2x – Exposure-sensitivity; I – wellbeing & governance; H1 – Health-water quality; H2 – Health-Malnutrition.

Indicators	En1	En2	R1x	R2x	I	H1	H2
En1	1.00	1.05	1.05	1.00	0.96	0.93	0.93
En2	0.95	1.00	0.93	0.90	0.88	0.95	0.86
R1x	0.95	1.07	1.00	0.82	0.82	0.90	0.94
R2x	1.00	1.11	1.22	1.00	0.86	0.82	0.82
I	1.04	1.14	1.22	1.16	1.00	0.89	0.93
H1	1.08	1.06	1.12	1.22	1.13	1.00	1.00
H2	1.08	1.16	1.06	1.22	1.08	1.00	1.00

Table 4
Pairwise comparison matrix of sustainable livelihood, health, and wellbeing indicators for VDM.

Indicators	En1	En2	R1x	R2x	I	H1	H2
En1	1.00	1.44	1.00	0.69	1.00	0.69	1.00
En2	0.69	1.00	0.48	0.41	0.48	0.48	0.44
R1x	1.00	2.08	1.00	0.35	0.44	0.44	0.83
R2x	1.44	2.47	2.88	1.00	0.83	0.58	0.83
I	1.00	2.08	2.26	1.0	1.00	0.83	1.57
H1	1.44	2.08	2.26	1.73	1.20	1.00	1.89
H2	1.00	2.26	1.20	1.20	0.64	0.53	1.00

of equal importance. Only the upper half of the matrix elements was populated, and the lower triangle represents the reciprocals and is therefore omitted. The values of the paired matrix range from the lowest of 0.82 to the highest of 1.22 for Narok County and from 0.35 to 2.88 for VDM.

The results for the normalized values of sustainable livelihoods, human health, and wellbeing indicators for Narok County are presented in Table 5. The values range from the lowest value of 0.112 for Risks-vulnerability (R1x) and Exposure-sensitivity (R2x) to the highest value of 0.168 for wellbeing & governance (I) and Health-water quality (HI). The second highest score is 0.166, observed between Exposure-sensitivity (R2x) and Health-water quality (HI) as well as Exposure-sensitivity (R2x) and Health-Malnutrition (H2). The result shows a corresponding Consistency Ratio (CR) value of 0.046 (or 4,6 %) and a composite integrated WEF nexus index of 0.143. In contrast to Narok County's normalized values, the highest value for VDM is 0.260, which corresponds to the Exposure-sensitivity (R2x) and Health-water quality (HI) paired sustainable indicators, followed by Exposure-sensitivity (R2x) and Risks-vulnerability (R1x) paired indicators at 0.256. Risks-vulnerability (R1x) and Climate Change (En2) and Exposure-sensitivity (R2x) and Risks-vulnerability (R1x) have the lowest values of 0.04 and 0.05, respectively (see results in Table 6). VDM has a CR value of 0.067, which is 0.021 higher than Narok County. The results suggest that water resources in Vhembe District are more sustainable than those in Narok County. The CR values for both study sites are within the accepted range according to the classification in Nhamo et al. (2020b).

The normalized data of the various variables for each study area was presented in the form of spider graphs for easy visualization and understanding of the variables' interrelations, as well as the different significance of resource indicators and their ranking. In this regard, low weights indicate less significance, whereas higher weights reflect higher importance. The spider or radar chart for sustainable livelihoods, human health, and wellbeing indicators in Narok County is shown in Fig. 2. Fig. 2 illustrates that wellbeing & governance and Health-water quality, Exposure-sensitivity, and Health-Malnutrition are the most related having a score of 0.23. Other closely related indices include Risk-vulnerability, wellbeing, and governance.

Fig. 3 depicts a spider diagram for the performance of indicators for sustainable livelihoods, human health, and wellbeing in VDM. The weighting values range between 0.05 and 0.32. Compared to other sustainable livelihood indicators, the results show that exposure sensitivity (R2x) and risk vulnerability (R1x) have the greatest impact. The health-malnutrition (H2) indicator is ranked second. Furthermore, Fig. 3 shows that Climate change (En2) has less impact on the sustainable livelihood in VDM, with Health-Water quality (H1) and Wellbeing & Governance having a fair impact.

3.2. Assessing the WEF resources and sustainable livelihood indicators

3.2.1. Water and sustainable livelihood indicators

According to the pairwise matrix values (Table 7), the sustainable livelihood indicators are high, with a value of 1.55, when wellbeing and governance (I) are contrasted with population and urbanisation (En1) as well as climate change (En2). The lowest paired matrices correspond to H2/R1x (risks-vulnerability/health-malnutrition) and W2/R1x (water productivity/risks-vulnerability), given by the value of 0.64. These results corroborate information gathered through focused group discussions. In particular, participants in Narok indicated that many rivers in the county had been affected by population growth and the clearing of forests due to the increased number of people moving to urban areas. The Ogiek community in the Mau Forest was among the most affected communities as they were nomads who now had to travel long distances to get water for their livestock. The men usually leave women and children to fend for themselves; however, the wellbeing of these families was more vulnerable as other livelihood activities, such as beekeeping, had also been affected by deforestation.

Table 8 shows the results for the normalized values of water and livelihood indicators. The lowest value is 0.70, observed in three sub-indicator pairs that include Wellbeing & Governance (I)/ Health-Malnutrition (H2); Health-Malnutrition (H2)/ risks-vulnerability (R1x) and Water productivity (W2)/ Risks-vulnerability (R1x). The highest value is observed for the Wellbeing & Governance (I) and population & urbanisation (En1) as well as Wellbeing & Governance (I) and Climate Change (En2) pairs. The corresponding CR value is 0.053 (e.g., 5.3 %), with a weighted average of 0.111.

The impacts of water resources on sustainable livelihood indicators are assessed based on a spider diagram shown in Fig. 4. The selected metrics for the water component of the WEF resources are water access

Table 5
Normalized pairwise comparison matrix and composite index for Narok County.

Indicators	En1	En2	R1x	R2x	I	H1	H2	Index
En1	0.141	0.138	0.138	0.137	0.143	0.143	0.143	0.141
En2	0.134	0.132	0.123	0.123	0.131	0.146	0.133	0.132
R1x	0.134	0.141	0.132	0.112	0.122	0.138	0.145	0.132
R2x	0.141	0.146	0.160	0.137	0.128	0.127	0.127	0.138
I	0.146	0.150	0.160	0.158	0.148	0.137	0.143	0.149
H1	0.152	0.139	0.147	0.166	0.168	0.154	0.154	0.154
H2	0.152	0.153	0.140	0.166	0.160	0.154	0.154	0.154
			CR = 0.046					$\sum = 1$
Composite integrated index (weighted average)								0.143

Table 6
Normalized pairwise comparison matrix and composite index for VDM.

Indicators	En1	En2	R1x	R2x	I	H1	H2	Index
En1	0.132	0.108	0.090	0.105	0.179	0.152	0.132	0.128
En2	0.091	0.075	0.043	0.062	0.086	0.106	0.058	0.074
R1x	0.132	0.155	0.090	0.053	0.079	0.097	0.110	0.102
R2x	0.190	0.184	0.259	0.152	0.149	0.127	0.110	0.167
I	0.132	0.155	0.204	0.183	0.179	0.183	0.208	0.178
H1	0.190	0.155	0.204	0.263	0.215	0.219	0.249	0.214
H2	0.132	0.169	0.108	0.183	0.114	0.116	0.132	0.136
CR = 0.067								$\sum = 1$
Composite integrated index (weighted average)								0.143

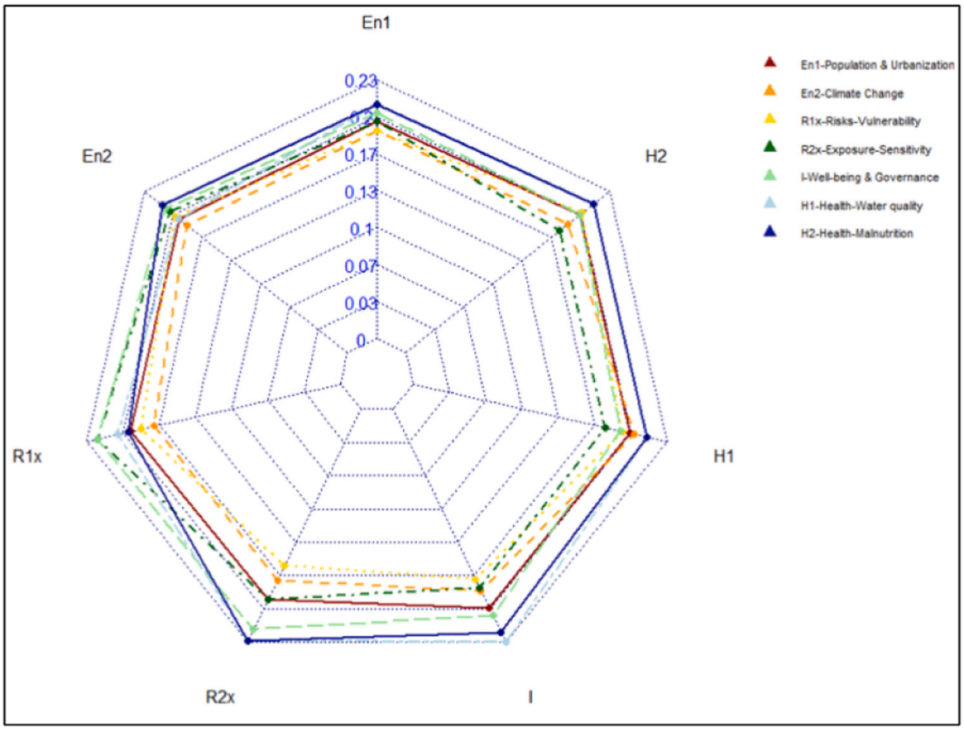

Fig. 2. Performance of sustainable livelihoods, human health and wellbeing indicators for Narok County.

(W1 in royal blue) and water productivity (W2 in purple). The impacts of these water indicators are assessed based on their position within the spider graph against the sustainable livelihoods, human health, and wellbeing indicators. As given in Fig. 4, the weighting values for water productivity range from a low weighting value of 0.13 for health–malnutrition (H2) to a high weighting value of 0.20 for water access (W1). In general, the results indicate that the impact of water productivity on sustainable livelihoods in Narok County is mostly high for the following indicators: population growth and urbanisation, water access, and vulnerability and risks. In terms of water access, the impacts are high on health-water quality, health–malnutrition, population and urbanisation, and exposure sensitivity. The general performance of water and sustainability livelihood indicators suggests a need to improve water access to match population growth and urbanisation in Narok County. This resource constraint was determined to be felt by key institutions such as schools, hospitals, and local retail shopping centers. Governance actors need to be more proactive in enforcing water by-laws and reducing pollution of rivers in the county and the country in general.

3.2.2. *Energy and sustainable livelihood indicators*

The paired matrix considered in this section includes accessibility and productivity drivers of change for energy resources, a component of the WEF nexus resources. Based on the results presented in Table 9, the pairwise matrix values range between 0.64 and 1.93. The highest value of 1.93 corresponds to H2/R1x (health-malnutrition/risks-vulnerability) and R1x/H2 (risks-vulnerability/health-malnutrition) sustainable indicators. The pairwise matrix between most sustainable livelihood, health and wellbeing, and energy indicators depicts values close to unity, suggesting that the paired indicators are worthy and equally important in Narok County.

For VDM, the results presented in Table 10 show that the pairwise matrix ranges between 0.58 and 1.73. The highest value of 1.73 corresponds to the following set of paired sustainable indicators: wellbeing and governance (I) to climate change (En2), risks-vulnerability (R1x), exposure-sensitivity (R2x); health-water quality (H1) to climate change (En2), risks-vulnerability (R1x), exposure-sensitivity (R2x); Health-Malnutrition (H2) to climate change (En2), risks-vulnerability (R1x), exposure-sensitivity (R2x), health-water quality (H1); energy-access (E1) to climate change (En2), risks-vulnerability (R1x), exposure-sensitivity (R2x), wellbeing and governance (I) and health-water quality (H1); energy productivity (E2) to climate change (En2), exposure-sensitivity (R2x), wellbeing and governance (I) and health-water quality (H1). The lowest value of 0.58 corresponds to the paired sustainable indicators: climate change (En2) to wellbeing and governance (I), health-water quality (H1), Health-Malnutrition (H2), energy-access (E1) and energy productivity (E2); risks-vulnerability (R1x) to exposure-

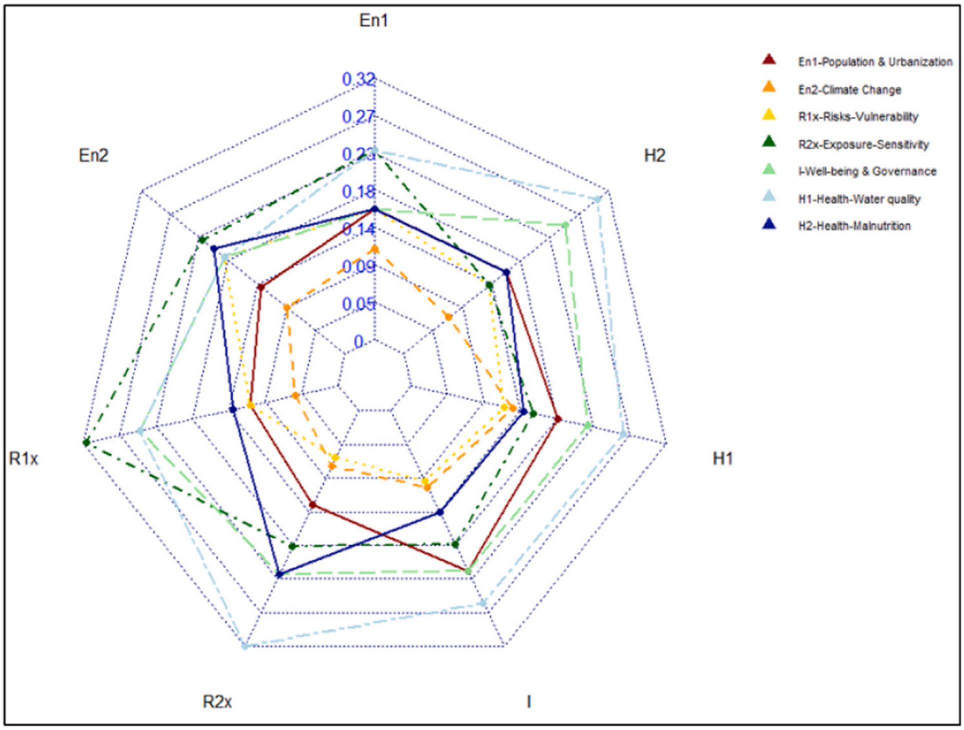

Fig. 3. Performance of sustainable livelihoods, human health and wellbeing indicators for VDM.

Table 7
Pairwise comparison matrix and water indicators for Narok County. W1 – Water access and W2 – Water productivity.

Indicators	En1	En2	R1x	R2x	I	H1	H2	W1	W2
En1	1.00	1.25	1.25	1.00	1.55	1.25	1.25	1.25	1.00
En2	0.80	1.00	1.00	0.80	1.55	1.25	1.25	1.00	1.25
R1x	0.80	1.00	1.00	1.00	0.80	0.80	0.64	0.80	0.64
R2x	1.00	1.25	1.00	1.00	1.55	1.25	1.25	1.00	1.25
I	0.64	0.64	1.25	0.64	1.00	1.00	1.38	1.25	1.00
H1	0.80	0.80	1.25	0.80	1.00	1.00	1.00	0.80	1.00
H2	0.80	0.80	1.55	0.80	0.72	1.00	1.00	0.80	1.25
W1	0.80	1.00	1.25	1.00	0.80	1.25	1.25	1.00	0.80
W2	1.00	0.80	1.55	0.80	1.00	1.00	0.80	1.25	1.00

Table 8
Normalized pairwise comparison matrix and water indicators and the composite indices for Narok County.

Indicators	En1	En2	R1x	R2x	I	H1	H2	W1	W2	index
En1	0.131	0.146	0.112	0.127	0.155	0.127	0.127	0.136	0.109	0.130
En2	0.105	0.117	0.090	0.102	0.155	0.127	0.127	0.109	0.136	0.119
R1x	0.105	0.117	0.090	0.127	0.080	0.082	0.066	0.088	0.070	0.092
R2x	0.131	0.146	0.090	0.127	0.155	0.127	0.127	0.109	0.136	0.128
I	0.084	0.075	0.112	0.082	0.100	0.102	0.141	0.136	0.109	0.105
H1	0.105	0.094	0.112	0.102	0.100	0.102	0.102	0.088	0.109	0.102
H2	0.105	0.094	0.140	0.102	0.073	0.102	0.102	0.088	0.136	0.105
W1	0.105	0.117	0.112	0.127	0.080	0.127	0.127	0.109	0.087	0.110
W2	0.131	0.094	0.140	0.102	0.100	0.102	0.082	0.136	0.109	0.111
			CR = 0.053							$\sum = 1$
Composite integrated index (weighted average)										0.111

sensitivity (R2x), wellbeing and governance (I), health-water quality (H1), Health-Malnutrition (H2), and energy-access (E1); exposure-sensitivity (R2x) to wellbeing and governance (I), health-water quality (H1), Health-Malnutrition (H2), energy-access (E1), and energy productivity (E2); wellbeing and governance (I) to energy-access (E1) and energy productivity (E2); and health-water quality (H1) to Health-Malnutrition (H2), energy-access (E1), and energy productivity (E2).

The results reflect that the pairwise matrix among sustainable livelihood, health and wellbeing, and energy indicators are close to unity values, suggesting that the paired indicators are almost equally important in VDM. The respondents in VDM indicated that energy access and productivity are impacted by population and urbanisation, climate change, and demand from various sectors as the economy grows.

Similarly, Table 11 depicts results for the normalized pairwise matrix for Narok County for the energy indicators as constrained by livelihood, human health, and being indicators. In this case, the normalized values range from lower values of 0.070 for R1x/E2 (risks – vulnerability/energy productivity) to 0.146 for En1/E1 (population and urbanisation/

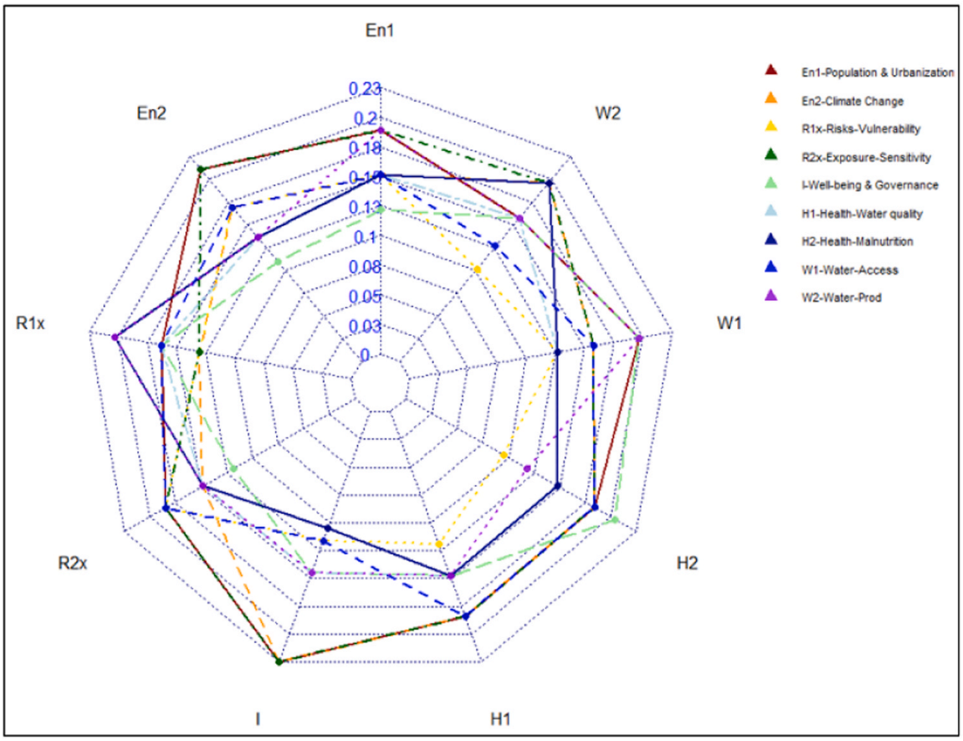

Fig. 4. Performance of sustainable livelihood indicators against water indicators – Narok County.

Table 9
Pairwise comparison matrix of sustainable and water indicators for Narok County, where E1 – energy access and E2 – energy productivity.

Indicators	En1	En2	R1x	R2x	I	H1	H2	E1	E2
En1	1.00	1.25	1.25	1.00	1.55	1.25	1.25	1.25	1.00
En2	0.80	1.00	1.00	0.80	1.25	1.00	1.00	0.80	1.00
R1x	0.80	1.00	1.00	0.80	0.64	0.64	0.52	0.64	0.64
R2x	1.00	1.25	1.25	1.00	1.25	1.00	1.00	0.80	1.00
I	0.64	0.80	1.55	0.80	1.00	1.00	1.55	1.25	1.00
H1	0.80	1.00	1.55	1.00	1.00	1.00	1.00	0.80	1.00
H2	0.80	1.00	1.93	1.00	0.64	1.00	1.00	1.00	1.55
E1	0.80	1.25	1.55	1.25	0.80	1.25	1.00	1.00	1.00
E2	1.00	1.00	1.55	1.00	1.00	1.00	0.64	1.00	1.00

Table 10
Pairwise comparison matrix of sustainable and water indicators for VDM, where E1 – energy access and E2 – energy productivity.

Indicators	**En1**	**En2**	**R1x**	**R2x**	**I**	**H1**	**H2**	**E1**	**E2**
En1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
En2	1.00	1.00	1.00	1.00	0.58	0.58	0.58	0.58	0.58
R1x	1.,00	1.00	1.00	0.58	0.58	0.58	0.58	0.58	1.00
R2x	1.00	1.00	1.73	1.00	0.58	0.58	0.58	0.58	0.58
I	1.00	1.73	1.73	1.73	1.00	1.00	1.00	0.58	0.58
H1	1.00	1.73	1.73	1.73	1.00	1.00	0.58	0.58	0.58
H2	1.00	1.73	1.73	1.73	1.00	1.73	1.00	1.00	1.00
E1	1.00	1.73	1.73	1.73	1.73	1.73	1.00	1.00	1.00
E2	1.00	1.73	1.00	1.73	1.73	1.73	1.00	1.00	1.00

energy access). The corresponding CR value is 0.056 (5,6 %). It is within the accepted range, as per the classification in Nhamo et al. (2020b), while the composite integrated index (weighted average) across sustainable and energy indicators is 0.111. For VDM, the results for the normalized pairwise matrix for the energy indicators are shown in Table 12. The normalized values range from between 0.047 for risks – vulnerability/exposure-sensitivity (R1x/Rx2) and 0.188 for En1/E1 energy access/wellbeing and governance (E1/I) and energy productivity/wellbeing and governance (E2/I) paired with sustainability indicators for livelihood, human health and wellbeing. The corresponding CR value is 0.038 (3,8 %), within the accepted range, while the composite integrated index (weighted average) across the sustainable and energy indicators is 0.111.

The impacts of energy access (E1) and productivity (E2) on sustainable livelihoods, human health, and wellbeing indicators on the spider diagram - represented by the royal blue and purple colours, respectively, are depicted in Fig. 5. As shown in Fig. 5, the impacts of energy security are less on wellbeing and governance (I) and relatively higher for population growth and urbanisation (En1) and energy productivity (E2). This implies that there is a need for decisions or

Table 11
Normalized pairwise comparison matrix of sustainable and energy indicators and the composite indices for Narok County, where E1 – energy access and E2 – energy productivity.

Indicators	En1	En2	R1x	R2x	I	H1	H2	E1	E2	Index
En1	0.131	0.131	0.099	0.116	0.170	0.136	0.139	0.146	0.109	0.131
En2	0.105	0.105	0.079	0.093	0.136	0.109	0.112	0.094	0.109	0.105
R1x	0.105	0.105	0.079	0.093	0.071	0.071	0.058	0.075	0.070	0.081
R2x	0.131	0.131	0.099	0.116	0.136	0.109	0.112	0.094	0.109	0.115
I	0.084	0.084	0.123	0.093	0.109	0.109	0.173	0.146	0.109	0.115
H1	0.105	0.105	0.123	0.116	0.109	0.109	0.112	0.094	0.109	0.109
H2	0.105	0.105	0.153	0.116	0.071	0.109	0.112	0.117	0.169	0.117
E1	0.105	0.131	0.123	0.144	0.088	0.136	0.112	0.117	0.109	0.118
E2	0.131	0.105	0.123	0.116	0.109	0.109	0.072	0.117	0.109	0.110
			CR = 0.056							$\sum = 1$
Composite integrated index (weighted average)										0.111

Table 12
Normalized pairwise comparison matrix of sustainable and energy indicators and composite indices for VDM, where E1 – energy access and E2 – energy productivity.

Indicators	**En1**	**En2**	**R1x**	**R2x**	**I**	**H1**	**H2**	**E1**	**E2**	**Index**
En1	0.111	0.079	0.079	0.082	0.109	0.101	0.137	0.145	0.137	0.109
En2	0.111	0.079	0.079	0.082	0.063	0.058	0.079	0.084	0.079	0.079
R1x	0.111	0.079	0.079	0.047	0.063	0.058	0.079	0.084	0.137	0.082
R2x	0.111	0.079	0.137	0.082	0.063	0.058	0.079	0.084	0.079	0.086
I	0.111	0.137	0.137	0.142	0.109	0.101	0.137	0.084	0.079	0.115
H1	0.111	0.137	0.137	0.142	0.109	0.101	0.079	0.084	0.079	0.109
H2	0.111	0.137	0.137	0.142	0.109	0.174	0.137	0.145	0.137	0.136
E1	0.111	0.137	0.137	0.142	0.188	0.174	0.137	0.145	0.137	0.145
E2	0.111	0.137	0.079	0.142	0.188	0.174	0.137	0.145	0.137	0.139
			CR = 0.038							$\sum = 1$
Composite integrated index (weighted average)										0.111

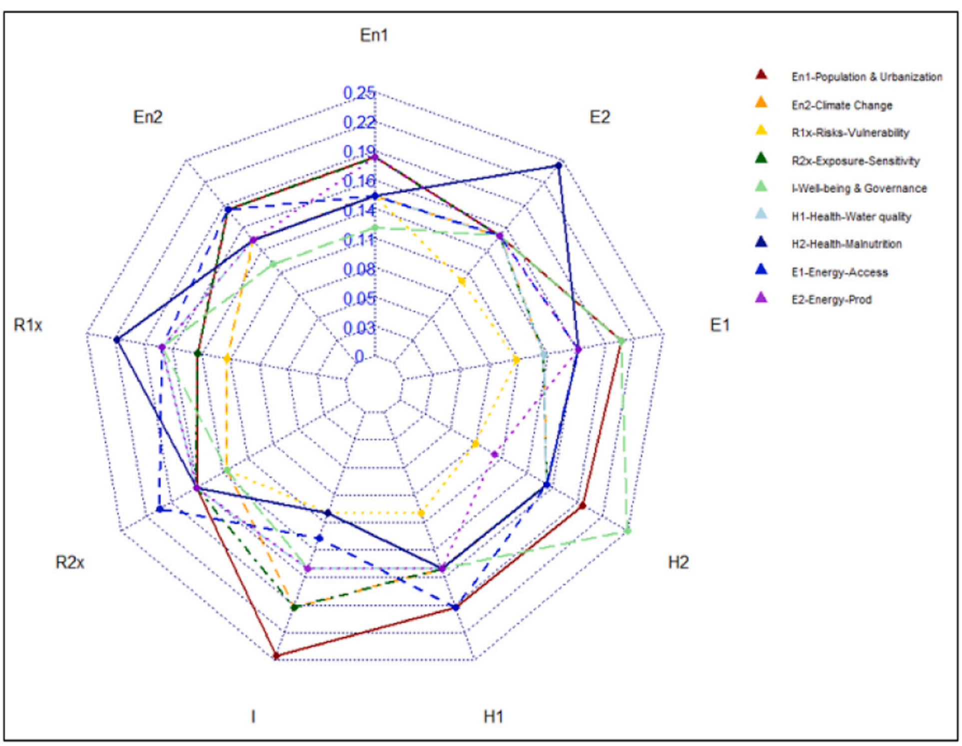

Fig. 5. Performance of sustainable indicators against energy indicators – Narok County.

policymakers to focus on energy provision to improve the community's livelihoods and meet the energy demand due to the increasing population and urbanisation trends. Deforestation is one of the major environmental problems identified in Narok as communities cut down trees for firewood and charcoal, contributing to increased soil erosion and degradation. The Narok country has no energy policy to support the uptake of renewable energy or regulate the use of non-renewable energy sources such as charcoal, which several people sell as a livelihood source. A high impact is observed for risks and vulnerability (R2x) with a weighting value of 0.21, followed by climate change (En2) and health-water quality (H1). Energy productivity is high on population and urbanisation (EN1) and relatively high for all sub-indicators except for health malnutrition (H2), showing that for Narok, generally, the focus should be on improving energy productivity.

The impacts of energy access (E1) and productivity (E2) on sustainable livelihoods, as well as human health and wellbeing indicators for VDM, are shown in Fig. 6. From the spider chart given in Fig. 6, the impacts of energy security are less on wellbeing and governance (I), health-water quality (H1), risks–vulnerability (Rx1), exposure-sensitivity (R2x), and climate change (En2), but relatively higher for population and urbanisation (En1), Health-Malnutrition (H2), energy access (E1) and energy productivity (E2). This implies that policymakers must focus on energy provision to meet the energy demand associated with the increasing population and urbanisation trends, thereby improving the community's livelihoods. Deforestation is one of the major environmental problems identified in the district due to the cutting down of trees for firewood, leading to increased soil erosion and degradation. Although there are policies to support the uptake of renewable energy and energy access is high in the district, households still use firewood and other fossil-based fuels to meet their energy requirements. These sources negatively impact human health.

3.2.3. *Food security and sustainable livelihood indicators*

A pairwise comparison matrix for sustainable livelihood indicators and food security for Narok County is presented in Table 13. The pairwise matrix values for the sustainable livelihood and food security indicators ranged between 0.76 and 1.73. The highest value of 1.73 corresponds to En1/I (population and urbanization contrasted with wellbeing & governance), En2/I (climate change contrasted with exposure-sensitivity), and H2/R1x (Health-water quality contrasted with climate risks-vulnerability).

Similarly, the pairwise comparison matrix for sustainable livelihood indicators and food security for VDM ranged between 0.58 and 1.73 (Table 14). The highest value of 1.73 corresponds to the following paired sustainable livelihood indicators: I/En2, I/En2, I/R1x, I/H1, I/H2, H1/En2, H1/R1x, H2/En2, H2/R1x, H2/F1, H2/F2, F1/En2, F1R1x, and F2/En2. These results indicate that for VDM, food access and productivity are mostly impacted by climate change (En2) and the associated risks and vulnerability (R1x). The lowest value of 0.58 corresponds to the following paired sustainable livelihood indicators: En2/I, En2/H1, En2/H2, En2/F1, En2/F2, R1x/R2x, R1x/I, R1x/H1, R1x/H2, R1x/F1, H1/I, H2/I, F1/H2, and F2/H2. The rest of the pairwise comparison results have a value of 1, suggesting that the paired indicators are almost equally important in VDM.

The normalization of the PCM for the sustainability livelihood indicators for Narok County is presented in Table 15. The sum of the indices is 1, showing that the indicators are numerically linked and can be analysed for sustainable development. The CR for the normalized pairwise matrix for Narok County is 0.054, a value lower than 0.10, which shows that the matrix judgments were generated randomly and the weights calculated are consistent. The results show that the indicators with the highest weights are Population and urbanisation (En1), Food production (F2), and Health/water quality (H1). Climate change (En2) and Food access (F1) also showed significantly higher weights. The highest mean score is for Population and urbanisation (En1), indicating a greater impact on livelihood than the other indicators. For Narok County, the demand for food production is increasing with population growth and urbanisation, affecting food security and livelihood the most. Pastoralists are some of the vulnerable people in Narok; hence, there is a need to provide them with information and build their capacity to diversify their livelihood activities to be more resilient to climatic and non-climate changes in their community. Overall, the integrated composite index for Narok County is 0.11, suggesting that the county is in the low sustainable livelihood category (Table 15).

For VDM (Table 16), the results show that the indicators with the highest weights are wellbeing and governance (I), Health-Malnutrition (H2), and Food access (F1). The highest mean score is for wellbeing and governance (I), indicating a greater impact on livelihood than the other indicators. As shown in Table 16, climate change (En2) and wellbeing and governance (I) impact food access and productivity the most. Overall, the integrated composite index for VDM is 0.11, classifying the county into a low sustainable livelihood category (Table 16). From the food security perspective, our analysis results suggest that the communities in both study sites generally have low sustainable

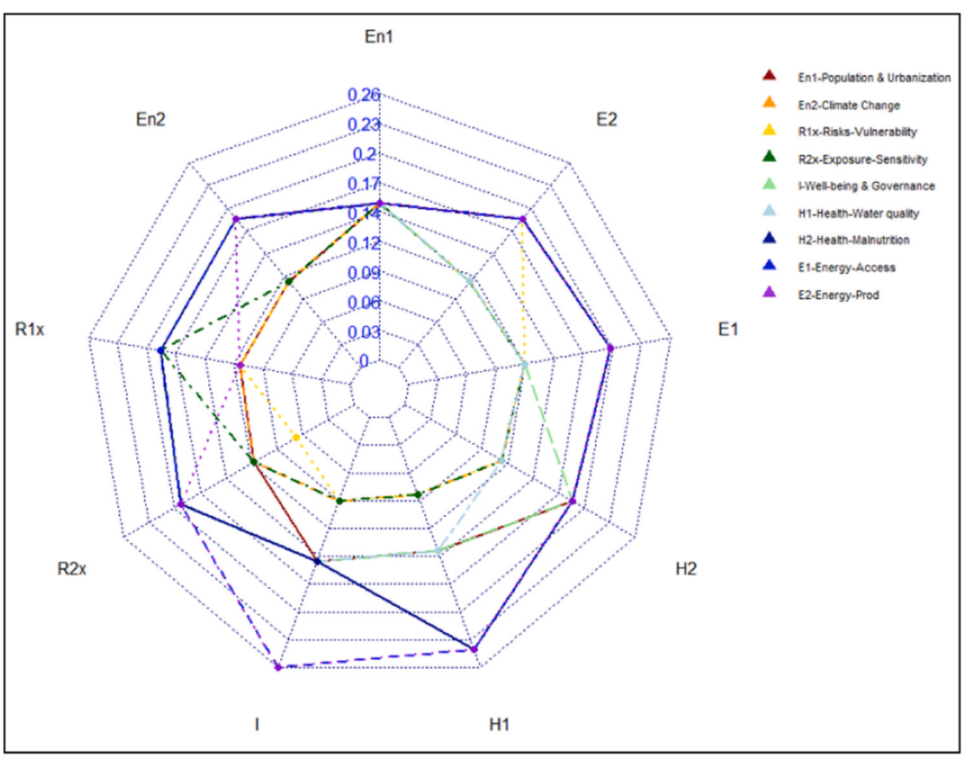

Fig. 6. Performance of sustainable indicators against energy indicators for VDM.

Table 13
Pairwise comparison matrix for sustainable livelihood indicators and food security for Narok county. F1 – Food access and F2 – Food productivity.

Indicators	En1	En2	R1x	R2x	I	H1	H2	F1	F2
En1	1.00	1.32	1.32	1.00	1.73	1.32	1.32	1.32	1.00
En2	0.76	1.00	1.00	0.76	1.73	1.32	1.32	1.00	1.32
R1x	0.76	1.00	1.00	1.00	0.76	0.76	0.58	0.76	0.58
R2x	1.00	1.32	1.00	1.00	1.32	1.00	1.00	0.76	1.00
I	0.58	0.58	1.32	0.76	1.00	0.76	1.32	1.32	1.00
H1	0.76	0.76	1.32	1.00	1.32	1.00	1.00	0.76	1.00
H2	0.76	0.76	1.73	1.00	0.76	1.00	1.00	0.76	1.32
F1	0.76	1.00	1.32	1.32	0.76	1.32	1.32	1.00	1.00
F2	1.00	0.76	1.73	1.00	1.00	1.00	0.76	1.00	1.00

Table 14
Pairwise comparison matrix for sustainable livelihood indicators and food security for Narok county. F1 – Food access and F2 – Food productivity.

Indicators	**En1**	**En2**	**R1x**	**R2x**	**I**	**H1**	**H2**	**F1**	**F2**
En1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
En2	1.00	1.00	1.00	1.00	0.58	0.58	0.58	0.58	0.58
R1x	1.00	1.00	1.00	0.58	0.58	0.58	0.58	0.58	1.00
R2x	1.00	1.00	1.73	1.00	1.00	1.00	1.00	1.00	1.00
I	1.00	1.73	1.73	1.00	1.00	1.73	1.73	1.00	1.00
H1	1.00	1.73	1.73	1.00	0.58	1.00	1.00	1.00	1.00
H2	1.00	1.73	1.73	1.00	0.58	1.00	1.00	1.73	1.73
F1	1.00	1.73	1.73	1.00	1.00	1.00	0.58	1.00	1.00
F2	1.00	1.73	1.00	1.00	1.00	1.00	0.58	1.00	1.00

Table 15
Normalized pairwise comparison matrix, consistency ratio (CR), and composite index for sustainable livelihood indicators and food security for Narok county.

Indicators	**En1**	**En2**	**R1x**	**R2x**	**I**	**H1**	**H2**	**F1**	**F2**	**Index**
En1	0.136	0.155	0.112	0.113	0.167	0.139	0.137	0.152	0.109	0.135
En2	0.103	0.118	0.085	0.086	0.167	0.139	0.137	0.115	0.143	0.121
R1x	0.103	0.118	0.085	0.113	0.073	0.080	0.060	0.088	0.063	0.087
R2x	0.136	0.155	0.085	0.113	0.127	0.106	0.104	0.088	0.109	0.114
I	0.078	0.068	0.112	0.086	0.096	0.080	0.137	0.152	0.109	0.102
H1	0.103	0.090	0.112	0.113	0.127	0.106	0.104	0.088	0.109	0.106
H2	0.103	0.090	0.148	0.113	0.073	0.106	0.104	0.088	0.143	0.107
F1	0.103	0.118	0.112	0.149	0.073	0.139	0.137	0.115	0.109	0.117
F2	0.136	0.090	0.148	0.113	0.096	0.106	0.079	0.115	0.109	0.110
			CR = 0.054							$\sum = 1$
Composite integrated index (weighted average)										0.111

Table 16
Normalized pairwise comparison matrix, consistency ratio (CR), and composite index for sustainable livelihood indicators and food security for VDM.

Indicators	**En1**	**En2**	**R1x**	**R2x**	**I**	**H1**	**H2**	**F1**	**F2**	**Index**
En1	0.111	0.079	0.079	0.117	0.137	0.113	0.124	0.113	0.107	0.109
En2	0.111	0.079	0.079	0.117	0.079	0.065	0.072	0.065	0.062	0.081
R1x	0.111	0.079	0.079	0.067	0.079	0.065	0.072	0.065	0.107	0.081
R2x	0.111	0.079	0.137	0.117	0.137	0.113	0.124	0.113	0.107	0.115
I	0.111	0.137	0.137	0.117	0.137	0.195	0.215	0.113	0.107	0.141
H1	0.111	0.137	0.137	0.117	0.079	0.113	0.124	0.113	0.107	0.115
H2	0.111	0.137	0.137	0.117	0.079	0.113	0.124	0.195	0.186	0.133
F1	0.111	0.137	0.137	0.117	0.137	0.113	0.072	0.113	0.107	0.116
F2	0.111	0.137	0.079	0.117	0.137	0.113	0.072	0.113	0.107	0.109
			CR = 0.032							$\sum = 1$
Composite integrated index (weighted average)										0.111

livelihoods.

Fig. 7 depicts results for impacts of food security (food accessibility F1 and productivity, F2) on sustainable livelihoods, human health, and wellbeing indicators. Based on the spider chart diagram, food security, and food accessibility impacts are fairly high for the following indicators: climate exposure-sensitivity (R2x) and health-water quality (H1), health-malnutrition (H2), and notable low for wellbeing and governance (I). Food productivity impacts are comparatively high for climate risk-vulnerability (R1x), health-water quality (H1), and population and urbanisation (En1) and low for health-malnutrition (H2) and climate change (En2).

The impacts of food accessibility and productivity on sustainable livelihood indicators for VDM are depicted in Fig. 8. Food accessibility impacts are specifically high for the following indicators: wellbeing and governance (I), climate change (En2), and climate risk-vulnerability (R1x), and notably low for health-malnutrition (H2). Likewise, food productivity impacts are relatively high for climate change (En2), wellbeing and governance (I), and climate exposure-sensitivity (R2x). Health-Malnutrition (H2) is one of the most impacted sustainable livelihood indicators by food access (F1) and food productivity (F2), as

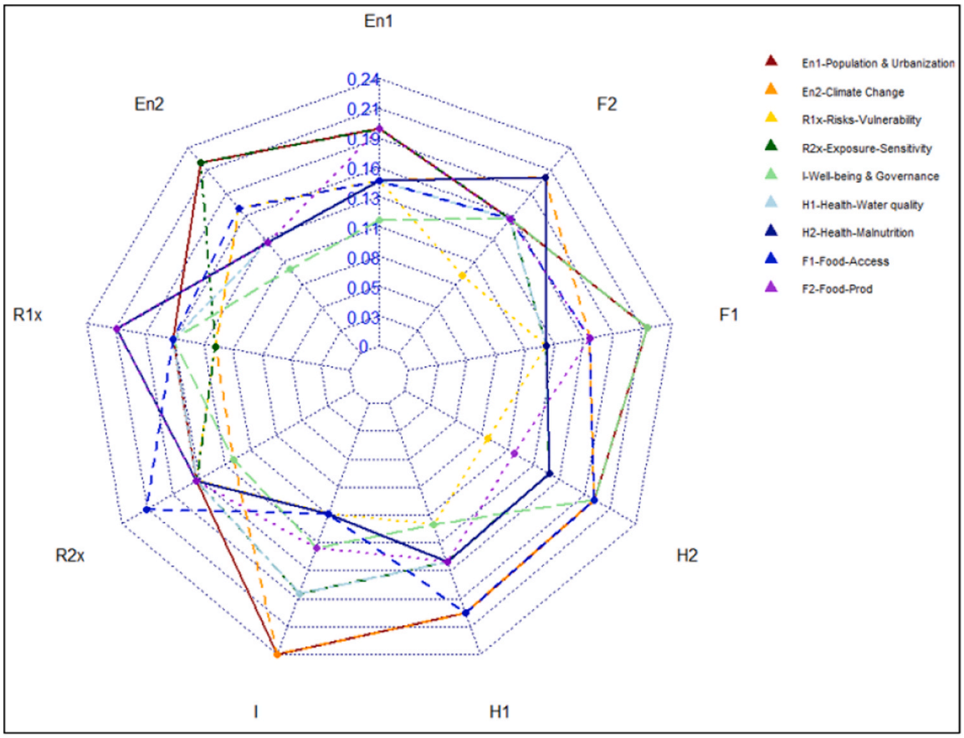

Fig. 7. Performance of sustainable indicators against Food security indicators – Narok County.

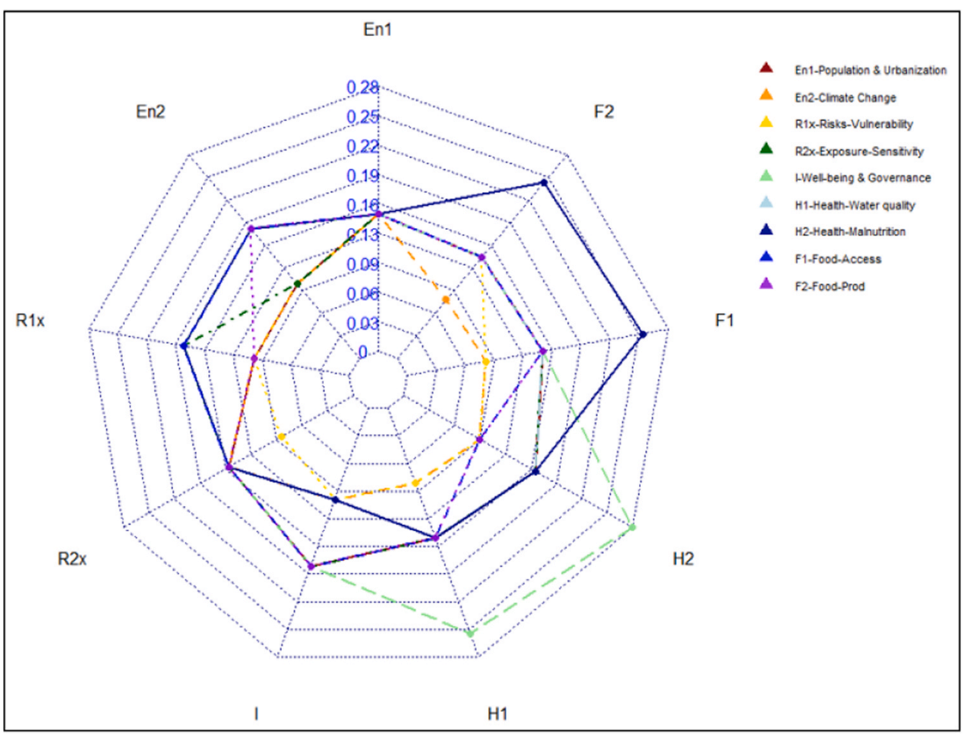

Fig. 8. Performance of sustainable indicators against Food security indicators – VDM.

shown in Table 16 and Fig. 8.

3.2.4. Assessment of the linkages between WEF resources and sustainable livelihood indicators

Correlation analysis was conducted to assess how much WEF resources correlate with the livelihood indicators. The results are presented in Figs. 9 and 10 for Narok County and VDM, respectively. In each case, a positive correlation exists when high values of the WEF nexus are associated with high values of livelihood indicators. Similarly, a negative correlation exists when high values of WEF resources are associated with low values of livelihood indicators. As given in Fig. 9, the correlation (at p-value =0,05) between the sustainable livelihood indicators and the WEF nexus resources in Narok County is generally dispersed with the following notable inferences:

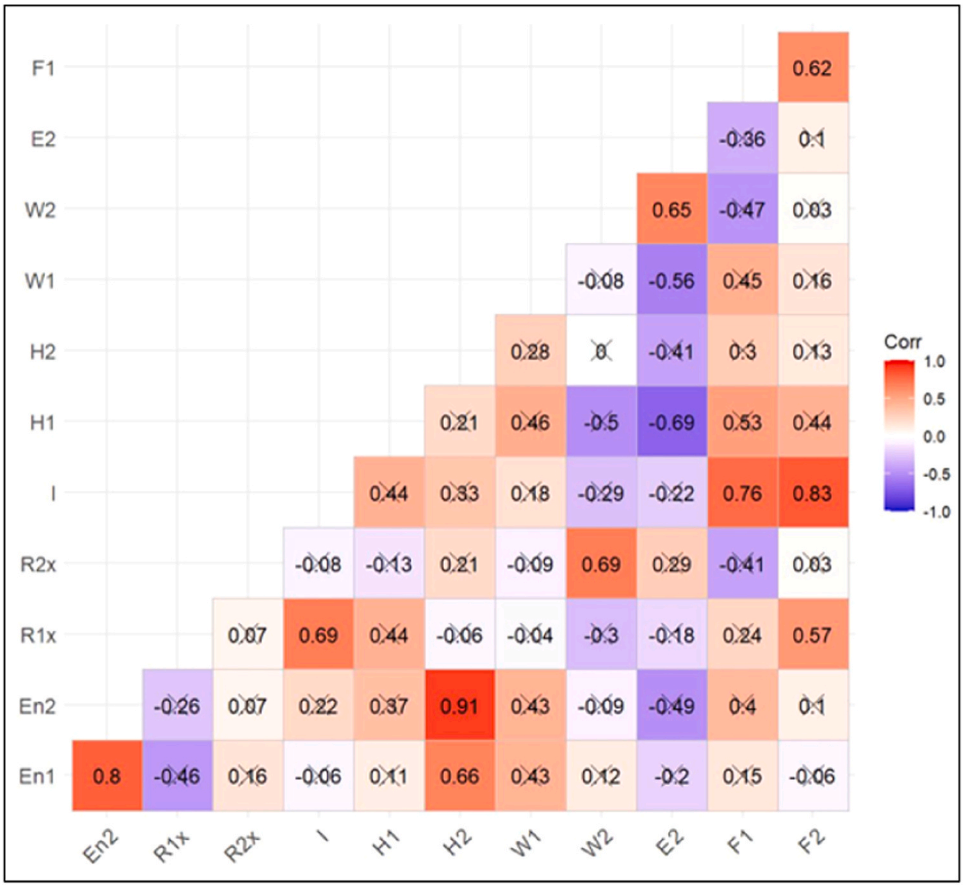

Fig. 9. The correlation matrix for the composite weights of sustainable livelihood indicators and the WEF resources is based on the Narok County analysis.

- There exists a strong positive (and significant) correlation between the present and future agricultural production and the impact of weak governance institutions on the general wellbeing of communities (F2-I: ρ∼0.83) as well as the high exposure to the limited WEF nexus resources attributed to the present and future drivers of economic, and socio-economic changes in the communities (F2-R1x: ρ∼0.57).
- A strong, significant positive correlation exists between water use for irrigation and the risks and vulnerabilities experienced by communities due to the changes in present and future environmental and socio-economic conditions (E2-R2x: ρ∼0.69).
- The present and future access to sufficient nutritive food by communities is positively (and significantly) correlated to the wellbeing of communities due to the weak government governance (F1-I: ρ∼0.76).
- The energy productivity (in the context of spurring economic growth) in Narok County is negatively (yet significant) correlated to the unsafe water, sanitation, and general hygiene of the communities (E2-H1: ρ∼-0.69).

Similarly, based on results presented in Fig. 10, the correlation (at p-value =0,05) between the sustainable livelihood indicators and the WEF nexus resources in VDM exhibits the following features:

- A strong positive (and significant) correlation is observed between agricultural productivity (F2) and the following indicators: food security (accessibility; F1), energy production (E2), water access (W1), climate change risk-vulnerability (R2x) and greater exposure and sensitivity (R1x).
- Food security (F1) correlates strongly with energy production, water access, risk vulnerability, and greater exposure and sensitivity.
- A strong, significant positive correlation exists between energy productivity, water access (0.99), and health and water quality (0.74). In general, energy productivity positively correlates with all livelihood indicators, although the correlation across most indicators is non-significant.
- Water accessibility strongly correlates with health and water quality (0.73). Similarly, the water indicator positively correlates with most livelihood indicators; however, only R2x and H1 depict a significant positive correlation.

Overall, the correlation results of the WEF nexus and sustainable livelihoods indicators corroborate those reported in, e.g., Laspidou et al. (2019) and Wolde et al. (2022), thereby establishing the inherent association between the sustainable livelihood indicators and the WEF nexus resources. The correlation results demonstrate that sustainable WEF nexus resource utilization will inadvertently translate to sustainable livelihoods, health, and wellbeing of the community.

4. Recommendations

The 2030 Sustainable Development Agenda was formulated to eradicate extreme poverty in all its forms, consequently calling for all countries to act on such goals to promote prosperity while protecting the planet (UN. 2021). Eradicating extreme poverty and improving rural livelihoods have become a priority in rural areas where the population comprises 70 % and 60 % of low and lower-middle income earners, respectively, and approximately 80 % of the people living below the poverty line (Castaneda et al., 2016). In addition, economic growth forms the fundamental basis for addressing poverty, unemployment, and inequality, yet global economic growth has significantly slowed down in recent years (Ferreira et al., 2015; Castaneda et al., 2016). The rate at

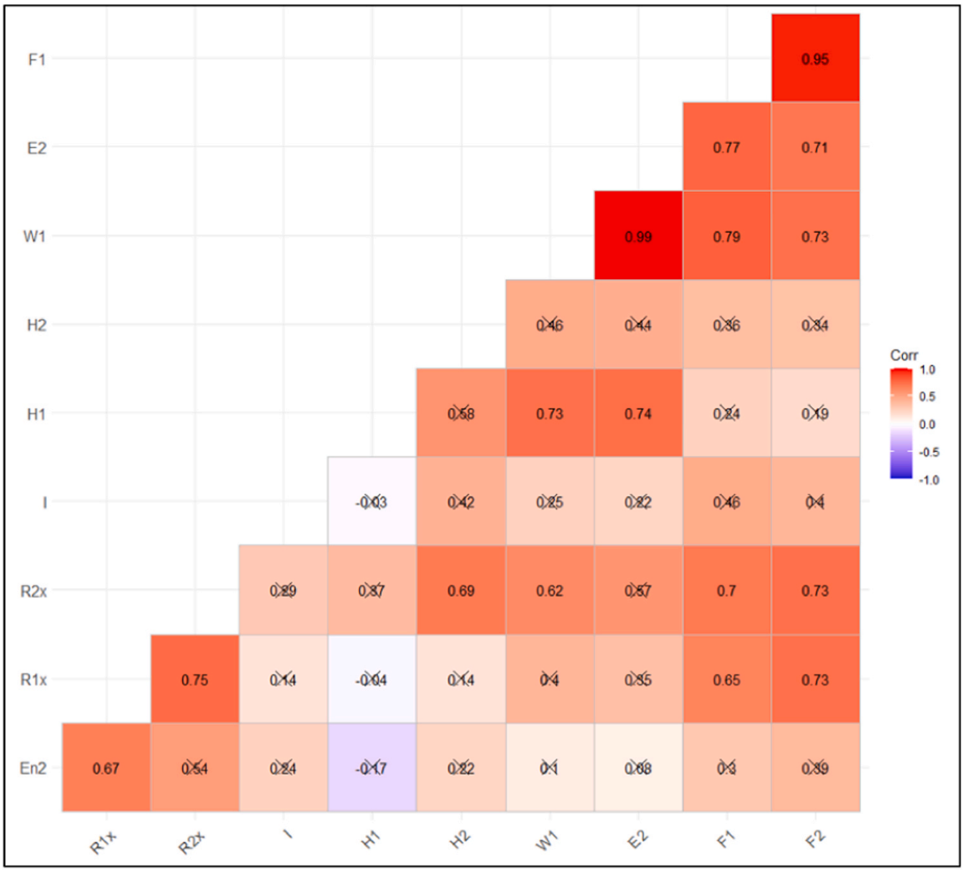

Fig. 10. The correlation matrix for the composite weights of sustainable livelihood indicators and the WEF resources is based on the VDM analysis.

which extreme poverty can be minimised critically depends on engendering practices that bring rural development to the fore and integrate insights and proper interventions beyond sectoral boundaries. Additionally, to gain a sustainable livelihood, health, and wellbeing, it is recommended that an integrated, inclusive and equitable approach, such as the WEF nexus, be considered to ensure that no one is left behind: youth, women and underprivileged/marginalised sections of society should be brought to the fore. Ultimately, the livelihoods of all in rural communities are bound to gain.

Furthermore, the WEF resources form the main livelihood drivers for sustainable socio-economic development. Yet, their security is continuously threatened, particularly in rural areas facing the triple challenges of poverty, inequality, and unemployment. As reported by Biggs et al. (2015) and Mabhaudhi et al. (2019), the WEF nexus framework has the potential to promote sustainable development as long as the tenets of sustainable livelihoods are embedded with the WEF nexus inclusive and equitable operationalisation. This is especially true because inherent interrelations between the WEF nexus undoubtedly constrain a holistic understanding of the underlying dynamics of the environment approaches and the theoretical-empirical aspects of sustainable livelihoods that manifest through socio-ecological pressures, governance, development priorities, environment and WEF resources securities. Climate variability and change amplify the diminishing security of these critical resources.

The WEF nexus should support inclusive and equitable partnerships that facilitate the co-development of integrated solutions across scales, from village to national to regional, ensuring that community perspectives resonate in national policies. It is against this background, and the outcome of the surveys carried out in Narok County and VDM study sites that the following recommendations are opined to improve the livelihoods within these communities (yet scaling out to national and regional levels can also not be overemphasised):

- Based on the survey results, it emerged that communities in both studies rely on traditional biomass to meet or supplement their daily energy requirements. Deforestation was identified as one of the major environmental problems affecting both study sites due to the cutting down of trees for firewood and clearing of land for agricultural purposes, which resulted in increased soil erosion and degradation as well as negative impacts of firewood use on human health. Therefore, policymakers should focus on improving energy provision as energy is an important component of the linkages within the WEF nexus. This is also important for the improvement of the livelihoods of the community and meeting the energy demand due to the increasing population and urbanisation trends, which were also identified as major contributors to the nexus imbalance.
- While there are policies to support the transition to clean renewable energy sources to improve energy access, there is a need to intensify awareness and provide support to enable these communities to invest in these clean energy technologies (e.g., wind, solar, and biogas). Solar and wind resources are abundant in the study sites, and most households keep animals and poultry, which could also be combined with agricultural wastes to produce biogas. Supporting the implementation of biogas systems in the communities has many benefits besides providing energy, such as improving sanitation, providing manure for agricultural production, and mitigating the impacts of climate change.
- At commercial levels, synergies between livestock, food crop production, and renewable energy sources can be maximized through agro-industrial technologies and processes such as anaerobic digestion or gasification.

- Policymakers require detailed and in-depth information on regional changes in both temperature and rainfall to devise suitable plans to reduce the devastating effects of climate change. Therefore, the future planning and management of WEF resources should be based on climate change projections at relevant temporal and spatial scales.
- There is a need to promote the sharing of indigenous knowledge to support early warning and disaster response and agricultural activities such as growing drought-resistant crops and preserving grains to reduce vulnerability.
- There is a need to enforce national policies to manage water pollution from economic activities such as mining and agriculture to reduce the eutrophication of water bodies.
- Environmental laws and penalties need to be reinforced to manage illegal sand mining and deforestation for charcoal in Narok, affecting the quality and quantity of water in rivers, causing water use conflict in local communities, and a decline in forests and biodiversity.
- Procedures to address water and environmental non-compliance should be transparent to enable greater accountability and uptake of policies and initiatives at the community level.
- The issue of social inclusivity- bringing onboard the youth and gender- should also be considered while recommending robust ways to enhance WEF nexus resources securities across the study sites.

5. Conclusion

The study utilized ex-ante literature and stakeholder surveys in Narok County (Kenya) and VDM (South Africa). It identified the interactions between the WEF nexus components and their impact on communities' livelihoods, health, and wellbeing. The study assessed the linkages of the sustainable indicators and the impact of the WEF nexus components. The results showed that the WEF nexus resources are critical in improving the livelihoods, human health, and wellbeing of the communities in both study regions. Furthermore, population and urbanisation emerged strongly as aspects that impact water, energy, and food, consequently influencing the community's livelihoods, health, and wellbeing. Population growth and increased urbanisation have also impacted the environment, as evidenced by land degradation, water pollution, and deforestation, which also impact the livelihoods, health, and wellbeing of communities in the study sites. Information collected during stakeholder engagements indicated that both study sites are highly vulnerable to climate change. From the survey respondents, the notable climate-associated changes observed include an increase in intense storms that caused flooding, droughts, pests and diseases affecting crops, and changes in the onset of the rainfall season. Consequently, stakeholders such as government departments, civil society, and communities require information and support to make coordinated and integrated early decisions to support preparedness for these hydroclimatic extremes. Such decision support tools would help the vulnerable communities increase their adaptive capacity to climate variability and change, ensuring that their developmental priorities remain on course, thereby promoting sustainable development goals. Therefore, water, energy, and food components must be managed well to withstand the threats from socio-economic and climatic drivers, as all these impacts the sustainability of livelihoods in the communities. From the viewpoint of potential scaling, the present study makes the following scientific and empirical contributions. From the scientific perspective, the analysis results provide evidence and impetus for the methodology of integrating sustainable livelihoods within the WEF nexus frameworks. In this way, the results contribute to the body of empirical evidence on the WEF nexus-livelihoods research domain. From an empirical perspective, the synergies and/or trade-offs between the WEF nexus and the livelihood could be; a) used to inform revision or formulation of new policy instruments vital to key components of nexus livelihood securities (including water, energy, food, and environment), and b) embedded with alternative local and context-specific present and plausible future adaptation and mitigation options in response to present and projected hydroclimatic extremes of a given region.

Author statement

The research study aims to assess the rural livelihoods, health and wellbeing at a local level, taking into account that climate change has greater impacts at such scales, hence increased vulnerability within local communities. It is important to understand the linkages of water, energy and food nexus as they are key resources for sustainable development. The research therefore contributes to contributes towards empirical evidence of the WEF nexus-livelihood research domain while informing the formulation of policy instruments vital for maintaining the balance between society and environment interrelations, especially under changing environment.

CRediT authorship contribution statement

Eric Wamiti: Writing – review & editing. **Nosipho Zwane:** Data curation, Writing – review & editing. **Michael G. Mengistu:** Methodology, Writing – original draft. **Katlego P. Ncongwane:** Methodology, Writing – original draft. **Joel O. Botai:** Formal analysis, Methodology, Writing – original draft. **Christina Mihloti Botai:** Conceptualization, Formal analysis, Methodology, Writing – original draft. **Tafadzwanashe Mabhaudhi:** Methodology, Software, Writing – review & editing. **Masinde Muthoni:** Writing – review & editing. **Silvester Mpandeli:** Writing – review & editing. **Henerica Tazvinga:** Conceptualization, Formal analysis, Methodology, Writing – original draft. **Luxon Nhamo:** Validation, Writing – review & editing, Software. **Miriam Murambadoro:** Data curation, Methodology, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships

that could have appeared to influence the work reported in this paper. The authors have no conflict of interest.

Data availability

Data will be made available on request.

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