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Review of the land use and climate change impact assessments in semi-arid ecosystems in Africa: Opportunities and challenges

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ABSTRACT

Despite the existing literature on climate variability (CV) and land use change (LUC) impact assessments, understanding their effectiveness in semi-arid regions remains challenging. This review aims to assess the effectiveness of CV and LUC impact assessments in guiding adaptation options for smallholder farmers in semi-arid ecosystems and associated challenges and opportunities. We conducted a systematic literature review, primarily using Google Scholar, to examine the impact of LUC and CV in African semi-arid ecosystems. We employed Vos Viewer to analyze the relationships among the identified sources. Our findings reveal that current assessment approaches often fall short in capturing the intricate interactions within semi-arid ecosystems. These assessments frequently emphasize biophysical productivity, employ reductionist modeling methods, and neglect the social, economic, and adaptive aspects of these systems. Our review underscores the importance of integrating CV and LUC in impact assessments. While a majority of studies concentrate on CV adaptation (26%), they often overlook the pivotal role of LUC and their interplay with climate impacts. Only a small fraction (2%) integrates CV and LUC in impact assessments. Assessing the benefits of CV and LUC impact assessments presents mixed results, particularly for smallholder farmers. While global and regional benefits are discernible, quantifying these advantages at the local smallholder farmer level remains challenging due to diversified land use and small-scale operations. This highlights the need for localized studies addressing the specific challenges confronting smallholder farmers in semi-arid regions. To enhance assessments effectiveness, we recommend for more interdisciplinary research and the application of a complex systems approach, integrating GIS and remote sensing.

1.0 Introduction

Climate change and climate variability are among the most pressing issues currently facing the world. Although the climate is constantly changing, the pace of these changes has accelerated, especially in the last hundred years (Jackson et al. 2022). Climate change is already significantly impacting on the Earth's ecosystems or is on the verge of doing so, making it one of the most important and defining issues facing the world today (Abbass et al. 2022). Anthropogenic land use changes have contributed significantly to changes in semi-arid ecosystems.

Increased food demand, changing consumption patterns, and land development for infrastructure have contributed to semi-arid ecosystem alterations due to population growth (Etowa et al. 2022). For instance, recent LUCs have been responsible for a 0.9°C increase in the average global temperature, primarily due to the emission of greenhouse gases (GHGs) into the atmosphere (Reed et al. (2022), illustrating how closely linked land use, climate variability and change are. In sub-Saharan Africa, the impacts of land use and climate variability on agricultural production and the ecosystems resilience are increasingly severe, particularly in semi-arid ecosystems (Govender et al. 2022).

Semi-arid areas, covering 41% of Earth's surface, are critical for the livelihoods of 33% of the global population (Göl 2022; Scholes 2020). However, these regions often coincide with countries experiencing poverty and limited adaptive capacity to external shocks and changes (Guye et al. 2023). Coincidentally, most of these areas are located in the semi-arid regions of Africa. The local populations in semi-arid areas heavily rely on natural resources for their basic needs, including food, housing, fuel, and medicines (IPCC 2014; Nhapi 2022; Zhou et al. 2022). Nonetheless, these semi-arid areas are highly vulnerable to climate variability and land use change impacts.

Semi-arid ecosystems, despite sharing some common features like limited rainfall and high temperatures, exhibit significant heterogeneity. This diversity leads to varying and disproportionate adverse impacts of land use and climate change, particularly on agricultural practices and the ecosystems' responses to climate variability and land use changes (Zhou et al. 2022). This poses significant uncertainty and complexity in understanding the interactions between climate variability, land use, socio-economic, agriculture, and semi-arid ecosystems. Therefore, robust impact assessment methods are necessary to effectively address the risks posed to semi-arid ecosystems. Various CV and LUC impact assessment methodologies exist, such as vulnerability assessments, biophysical and socio-economic approaches, and hazard-driven risk assessments. However, debates persist regarding the methods and applications of vulnerability assessments, with concerns about their ability to inform decision-makers effectively (Adger 2006; Grothmann et al. 2017; Hinkel 2011; Smit and Wandel 2006; Varadan and Kumar 2015).

LUC and CV impact assessment is a systematic process that aims to understand and evaluate the effects of changes in land use and land cover patterns, as well as variations in climate conditions, on natural ecosystems, human activities, and the environment (Jia et al. 2019; Kumar et al. 2022). This assessment seeks to quantify both direct and indirect impacts, anticipate potential consequences, and inform decision-making for sustainable land management, climate adaptation, and mitigation strategies.

Some CV assessments have also begun, including LUC as an additional variable in an attempt to improve the outputs of the assessments (Amadou et al. 2018; Froese and Schilling 2019). Yet attempts to take an inclusive approach in analysing the impacts both of CV and climate change and of LUC are limited. For instance, Jia et al. (2019) on land use and climate interactions and Froese and Schilling (2019) on the nexus between climate change, land use, and human conflicts have made attempts to integrate LUC and CV aspects. Nonetheless, these reports also underscore the need for further research in integrating CV and LUC in impact assessments, along with other relevant social variables. The integrated assessment is crucial for making informed decisions, shaping policies, and implementing adaptive measures that promote resilience, and sustainable development, in the face of ongoing global changes.

Smallholder farming systems, in semi-arid areas of sub-Saharan Africa are highly vulnerable to climate change impacts (Descheemaeker et al. 2018). To enhance their resilience and implement climate-resilient agricultural practices, it is crucial to gain contextual knowledge and address the uncertainties surrounding climate change responses (Lipper et al. 2014). However, there is still much ambiguity and a lack of knowledge regarding the options for responding to CV and LUC impacts in semi-arid regions in Africa. The effectiveness of LUC and CV impact assessments for smallholder farmers can be hindered by several factors. Obstacles to effective impact assessments include the absence of reliable climate and land use data at the rural/local level, intricate mixed land use patterns, discrepancies between local knowledge and scientific assessments, and challenges of scale.

The paper aims to evaluate the effectiveness of current climate and land use impact assessments in guiding adaptation strategies for smallholder farmers in semi-arid ecosystems in Africa and associated challenges and opportunities.

2.0 Methods

The review undertook a systematic analysis of the literature on land use and climate change impact assessments in semi-arid ecosystems in Africa. The Google Scholar database was used as the primary source for the literature review. The literature included research articles, reviews and reports from international organizations like the Food &

Agriculture Organisation (FAO) of the United Nations addressing climate change vulnerability in Africa. The literature sources were limited to works published in English.

An initial search on Google Scholar using the search terms "land use and climate change impact assessments in semi-arid areas in Africa," "climate vulnerability in smallholder farmers semi-arid regions of Africa," and "vulnerability to climate change of semi-arid agroecological systems in Africa" yielded a total of 2301 articles. To narrow down the results, a user-defined time frame of 2014 to 2023 was applied, with a few additional articles beyond this timeframe based on key concepts. The rationale behind opting for this timeframe was to guarantee the inclusion of content that remains pertinent to the present understanding, encompassing recent scholarly works, while also concentrating on a more controllable selection of publications. After screening the titles and abstracts, 197 articles were retained. Further selection focused on articles containing the search terms "land use and climate variability and change impact assessments on smallholders in Africa" in either the title or abstract, resulting in a final selection of 173 articles. Subsequently, a comprehensive full-text analysis was undertaken as the final phase of the process. This step ensured that the selected articles aligned with the primary focus of the study, which centred on climate change impact assessments on smallholder farmers in Africa. As a result, a total of 67 articles were ultimately included in the review. The Vos-viewer was employed to analyze the connections between key search words within the articles and illustrate linkages. The methodological approach followed is shown in figure 1.

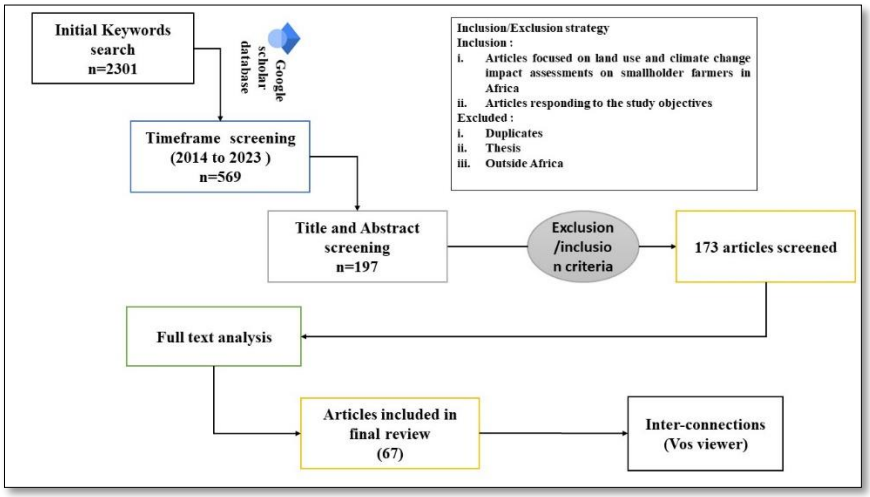

Figure 1: Literature screening and organisation flow process.

3.0 Results

3.1 Analysis of publications

3.1.1 Main themes of the articles reviewed

Studies focusing on the assessment of land use and climate change impacts in semi-arid ecosystems across Africa can be categorized into distinct themes. Notably, a significant portion of the research (26%) is dedicated to the exploration of adaptation and mitigation strategies in the face of climate variability and change. Another substantial category, accounting for 19% of the reviewed studies, pertains to investigations into the vulnerability of these ecosystems to climate variability and change. The other categories are shown in figure 2.

Conversely, the category receiving the least attention involves the interactions between climate variability and change and land use change patterns. This aspect, encompassing the nexus of these two factors, is comparatively underrepresented in the current body of research.

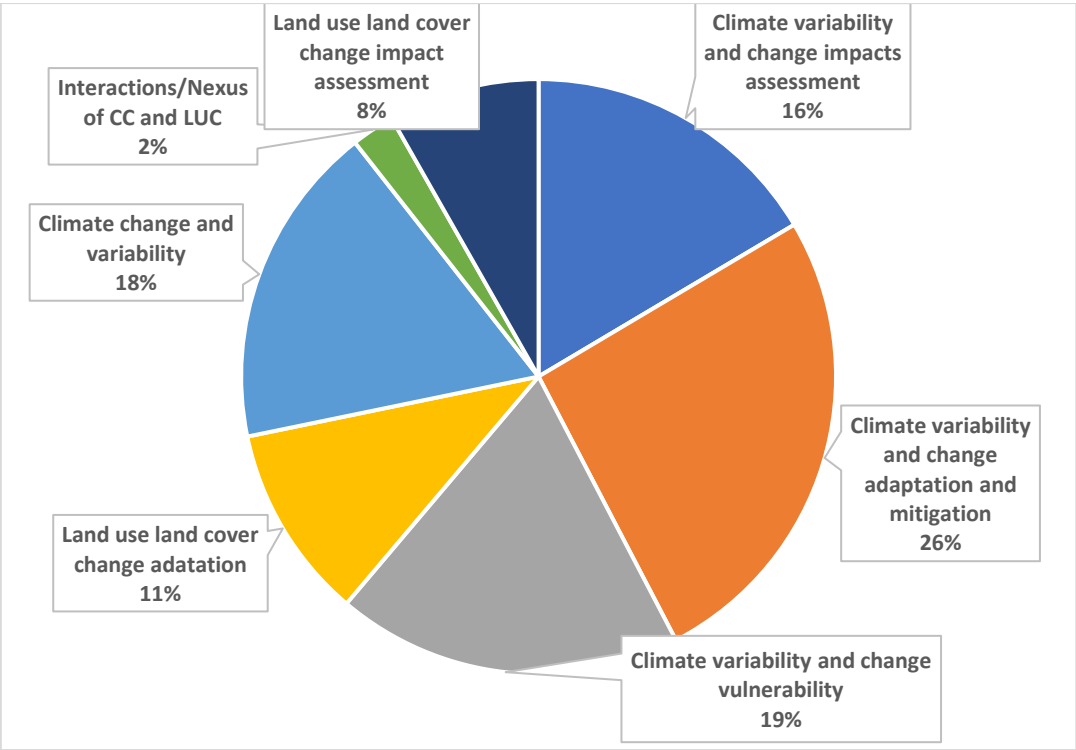

Figure 2: Reviewed articles main themes and focus.

3.1.2 Geographic scope of the articles

The literature review concerning the impact assessments of land use and climate change in semi-arid ecosystems within Africa reveals distinct coverage patterns. The majority of the studies (47%) adopt a comprehensive geographic approach, encompassing the entire African continent. A considerable portion (29%) concentrates on individual countries within Africa, delving into specific regional dynamics. Additionally, a noteworthy fraction (24%) adopts a global perspective, incorporating Africa within the broader context of climate and land use change impacts. Intriguingly, none of the examined literature addresses the impact assessments of land use and climate change in semi-arid ecosystems at sub-national levels of analysis.

3.2 Impact of land use and climate variability on semi-arid agroecosystems

Semi-arid ecosystems in Africa are facing degradation due to the combined effects of changing land use and climate change. Climate variability, with its inherent natural consequences, can be further intensified by land use change. The impacts of land use change are largely influenced by the actions taken by local communities and neighbouring regions. In the semi-arid regions of Africa, where smallholder farmers constitute the majority of the population, the effects of CV and LUC are particularly significant. In the following section, we will delve into a detailed examination of these impacts, considering both climate change (CV) and land use (LUC) factors.

3.2.1 Land use change (LUC) impacts on semi-arid ecosystems

Semi-arid ecosystems have been subjected to significant strain from human activities (Liu et al. 2022). The expansion of human settlements, driven by population growth, has led to the clearance of natural vegetation, resulting in the fragmentation of local ecosystems (Mugari and Masundire 2022). Such fragmentation has caused a loss of biodiversity and impaired critical ecosystem functions, affecting the provision of essential ecosystem services. The magnitude of biodiversity loss often surpasses the ecosystems' ability to regenerate (Mugari and Masundire 2022). This loss of biodiversity poses threats to livelihoods and diminishes the adaptive capacity of communities in semi-arid areas, where reliance on the natural environment remains substantial (Guye et al. 2023). Additionally studies by Ndehedehe et al. (2018) also showed that land use activities and climate variability alter watershed storage, soil quality, and soil quality hydrological processes, modifying or increasing drought severity.

Consequently, land use change emerges as a crucial variable that must be considered in climate variability (CV) and land use change (LUC) impact assessments for semi-arid ecosystems.

3.2.2 Climate variability and change impacts

Globally, ecosystems have shown a tendency to adapt to prevailing climatic conditions, but he impacts of climate variability and change are increasingly evident through temperature fluctuations, precipitation variations, seasonal shifts, and changes in CO_2 concentrations. In semi-arid ecosystems across Africa, observable warming trends are already affecting regions like Botswana, Zimbabwe, and western South Africa, with a projected mean annual temperature increase of approximatelyapproximately 2 degrees Celsius by 2100 (Pereira 2017). Rising temperatures and changing rainfall patterns pose significant challenges to agricultural systems, especially in semi-arid regions, impacting yields of high-value perennial crops and cereals (Jones and Thornton 2009). Climate change models also indicate a potential decline in reliable farming days to as low as 90 by 2050 in sub Saharan Africa, making rainfed crop cultivation increasingly risky and driving farmers to transition to animal husbandry (Descheemaeker et al. 2018). Beyond the temperature trend, concerns about precipitation patterns are growing, with some regions experiencing slight decreases in rainfall and alterations in the onset, duration, and intensity of rainy seasons. In Southern Africa, a projected 3-6 °C temperature increase by the end of the century, along with erratic rainfall, this could lead to more frequent and intense droughts and floods, adversely affecting livelihoods and the environment (Dosio et al. 2019) . Indirect impacts of climate variability on agricultural production, such as changes in pollinators, pests, and diseases, also pose significant challenges to production levels. These indirect CV factors are complex and challenging to assess and predict (FAO 2012). As climate variability and change progresses, there is an expected increase in the incidence of diseases, weeds, and pests, posing a threat to agricultural productivity (Bedeke 2023) , impacting yields, market prices, ecosystem services, national income, agriculture and other livelihoods (Ahmad et al. 2022). Empirical evidence indicate that climate change has negatively impacted regional and global crop yields, increasing the unpredictability of agricultural production worldwide (FAO 2016).

3.3 Drivers of LUC and CV in semi-arid ecosystems

Climatic and non-climatic stressors will intensify the vulnerability of African semi-arid ecosystems to climate change (Ahmad et al. 2022). However, the impacts will not be universal. Adaptation to the effects of CV and LUC on farming systems in semi-arid areas will, therefore, require context-specific approaches. This section examines the methodologies employed in assessing the impacts of land use and climate variability in various studies within semi-arid regions.

LUC and CV impact assessment methodologies

Various methodologies have been applied to evaluate the impacts of LUC and CV by multiple authors for different semi-arid ecosystems (Hachemaoui et al. 2022; Jones and Thornton 2009; Orimoloye et al. 2022). These assessments vary in terms of subject matter, spatial and temporal scales, and objectives. For example, agriculture could be the subject matter, the temporal scale could be seasonal, the geographic scale could be the farm level, and the objective could be the impact of drought on crop production. As a result, various methods and tools have been developed to support the assessments using appropriate data and information. Various CV and LUC impact assessment methods have been used in research studies, as summarized in Table 1. Each strategy/method has its driving factors, objectives, geographic scope, timeframe, techniques, tools and data requirements (particularly concerning future ecological and socio-economic conditions). These methods, approaches and technologies have evolved in response to the demand for information on potential impacts, vulnerability and adaptation options relevant to policy-making. Increasingly, stakeholder engagement and addressing uncertainties have become important considerations in these assessments. What can be noted from the array of methods employed in the literature is that pragmatism has been the guiding principle in selecting and use methods and tools. This principle requires an assessment of the need for robustness, feasibility and availability of data and resources. It is also noteworthy that although the methods offer valuable insights, they may not comprehensively address all policy-related questions. Participation and input from key stakeholders are necessary to gather data on the decision-making context and key decision elements. To assess current vulnerabilities and adaptive capacities, bottom-up methods based on socio-economic realities and livelihoods are preferable to future climate change impacts and large-scale vulnerabilities. While scenario- and model-based approaches are suitable for global-level assessments, they may be less effective at the local level. For improved adaptation planning that considers long-term climate change impacts and vulnerability, a combination of scenario- and model-based approaches with socio-economic and livelihood-based methods is recommended.

Table 1: CV and LUC impact assessment methods applied in another research

				Examples				
Approach	Motivation	Objectives/Goal	Underlying Methods	Impact	Aspects covered	Data/Method	Scale	Reference
Impact oriented	Research	Mitigation of risks	Standard methods: -Biophysical methods -Socioeconomic -Driver-state-impact-response -Hazard-driven risk assessments	Climate variability	The trend of temperature and rainfall extremes	Temperature and rainfall	National *Arid and Semi-Arid Regions*	(Ouma et al. 2018)
				Climate change	Droughts Dry spells Rainfall and temperature trends Variability of rainfall depth and river discharge	Daily discharge Temperature Rainfall	Regional Catchment level Arid and semi-arid regions	(Descheemaeker et al. 2018; Pereira 2017)
Vulnerability oriented	-Research -Stakeholder led	Mitigation of vulnerability	-vulnerability indicators -Past and present climate risks -Livelihood analysis -Narrative methods -	Climate change and variability	Droughts Tterrestrial water budget closure Hydrological characteristics, Subsurface water storage, Aquifer system processes	Remote sensing/Satellite imagery	Region and basin specific	(Ndehedehe et al. 2018)
				Revenue from all crops, such as maise and tea	Household and climate (rainfall and temperature)	Survey (socio-economic and ecological) : Application of Ostrom framework	National Catchment and sub catchment	(Ochieng et al. 2016) (Grothmann et al. 2017)
Adaptation-oriented	-Research -Stakeholder led	Adaptation	-Integrated assessment modelling -Cross-sectional interactions -Integration with climate drivers -Stakeholder discussions -Linking models across types and scales -Combining assessment/approaches	Climate risks and adaptation		Survey (socio-economic and ecological)	Village and district level	(Bedeke 2023; Below et al. 2015)
Integrated	-Research -Stakeholder led	Global climate policy and economic options	-Methods applied under all other approaches -Methods of characterising and managing uncertainties	Climate Impacts		Integrated Assessment Models (IAMs)	Global	(Asefi-Najafabady et al. 2021) (Willmott and Matsuura 2005)

3.4 Value of LU and CV impact assessments on adaptation and policy

Assessments of the impact of CV and LU are fundamental to finding answers to the following questions such as: i. What are the nature and magnitude of the impacts? ii. how vulnerable are specific local or regional agricultural production systems to climate patterns and land use changes? iii. What mitigation and adaptation options are available? The impact assessments are essential for justifying the adoption of climate-smart interventions and determining effective measures to achieve desired outcomes (Singh et al. 2022; Tilahun et al. 2023). For instance, if smallholder farmers understand which crops or livelihood activities are more sensitive to CV and LUC, they can make informed decisions such as choosing more resilient crops and diversifying their income. Additionally, informing stakeholders about changing climate and land use patterns and their spatial distributions can improve response and ecological resource management (Teck et al. 2023). Therefore, conducting a comprehensive CV and LUC impact assessment is crucial to support a prompt and effective response to the negative impacts of climate and land use changes.

Despite extensive research and technological advancements, assessing the impacts of LUC and CV remains challenging. Scholars argue that the value of LUC and CV impact assessments lies in their potential to influence policies and drive stakeholder action (Figure 3) ultimately leading to different outcomes compared to maintaining the status quo (Bedeke 2023; Yeleliere et al. 2022). However, the land use component is is often neglected in in the impact analysis. Moreover, generating value in these assessments requires considering the interactions between climate variability and change, land use change, socio-economic factors, political dynamics, and institutional structures. Therefore, the following section explores the challenges and opportunities involved in conducting LU and CC impact assessments. This exploration aims to identify ways to enhance the effectiveness of these assessments and improve decision-making processes in the face of changing climate and environmental conditions.

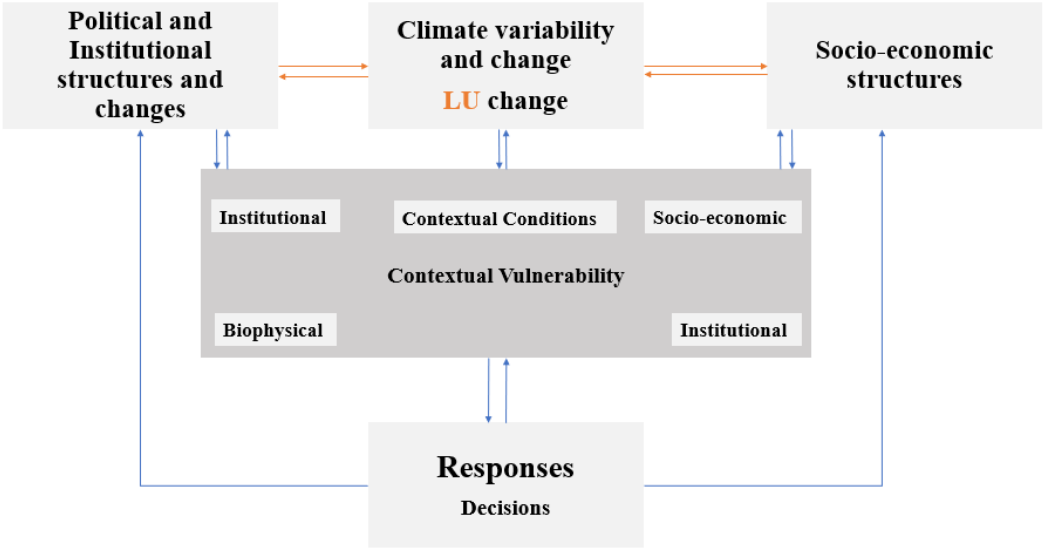

Figure 3: Contextual climate vulnerability impact assessment (adapted and modified from (FAO 2012))
[The author has added the areas highlighted in red as they are critical areas in generating values of the impact assessments]

3.5 Opportunities and challenges of LU and CV impact assessments

3.5.1 Challenges for effective CV and LU impact assessments

Assessing the impacts of climate variability and change (CV) and land use change (LUC) in semi-arid regions presents significant challenges due to inherent heterogeneity and uncertainties in these ecosystems. This complexity makes it difficult to tailor location-specific decision-making for mitigation and adaptation, particularly for smallholder farmers who constitute a substantial portion of the semi-arid regions (Feleke 2015; Zhou et al. 2022). Abbass et al. (2022) and Pereira (2017) noted that a major obstacle to research on CV and LUC impact assessments in Africa has been relatively limited, compared to developed countries, with a focus on regional rather than country-specific or localized studies. This may be attributed, in part, to the lack of impact assessment

adequate data in Africa. Agrometeorological stations are scarce especially in semi-arid areas of developing countries in Africa, resulting in limited access to historical and current climate data (Dinku et al. 2022). Furthermore, the existing data are often stored in analogue format, hindering their immediately analysis.

Apart from the data availability challenges, the predictive ability of climate models in semi-arid agroecosystems of Africa is hampered by biases and errors, even at finer spatial scales. For example, Döll et al. (2016) and Watson et al. (2022) reported that precipitation estimates and water balance indicators which are critical barrier for understanding vegetation responses to water stress are particularly uncertain. Furthermore, the research by Elnashar and Elyamany (2023) show that global-scale climate trend simulations using Monte Carlo methods have shown promise, but their low resolution limits their ability to capture small-scale heterogeneity.

Agricultural systems in semi-arid regions of Africa are highly vulnerable to the impacts of a changing climate and shifting land use patterns. The Intergovernmental Panel on Climate Change (IPCC) has developed the concept of exposure, sensitivity and adaptive capacity to determine how vulnerable a system is to a particular stressor or impact (de Ruiter and Van Loon 2022). However, previous research on the impacts of climate change on agricultural systems has rarely applied this concept. The threefold notion of vulnerability poses challenges to much of the research conducted in this area of vulnerability (de Ruiter and Van Loon 2022). Consequently, clarification and empirical investigation of this vulnerability concept are essential for more effective decision-making. Smallholder farmers in semi-arid ecosystems often practice diversified and mixed land use, combining crops, livestock, and other activities on limited land. These complex farming systems can be difficult to characterize accurately and may not fit well into standard land cover categories.

Aside from the vulnerability concept challenges, some studies claim that LUC and CV impact assessments and adaptation options have concentrated more on effects than adaptation (Ayanlade et al. 2022; Biesbroek et al. 2022). Existing assessments of CV and LUC impacts in agriculture have tended to focus on biophysical productivity, mainly employing reductionist modeling approaches (FAO 2012). These approaches, whether dynamic crop/agroecosystem models or Ricardian economic methods, have limitations in modeling adaptation options. Biophysical models lack context (Preston 2012) and adaptation considerations, while Ricardian methods make assumptions that may not hold in reality, such as long-term equilibrium in factor markets and no adaptation costs (Huong et al. 2019; Seo et al. 2009). As a result, vulnerability and impact assessments often underestimate the adaptive capacity of social systems, providing limited guidance to decision-makers (Biesbroek et al. 2022).

Moreover, the choice of indicators used in CV and LUC impact assessments poses challenges. While hydrological parameters such as precipitation and soil moisture are crucial determinants of climate change effects on agricultural ecosystems (Rao et al. 2019), their suitability as indicators in semi-arid regions requires investigation. For instance, in the semi-arid Sahel, rainfall and soil moisture have shown weaknesses as indicators of water availability (Abdi et al. 2017). Additionally, the indicators may not adequately capture local knowledge systems. Smallholder farmers possess valuable local knowledge about their local ecosystems and climate patterns. However, this knowledge might not always align with scientific assessments, leading to discrepancies in the perceived impacts and priorities. Therefore, a comprehensive impact assessment should consider social indicators alongside these hydrological parameters, including factors like population dynamics, access to resources, and climate-related information (Grothmann et al. 2017). Following the identification of challenges, the subsequent section explores the potential opportunities concerning CV and LUC impact assessments within the semi-arid ecosystems of Africa.

3.5.2 Opportunities for effective LUC and CV impact assessments

Interdisciplinary research offers the opportunity to comprehensively assess climate and land use impacts (Figure 4). By integrating climate, natural, environmental and social sciences, such research endeavours can yield more useful results more for decision-making, adaptation and policy at all levels. Some researchers have explored using integrated assessment models (IAMs) (Cui et al. 2022; Ferrari et al. 2022; Keppo et al. 2021). However, there are many criticisms of IAMs including technical limitations and concerns about assumptions, concepts and goals (Asefi-Najafabady et al. 2021). These critiques argue that IAMs do not adequately capture the interactions between Earth and human systems.

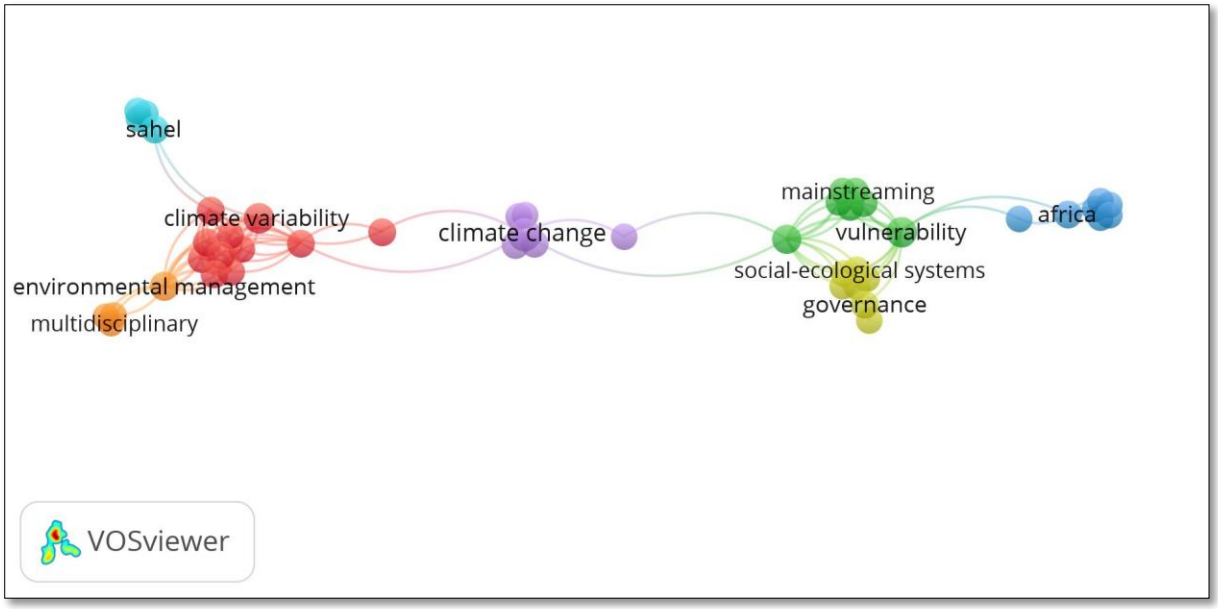

Figure 4: Linkages of the keywords in LU and CC impact assessments literature search. (There are some interlinkages between climate change and other variables ecology, environmental management, governance and socioecological systems.)

Another approach that can be explored as a possibility is to use the systems approach to assess the relationships, interconnections and feedback in different components between society, climate, land use, agriculture and ecosystems (Figure 5). Amadou, Villamor and Kyei-Baffour, (2018) advocate for using complex systems approach to analyse climate change and land use change impacts. Complex systems require the study of human-environment-climate interactions across geographic and temporal dimensions. Such complex systems approach can be achieved through integrating interdisciplinary research methods with specialised studies of organismal processes and mechanisms (Amadou et al. 2018). The socio-economic context of communities is also a crucial factor to be considered when applying a complex systems approach. Regarding guiding agricultural policy and making effective decisions, a comprehensive and relevant approach is essential to capture all dimensions of climate and land use change impacts. Kjøhl et al. (2011) argue that the effects of climate and LUC on the overall ecosystem are much more difficult to predict by pure integration due to the complexity. Existing approaches that rely on a single metric may not adequately capture the complexity of LUC and CV drivers can leading to suboptimal and potentially counterproductive mitigation strategies (Cherubini et al. 2016). Thus, a systems approach is proposed because of the nonlinear relationships between critical components and the heterogeneous nature of semi-arid ecosystems and smallholder farming systems.

GIS and remote sensing present an important means of data provision, especially given the scarcity of data and the uneven distribution of observation stations in semi-arid regions. The improved spatial resolution of remote sensing datasets enhances the accuracy of impact assessment results, while the temporal resolution enables dynamic tracking of changes and trends over time.

Ecological vulnerability assessments, which integrate climate and land use variables, along with other factors, offer an option for impact assessments, can also be used to analyse land use and climate effect. By incorporating social and environmental variables, such assessments can better analyze the interactions with LUC and CV. Furthermore, the analysis may make use of GIS and remote sensing, as well as a systems analysis technique in a GIS environment.

One of the challenges mentioned in assessing climate and land use impacts was the limited scope of analysis. Semi-arid ecosystems are inhabited by many rural smallholder farmers with a rich indigenous knowledge system (IKS). Integrating this valuable IKS into formal assessments can significantly improve the evaluation of impacts and possible adaptation options. As the IKS is deeply intertwined with the daily lives of rural communities and their environment, it constitutes a crucial component that can complement other approaches.

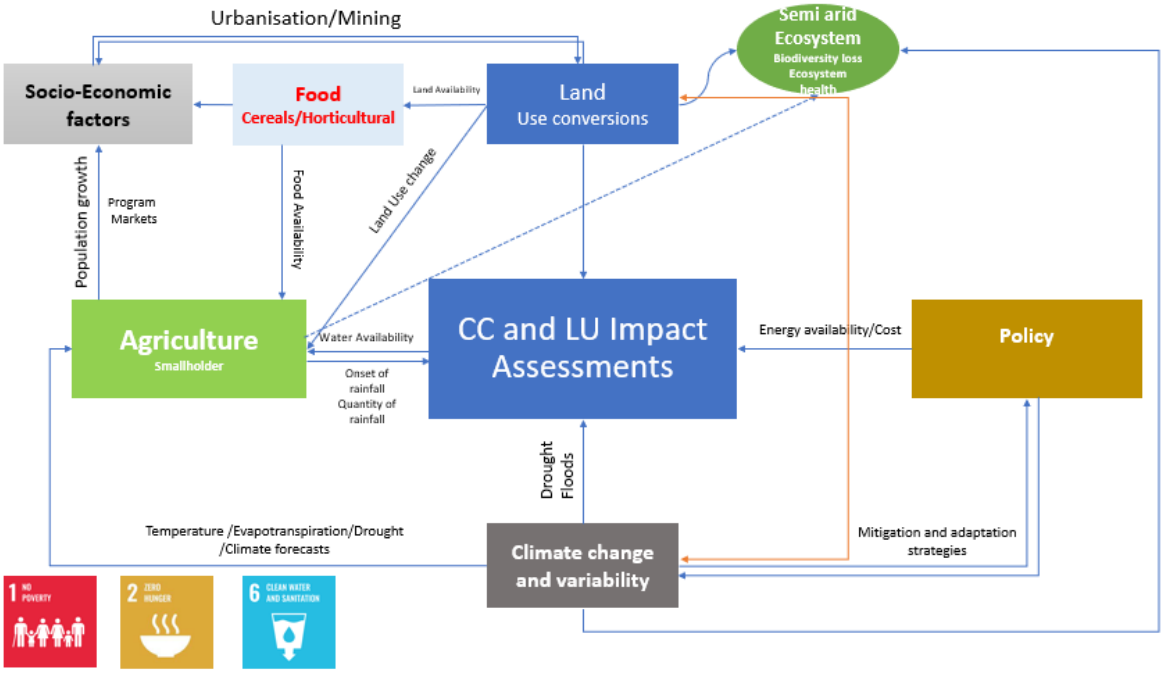

Figure 5: Conceptual framework for the interaction of key variables and sectors that are critical for CC and LU impact assessments (Author)

4.0 Concluding remarks

The impacts of land use change (LUC) and climate variability and change (CV) on semi-arid agriculture are significant and complex. The effects are manifested through changes in temperatures, precipitation, seasons and CO_2 concentration and patterns. Assessing these impacts requires careful consideration of various driving factors, objectives, geographical scope, timeframe, techniques, tools, and data requirements, especially regarding future environmental and socio-economic conditions.

However, the existing methods for assessing the impacts of LUC and CV can be categorized into four groups: impact, adaptation, vulnerability, and integrated alignment. Each approach has its strengths and drawbacks. Challenges such as the heterogeneity of semi-arid environments, data availability, model biases, lack of adaptation orientation, and limitations of indicators used pose obstacles to effective small-scale impact assessments.

To overcome these challenges and make assessment results more useful for decision-making, adaptation, and policy formulation, a shift towards an integrated systems approach is suggested. This interdisciplinary approach should consider the complex interactions between climate, natural, environmental, and social sciences at the local level. By understanding the intricate relationships between Earth and human systems, policymakers can make informed decisions and develop effective strategies for managing LUC and CV impacts.

One potential method to perform impact assessments in semi-arid environments is through vulnerability assessments using remotely sensed datasets in a Geographic Information System (GIS) environment. This approach allows for a comprehensive consideration of climate and land use changes, environmental factors, and social variables in the assessment process.

However, it is important to acknowledge that the results of LUC and CV impact assessments can vary, with some cases showing positive outcomes and others being difficult to quantify. This variability underscores the need for continuous improvement and refinement of LUC and CV impact assessment methods to enhance their value and effectiveness.

Author Contributions

BC, participated in designing, conceptualisation and writing the first draft of the study and data collection; OG, SPM and WM provided guidance and revision of the manuscript. OG, SPM and WM read all the versions of the manuscripts and made the necessary changes.

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Conflict of interest

The author declares that there was no conflict of interest.

Ethical standards

None.

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