Spatially targeting conservation and farm mechanization in Southern Africa: Insights from multicriteria analysis

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Abstract
The uptake of conservation agriculture and farm mechanization in Southern Africa has been slow and low. As a result, most smallholder farmers continue to grow crops under degraded soils using conventional tools and human powered farm operations. This leads to low productivity. Therefore, spatially visualizing areas where conservation agriculture and farm mechanization can be targeted can be crucial to guide targeting and scaling. In this study, a geographical information systems-based multicriteria analysis using the analytical hierarchical process was used to map the suitability of conservation agriculture and farm mechanization in Malawi, Zambia, and Zimbabwe. This included biophysical (soil, rainfall, temperature, slope, elevation, land use and biomass) and socioeconomic (population density, farming system and livestock ownership) as recommended domains. The Super Decision software 3.2.0 was used to generate the final weights through pairwise comparison. ArcGIS Pro 2.6 through fuzzy functions was used to standardise and generate the maps. The results show that over 95% of the land area in Zimbabwe, 73% in Zambia, and 67% in Malawi are suitable for conservation agriculture and farm mechanization. Malawi, however, has a bigger proportion of land (1%) among the three countries with low suitability. There are regional differences with Lilongwe and Balaka in Malawi; Southern, Central, Eastern and Western provinces in Zambia; and Matebeleland South and North, Mashonaland West, Midlands and Masvingo provinces in Zimbabwe being the most suitable for conservation agriculture and farm mechanization. After validation, the suitability map based on varying weights showed higher levels of reliability, resulting in context-specific suitability maps and that the mapping process was robust. Thus, the suitability maps generated from this study can be used for targeting conservation agriculture and farm mechanization by stakeholders and decision-makers in the three countries.

Keywords: Validation, sensitivity analysis, CA, and Farm mechanization.

Introduction

Soil degradation has adversely affected the production capacity of most parts of Africa. The increasing animal and human population coupled with traditional methods of farming are putting more pressure on the soil in Africa (Decaëns et al., 2006). This has in turn affected people's livelihoods, including food security in many countries (Erenstein, 2003). Conservation agriculture has been identified to help reduce soil degradation, enhance crop productivity, conserve water, and maintain yield stability (Tesfaye et al., 2015, Baudron et al., 2012). Conservation agriculture is also crucial in improving the survival of crops during a flood or drought as well as mitigating climate change through soil carbon sequestration (Umar and Nyanga, 2011, Giller et al., 2009, Gjengedal, 2016). According to Marongwe et al. (2012), conservation agriculture promotes crop management, weed management and efficient use of inorganic and organic fertilizers. Therefore, conservation agriculture is one of the promising ways of sustainably growing food or crops in Africa and the world over (Shetto and Owenya, 2007).

Several scholars (Erenstein, 2003, Tesfaye et al., 2015, Knowler and Bradshaw, 2007) contend that conservation agriculture adoption and performance differs from place to place due to varying levels of knowledge and mechanization. Thus, it is important to understand, ex-ante where CA and farm mechanization are most suitable to facilitate better targeting. In doing so, there is a need to recognise that factors or domains to consider for generating suitability maps for conservation agriculture and farm mechanization may differ from one country to another. This suggests the need for context-specific factors for mapping the suitability in particular geographical areas. Tesfaye et al. (2015) and Giller et al. (2009) argue that biophysical and socio-economic factors highly influence conservation agriculture and mechanization adoption and performance. Thus, both biophysical and socio-economic are key to map the suitability of conservation agriculture and mechanization.

Some smallholder farmers in Southern Africa consider conservation farming to be labour-intensive (Ngoma et al., 2016) as well as associated with increased weed pressure (Marongwe et al., 2011). This highlights the need for farm mechanization among smallholder farmers. The adoption of conservation agriculture and farm mechanization are complementary and are important to increase crop productivity, for sustainable food security, and profits while reducing soil disturbance and maintaining soil cover (Liao et al., 2022, Paudel et al., 2023). However, improved mechanization among smallholder farmers requires corresponding technical support to foster sustainability.

Mapping suitable areas for conservation agriculture and mechanization practices is important because it can guide where conservation agriculture can be potentially adopted (Bahri et al., 2019). It can also be useful for up-scaling and out-scaling (Tesfaye et al., 2015). Mapping the suitability of conservation agriculture and mechanization can also be used to attract more research and investment in the identified areas. Various methods and approaches have been used to map suitable areas for conservation agriculture in Africa. Chief among the methods is the use of Geographical Information Systems (GIS). This is because GIS allows the integration of different sources of data. GIS is also effective in capturing, storing, and analysing geographically referenced data. Tesfaye et al. (2015) used slope, soil texture, rainfall and human population, market access livestock and livestock density to map potential areas for conservation agriculture in Ethiopia, Kenya, and Malawi using ArcGIS 10.1. Muthoni et al. (2017) used K-means clustering and geospatial analysis to delineate recommendation domains for scaling improved crop varieties and good agronomic practices in Tanzania. However, both Tesfaye et al. (2015) and Muthoni et al. (2017) used equal weight to the recommended domains and did not conduct any sensitivity analysis. Therefore, the reliability of the results can be questioned.

Due to the need to consider local conditions and the complexity and diversity of factors to be considered in producing suitability maps for conservation agriculture and mechanization, multicriteria approaches are ideal (Chakraborty and Mukhopadhyay, 2019, Ouma and Tateishi, 2014, Lin et al., 2019). In particular, the Analytical Hierarchy Process (AHP) is one approach that has been used in various fields as a multicriteria technique with GIS. This is because of its applicability in making decisions because of its simplicity and because various domains are rated as per experts' priorities (Li et al., 2011, Ghorbanzadeh et al., 2018). Furthermore, the AHP helps to solve complex problems by comparing two factors based on their relative importance (Saaty, 2013, Feizizadeh et al., 2014). However, the mapping of suitable areas for conservation agriculture and mechanization using GIS-based Multi-Criteria Decision Making (MCDM) in Africa, particularly East and Southern Africa using varying weights, has not been adequately explored. This is mainly due to the many and complex domains involved in mapping the suitability of conservation agriculture and farm mechanization as well as the failure of many scholars to have stakeholders participate in the mapping process. This approach has however been used in mapping flood vulnerability (Membele et al., 2023).

Methodology

To identify what was required for mapping suitable areas for conservation agriculture and farm mechanization in East and Southern Africa, keywords "mapping", OR "suitability mapping", OR "adoption", AND "conservation agriculture", OR "mechanization" AND "Africa" were searched in three databases namely Web of Science, Science Direct and Google Scholar. Some literature was discarded based on the title and after reading the abstract. Additional literature was also considered on account of having been cited in the literature that was considered from the three databases. Hundred (100) journal articles, book chapters and other scholarly work were reviewed and only 40 were more related to the subject. Appendix 1 shows the literature reviewed, the countries covered in the literature, the crop, element, the biophysical and socio-economic factors conservation agriculture, and farm mechanization they highlighted and whether some maps were produced or provided.

Recommended domains that appeared four times or more were compiled and then subjected to experts in Zambia, Zimbabwe, and Malawi to ensure that context-specific domains for mapping conservation agriculture and farm mechanization were selected. Twenty-two experts were purposively selected on account of their knowledge of conservation and farm mechanization in Southern Africa. Six experts were from Malawi, nine from Zambia and seven from Zimbabwe. This information was collected using a structured digital online survey.

Various open-source platforms were searched for geospatial data to use in mapping the suitability of conservation agriculture and farm mechanization in the three countries. Only data that was available in all three countries was used to facilitate inter-country comparisons. The data collected was resampled to a spatial resolution of *1km x 1km* for the three countries. The data was also projected to a uniform coordinate reference system. Fuzzy functions in ArcGIS Pro 2.6 of 0 (low suitability) to 1 (high suitability) were used to reclassify all the spatial data layers into a common scale. The data was aggregated into a composite map in ArcGIS Pro 2.6 using weighted overlay first using equal weights and finally using varying weights generated by experts familiar with Malawi, Zambia, and Zimbabwe. Then Analytical Hierarchical Process (AHP) in Super Decision software was used to generate the final weights through pairwise comparison. The Super Decision software version 3.2.0 was developed by Saaty (Saaty 2007, 2013) and it is a free tool that can be downloaded from https://www.superdecisions.com/.

Results

From the twenty-two recommended domains that were generated from a review of the literature, experts from Malawi, Zambia and Zimbabwe generated twenty-four recommended domains (Table 1). From the biophysical factors, the climate domain was removed from the list generated from the review of the literature and was replaced by elevation. From the socioeconomic factors, the attitude domain was removed and replaced by years of conservation agriculture application. Furthermore, population density and farming systems were added by the experts.

Table 1: Recommended domains generated by experts.

Factor	Domain	Spatial Resolution	Source
Biophysical	Soil	250m	ISRIC https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/2a7d2fb8-e0db-4a4b-9661-4809865aaccf
	Rainfall	4km x 4km	CHIRPS https://chrsdata.eng.uci.edu/
	Temperature	4km x 4km	Climatology Lab https://www.climatologylab.org/terraclimate.html
	Altitude (Elevation)	90m x 90m	OpenTopography https://portal.opentopography.org/dataCatalog?group=global
	Slope	100m	WordPop https://hub.worldpop.org/geodata/listing?id=57
	Biomass	400m x 400m	FEWS NET https://earlywarning.usgs.gov/fews/datadownloads/East%20Africa/eMODIS%20NDVI%20C
	Land use	10m x 10m	ESRI http://www.globeland30.org/GLC30Download/index.aspx https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=147.744%2C-37.19%2C11&mode=step&timeExtent=2017%2C2022&year=2022
	Farm size		
Socio-economic	Farming inputs		
	Education		
	Experience/knowledge		
	Household size		
	Assets		
	Access to markets		
	Livestock ownership	9km x 9km	FAO https://www.fao.org/livestock-systems/global-distributions/cattle/en/
	Financial resources		
	Extension services		
	Gender		
	Age		
	Labour availability		
	Secure tenure		
	Population density	1km x 1km	WorldPop https://www.worldpop.org/
	Years of CA application		
	Farming system	1km x 1km	RCMRD http://geoportal.rcmrd.org/layers/servir%3Aafrica_farming_systems

After searching for spatial data from online open-source platforms only seven recommended domains from biophysical factors were found (Figure 1) while socioeconomic factors included population density, livestock ownership and farming systems (Figure 2).

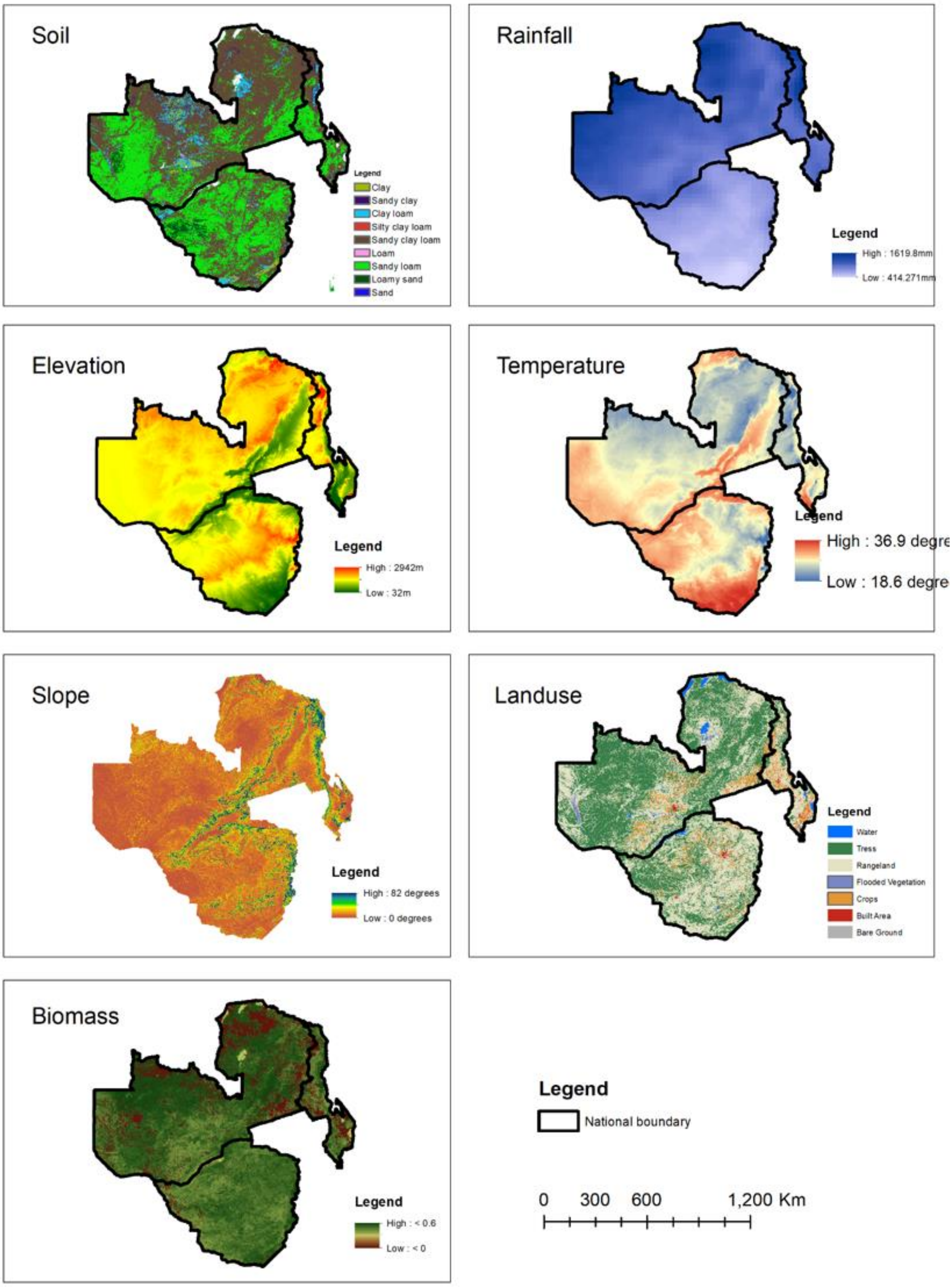

Figure 1 Biophysical domains used for mapping the suitability for conservation agriculture and farm mechanization.

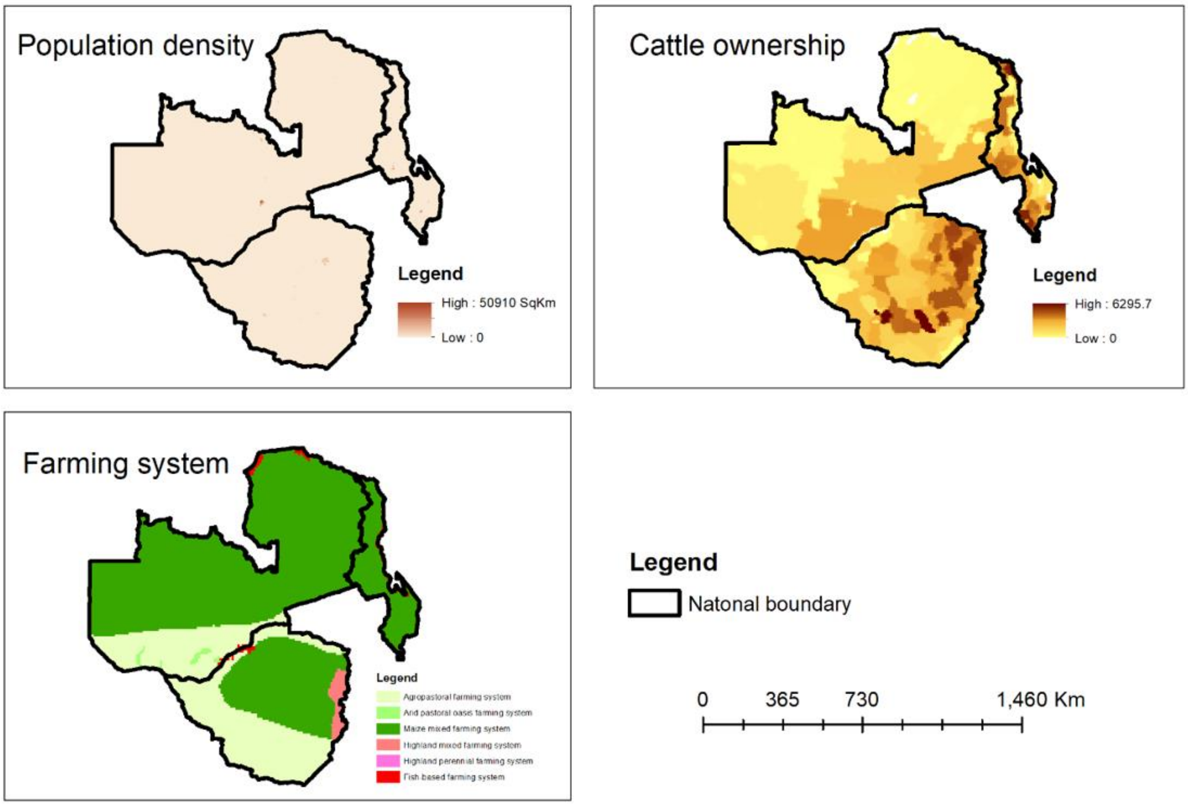

Figure 2 Socioeconomic recommended domains for conservation agriculture and farm mechanization.

Suitability mapping using equal weights

Based only on biophysical factors and equal weights, results suggest that Zimbabwe has many areas suitable for targeting conservation and farm mechanization compared to Malawi and Zambia (Figure 3).

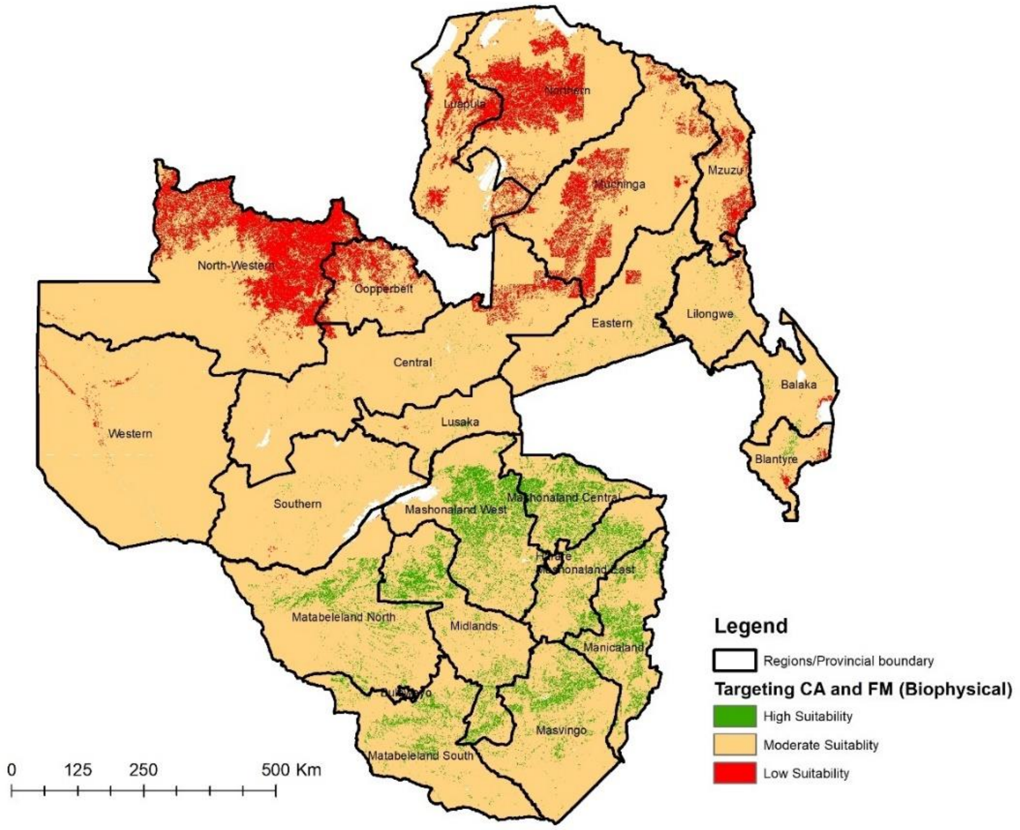

Figure 3 Suitability of conservation agriculture and farm mechanization based on biophysical domains.

When considering only socioeconomic domains, we see that Zambia has more areas suitable for conservation agriculture and mechanization than Zimbabwe and Malawi (Figure 4).

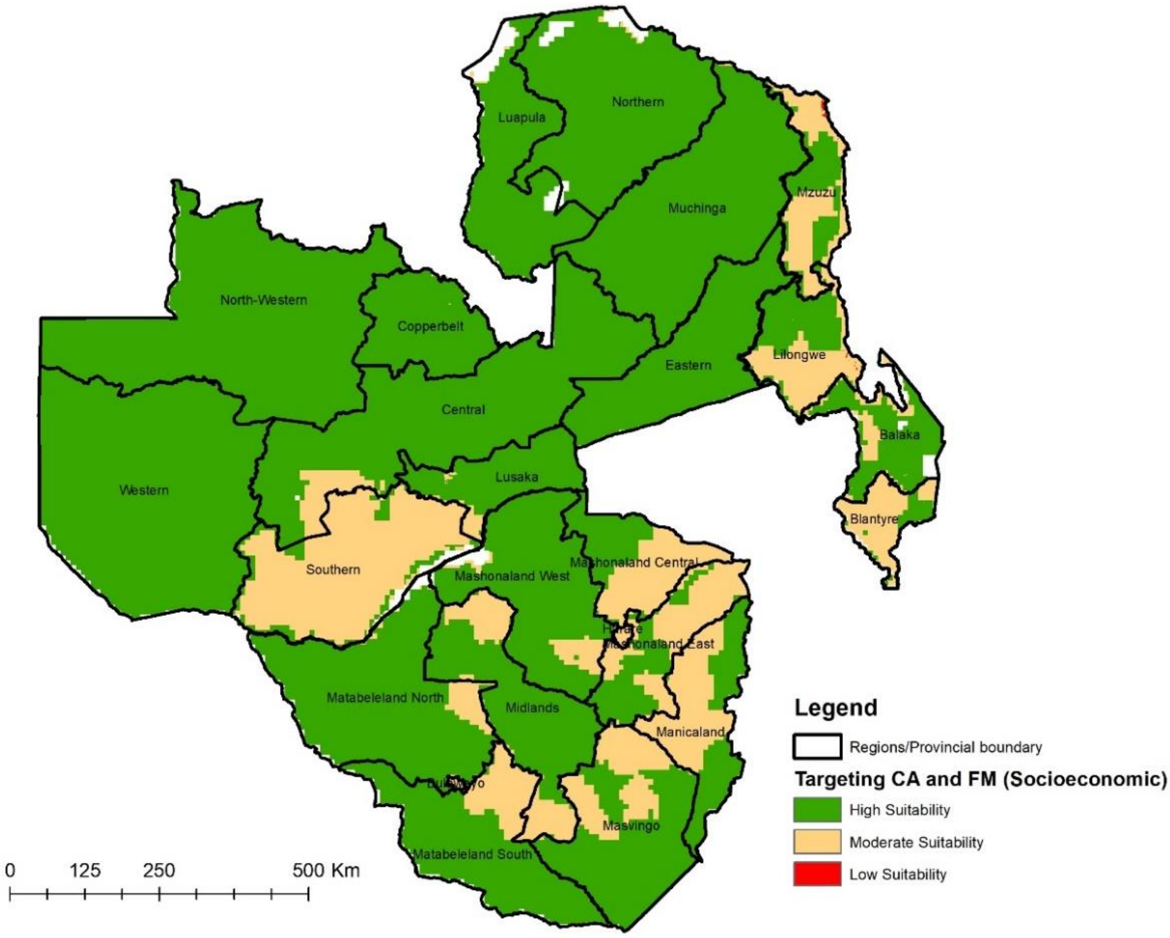

Figure 4 Suitability of conservation agriculture and farm mechanization based on socioeconomic domains.

Once the two domains are combined, results paint a different picture. The results from the aggregation of biophysical (Figure 3) and socioeconomic (Figure 4) using equal weighting resulted in a composite map showing the suitability of conservation agriculture and farm mechanization in the three countries (Figure 5). From these results, parts of southern, central, and eastern Zambia, northern, north-east, south and south-west parts of Zimbabwe and parts of southern and central Malawi are better suited for conservation agriculture and mechanization.

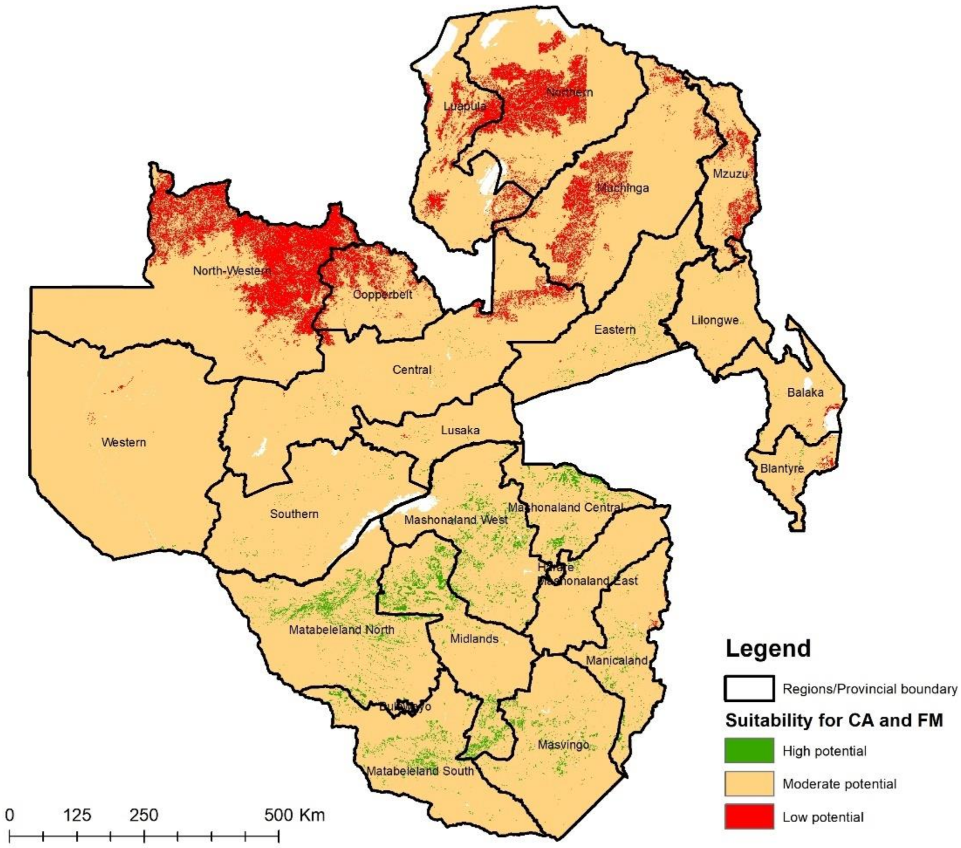

Figure 5 Suitability of conservation agriculture and farm mechanization in Malawi, Zambia, and Zimbabwe using equal weighting

Suitability mapping using varying weights

Through consensus, the experts weighted the recommended domains using percentages. The weights were then aligned to the ratio of 1-9 developed by Saaty for use during a pairwise comparison according to the Analytical Hierarchical Process. The results of this process show that the farming system was the most influential (38%) domain in determining the suitability of conservation agriculture and farm mechanization in Malawi, Zambia, and Zimbabwe (Table 2). The other influential domains included soil (22%) and rainfall (16%).

Table 2: Weights based on expert knowledge and Pairwise Comparison

Factor	Domain	Weight from Experts	Weight based on Pairwise Comparison
Biophysical	Soil	18	0.22
	Rainfall	17	0.16
	Biomass	8	0.03
	Elevation	9	0.05
	Slope	5	0.01
	Land use	6	0.01
	Temperature	8	0.03
Socioeconomic	Pop Density	10	0.10
	Livestock Ownership	6	0.02
	Farming System	13	0.38

Based on the weight generated in the Super Decision Software's pairwise comparison using the Analytical Hierarchical Process, a final composite map showing the suitability of conservation agriculture and farm mechanization in Malawi, Zambia and Zimbabwe was generated (Figure 6). The map shows that many districts in Malawi, Zambia and Zimbabwe were suitable for conservation agriculture and farm mechanization. Furthermore, moderately suitable areas for conservation agriculture and farm mechanization were in the northern parts of both Zambia and Malawi, and the southern tip of Zimbabwe.

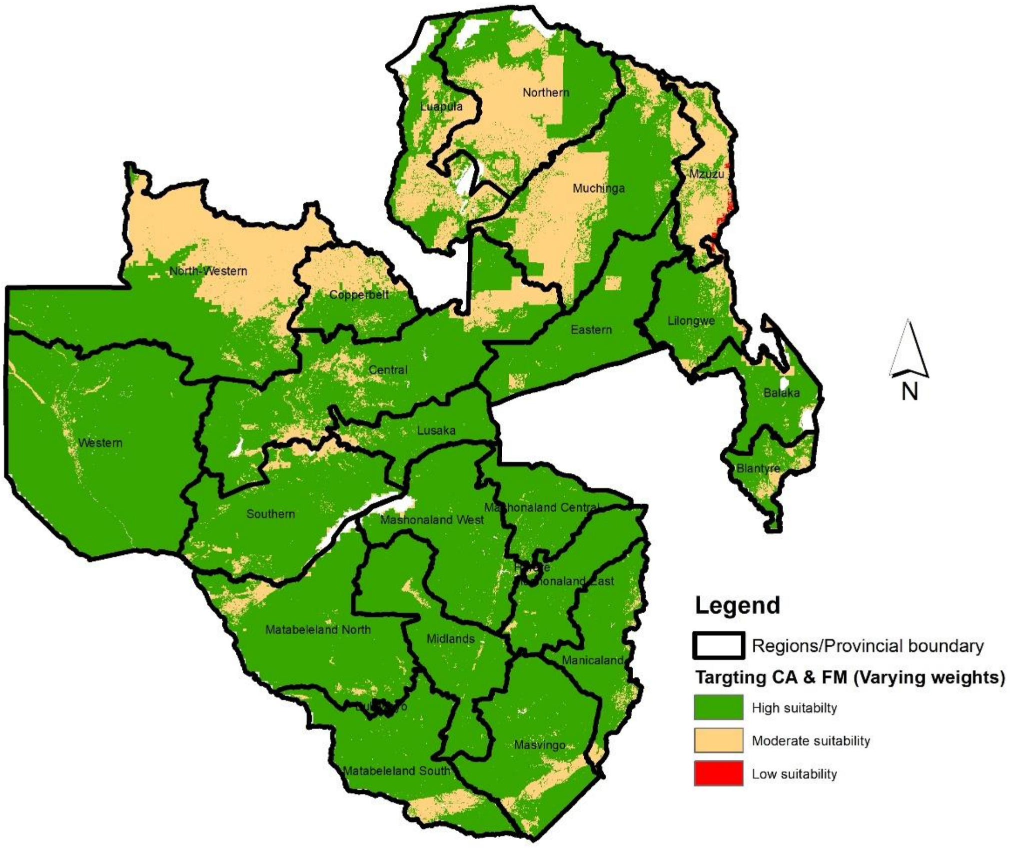

Figure 6 Suitability of conservation agriculture and farm mechanization in Malawi, Zambia and Zimbabwe using varying weights.

The results also show that Malawi has a bigger proportion of land mass with low suitability (1%) for conservation agriculture and farm mechanization (Figure 7) when compared to Zambia (Figure 8) and Zimbabwe (Figure 9).

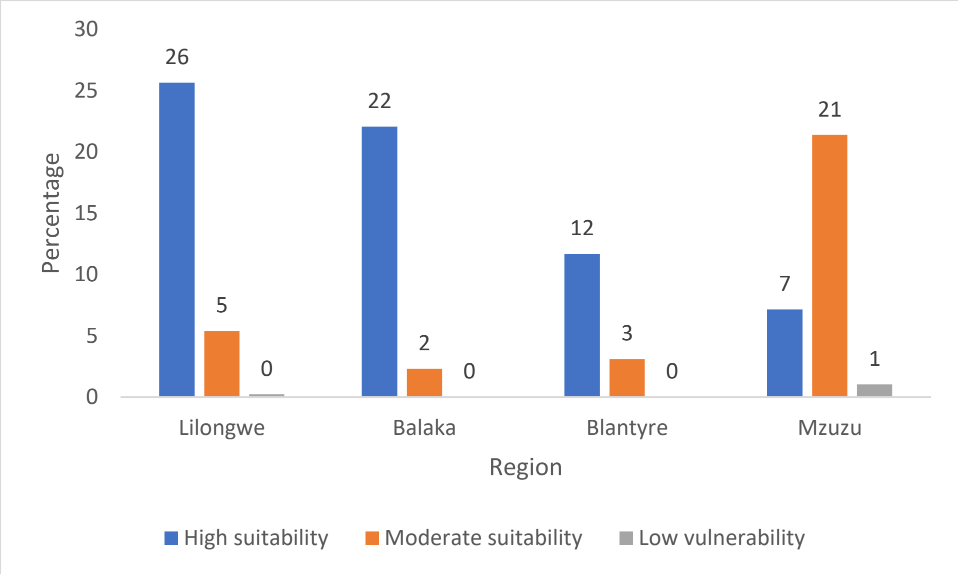

Figure 7 Proportion of land area suitable for conservation agriculture and farm mechanization in Malawi

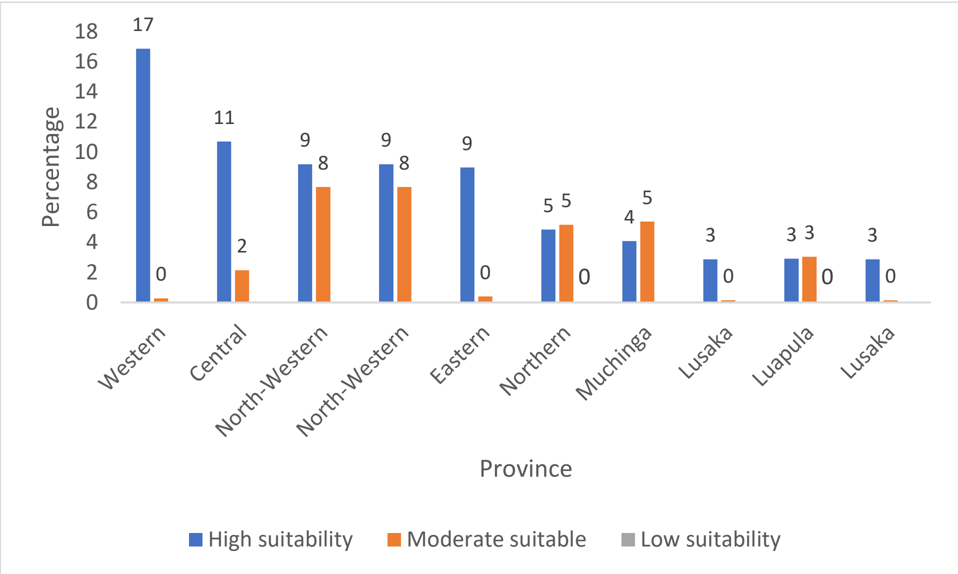

Figure 8 Proportion of land area suitable for conservation agriculture and farm mechanization in Zambia.

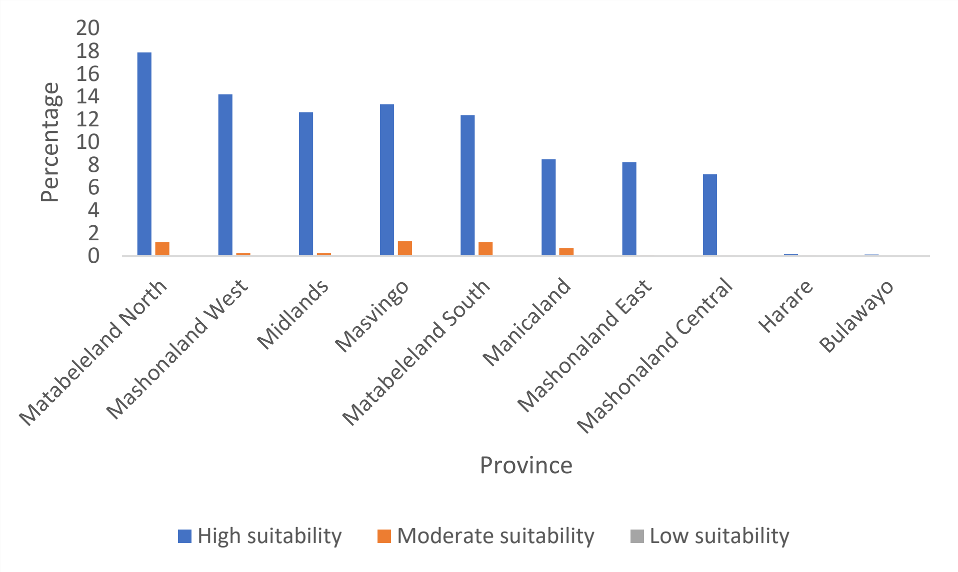

Figure 9 Proportion of land suitable for conservation agriculture and farm mechanization in Zimbabwe.

The results further reveal that a considerably bigger size (32%) of land is moderately suitable for conservation agriculture and farm mechanization in Malawi. Zimbabwe has the biggest proportion of land suitable for conservation agriculture and farm mechanization (95%) followed by Zambia (73%). At subnational level, areas highly suitable for conservation agriculture and farm mechanization and include Lilongwe and Balaka in Malawi; Southern, Central, Eastern and Western provinces in Zambia; and Matebeleland South, North, Mashonaland West, Midlands and Masvingo provinces in Zimbabwe.

Validation of final suitability maps

The final suitability map that was generated using varying weights was subjected to both quantitative and qualitative validation. The quantitative validation involved overlaying the geolocations of households found to be practising some elements of conservation agriculture in a multi-country survey conducted by CIMMYT and IITA in 2021. Results from an overlay of suitable areas and households practising conservation agriculture show that almost all (98%) of the households that had adopted conservation agriculture in Balaka (Malawi), Choma (Zambia) and Bubi (Zimbabwe) matched. This gives credence to the suitability mapping approaches used in the analysis and suggests that they are both internally and externally valid. Furthermore, one of the experts from Malawi indicated that the suitability map reflected what was on the ground.

For instance, the northern parts of Malawi were slow at adopting conservation agriculture and low-suitability areas matched the areas that were currently being used for rice cultivation.

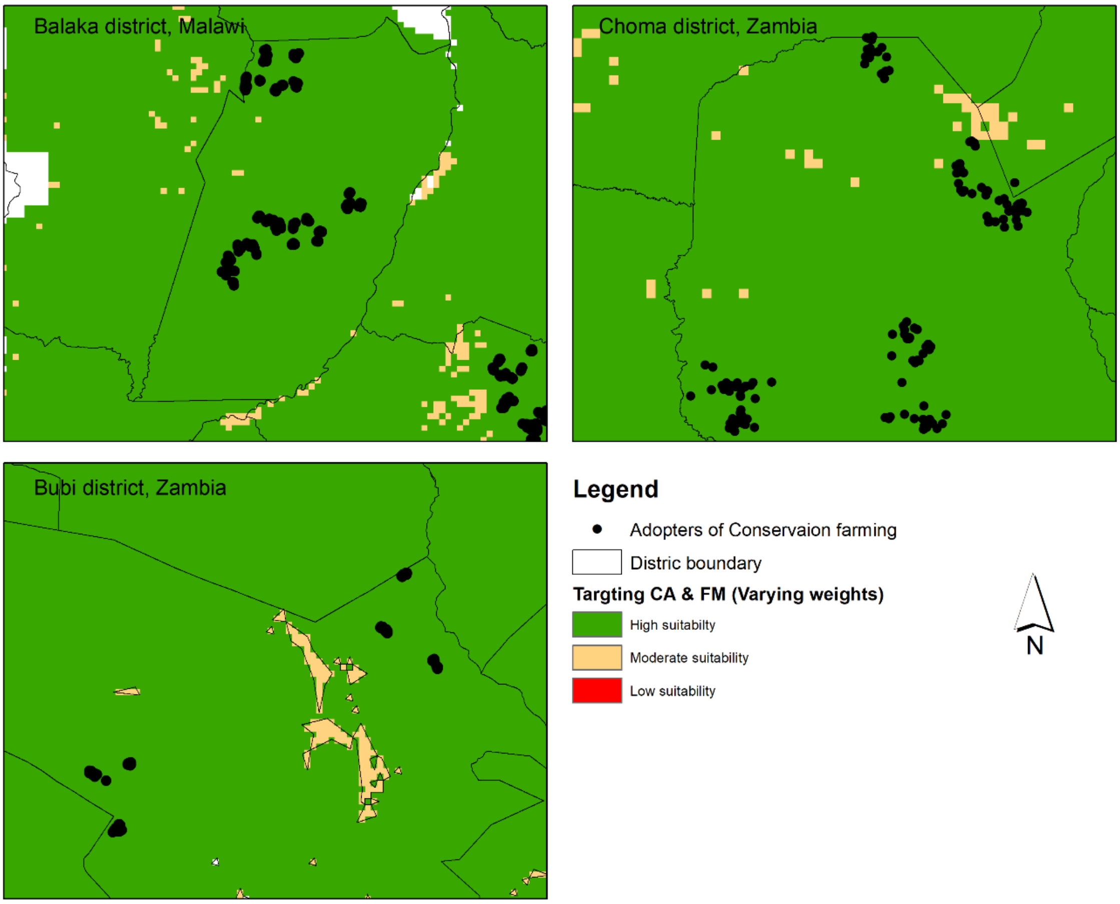

Figure 7: Validation of the final conservation agriculture and farm mechanization suitability map

Discussion

Several scholars (Ochola et al., 2010, Roy and Blaschke, 2013, Percival and Teeuw, 2019, Membele et al., 2022) that have used multicriteria approaches in mapping flood vulnerability, conservation agriculture, and water potential have used equal weight. However, results from this study show that the use of equal weight does not give a true picture of areas that are suitable for promoting conservation agriculture and farm mechanization. This is because the equal weight approach shows a gloomy picture with small areas suitable in Malawi, Zambia, and Zimbabwe. However, the suitability map based on varying weights shows a more realistic picture of suitability in the three countries. In particular, the suitability map showed that Zimbabwe had larger areas suitable for targeting conservation agriculture. Several scholars (Membele et al., 2023, Usman Kaoje et al., 2021, Tesfaye et al., 2015), have used varying weights to map different phenomena. This is because it gives accurate and context-specific results. This situation could be because of the low rainfall that has been experienced in Zimbabwe for a long time. Several scholars (Musara et al., 2022, Mamombe et al., 2016) have stated that Zimbabwe has experienced many years of dry spells mainly due to climate change.

Two additional recommended domains were added by experts from Malawi, Zambia, and Zimbabwe from the twenty-two domains that were generated from the literature. This highlights the significance of integrating the local context in the identification of domains for mapping the suitability of conservation agriculture and farm mechanization. The involvement of experts in the field resulted in a complete assessment of the domains that are crucial in supporting conservation agriculture and farm mechanization. The use of experts to generate indicators or weight is not new. Chabala et al. (2020) used expert options in the evaluation of the benefits of conservation agriculture in Malawi, Zambia, and Zimbabwe. Furthermore, Membele et al. (2023) used community members in the identification and weighting of criteria for mapping flood vulnerability. Hence Ataei et al. (2021) argue that expert views are very important in fostering the adoption of conservation agriculture.

Although climate was found in the literature to be an important domain to consider when mapping the suitability of conservation and farm mechanization, the experts removed it as it was already represented by rainfall and temperature. Furthermore, climate was difficult to measure when compared to rainfall and temperature. Rainfall is an important domain because it determines the kinds of crops to be grown in a particular area (Tesfaye et al., 2015, Thierfelder et al., 2015). In this study, areas of low rainfall were considered to have low suitability (Thierfelder et al., 2015, Rusinamhodzi et al., 2011). Areas of higher temperature were also identified to be areas highly suitable for conservation agriculture and farm mechanization. This is because the advent of climate change has contributed to increased temperatures across the world. For example, Erenstein (2003) argues that mulching can help reduce the impact of solar radiation and reduce soil temperature stress in warm areas. According to Kidane et al., (2019), crop yield variability was lower in areas with higher elevation. Therefore, areas with relatively high elevation were considered to have high suitability while very flat and low areas were considered to have low suitability as they can be used for other purposes. Soil with heavy texture was considered to have low suitability due to them being prone to waterlogging while sandy and loam were considered to have high suitability for conservation agriculture and farm mechanization (Rusinamhodzi, 2011). Areas with relatively steep slopes were considered to have a higher chance of adopting conservation agriculture than flat areas (Tesfaye, 2015). Normalized Difference Vegetation Index (NDVI) was used as a proxy for biomass. This is based on Chapungu et al. (2020), who argue that NDVI is a better proxy for above-ground biomass. NDIV is used to measure and monitor biomass production and vegetation cover. Land use is important because growing crops on unsustainable land reduces crop production and further degrades the land (Li et al., 2017).

Livestock ownership has been a big issue in Southern Africa (Li et al., 2017, Giller et al., 2011, Tufa et al., 2023). This is because two schools of thought have emerged. The first school of thought argues that since conservation agriculture is labour-intensive, having more livestock supports the adoption of conservation agriculture. The second school of thought contends that having more livestock reduces residuals which are important in conservation agriculture. Therefore, increased ownership of livestock is not suitable for conservation agriculture. The second school of thought underpinned this study. Population density and farming systems were added to the socioeconomic domains by the experts. Population density was added because areas with high population density tend not to adopt conservation agriculture and farm mechanization as two are more suitable where there is need for intensification (Notenbaert et al., 2013). On the other hand, conservation agriculture promotes sustainable intensification by using improved management practices that foster soil fertility and resilience during dry periods (Marongwe et al., 2011, Thierfelder et al., 2012). Although the farming system was found to be the most important domain in influencing the suitability of conservation agriculture in Malawi, Zambia, and Zimbabwe, it was hardly used in the literature in mapping the suitability of conservation agriculture so far (Tesfaye et al., 2015, Muthonia et al., 2017, Notenbaert et al., 2013). Therefore, using experts helps to better understand the local context to have more nuanced recommended domains. Tisdell (1996) argues that farming systems are important because they influence productivity. Niles et al. (2015), further argue that the impact of climate change in a particular geographical area was partly a function of farming systems.

Due to climate change, some areas that are currently considered to have moderate or low suitability for conservation agriculture may become highly suitable. This is due to the expected changes in the rainfall and temperature. Furthermore, scholars like Thierfelder et al. (2015) argue that most areas in Southern Africa are suitable for conservation agriculture. This is also why the validation of the maps showed a high accuracy level of suitability for conservation and farm mechanization in Malawi, Zambia, and Zimbabwe. The validation of the final suitability map is very important in any suitability mapping process. This is because it enhances legitimacy, usability, and acceptance by the public and decision-makers (Rincón et al., 2018, Mahmoody Vanolya et al., 2019).

Furthermore, the use of equal weights and different weights showed a different output of the suitability of conservation agriculture and farm mechanization in Malawi, Zambia, and Zimbabwe. This shows that the mapping process was robust and passed the sensitivity test. According to de Brito et al. (2019), sensitivity analysis is important in checking the change in weights would result in a change in the output. Sensitivity analysis was crucial in fostering transparency in the suitability mapping results (Membele et al., 2022, de Brito et al., 2019).

One limitation of this study was the availability of spatial data for different recommended domains. For instance, out of the sixteen socio-economic domains that were identified by experts, only three were used in this study. This is because the data was not easily available or was not consistent in the three countries. In a spatial data-scarce environment like developing countries, the unavailability of updated and accurate spatial data can be overcome by using proxy spatial data. In this study for instance cattle ownership was used as a proxy for livestock ownership. The availability of accurate, updated and consistent spatial data is a challenge in most developing countries (Kienberger, 2012, Hoque et al., 2019). There is, therefore, a need for developing countries to start working together to ensure that more updated and consistent spatial data is available on open-source platforms as this would increase the usability of spatial data in supporting planning and decision making.

Conclusion

The need to better target development interventions has been recognized for a long time, however, interventions proceed without ex-ante guidance. This paper used a geographical information system-based multicriteria decision analysis using the analytical hierarchical process to map areas most suitable for conservation agriculture and mechanization in Malawi, Zambia, and Zimbabwe. The analytical hierarchical process is suitable for this purpose because of its ability to deal with complex decision problems. In particular, the involvement of the experts in generating recommended domains and assigning varying weights provided a more context-specific picture of suitable areas for conservation agriculture and farm mechanization in the three countries. The analysis included biophysical (soil, rainfall, temperature, slope, elevation, land use and biomass) and socioeconomic (population density, farming system and livestock ownership) recommended domains. The Super Decision software 3.2.0 was used to generate the final weights through pairwise comparison. ArcGIS Pro 2.6 through fuzzy functions was used to standardise and generate the maps.

Results suggest that farming system and the nature of the soil in the three countries were very significant in influencing the final suitability maps. This is because they highly influence the type of crops that can be grown and the potential for mechanization. Further, we found that both conservation agriculture and farm mechanization are suitable in over 95% of the area in Zimbabwe, 73% in Zambia and 67% in Malawi at national level. In Malawi, however, we found that at least 1% of the land area has low suitability for both conservation agriculture and mechanization. This is the largest proportion of land with low suitability among the three countries. There are regional differences with Lilongwe and Balaka in Malawi; Southern, Central, Eastern and Western provinces in Zambia; and Matebeleland South and North, Mashonaland West, Midlands and Masvingo provinces in Zimbabwe being the most suitable for conservation agriculture and farm mechanization.

Thus, suitable areas for conservation agriculture and farm mechanization in Malawi, Zambia and Zimbabwe are larger than previously thought. This means that there is a need for up-scaling and out-scaling programmes to encourage more farmers to adopt conservation agriculture in the three countries. With the advent of climate change, even areas that were depicted to have moderate suitability will become highly suitable for targeting conservation agriculture. After validation, the suitability map based on varying weights showed higher levels of reliability. Thus, assigning different weights to the recommended domains resulted in context-specific suitability maps as opposed to using equal weighting. It also showed that the mapping process was robust. As such, the suitability maps generated from this study can be used for targeting conservation agriculture and farm mechanization by stakeholders and decision-makers in the three countries.

Appendix 1: Biophysical and socioeconomic domains for mapping conservation agriculture and mechanization in Africa.

Author & Country	Crop/CA element	Biophysical and socio-economic factors	Mapping CA suitability
(Erenstein, 2003)	Mulching	Temperature, rainfall, land use, biomass weathering rates, production, soil fertility, length of growing season, tillage systems, Crop production technology, resource endowments, attitudes, market services and infrastructure	No
(Knowler and Bradshaw, 2007) World	Conservation agriculture	Slope, soil type, soil erosion rate, soil's available water capacity, water quality, rainfall, temperature, length of growing season, number of field days, distance from residence, distance to paved road, distance to the market, size of farm, area planted, farm fragmentation, yield per hectare, land tenure, farm income, labour availability, education, age, farming experience, technical assistance,	No
(Mazvimavi and Twomlow, 2009) Zimbabwe	Conservation agriculture	Rainfall, agro-ecological location, farm size, farming experience, extension support, labour availability, gender, and age	No
(Thiombiano and Meshack, 2009) Africa	Conservation agriculture	Soil type, awareness, and secure tenure	Yes spatial farm typology analysis
(Chiputwa et al., 2010) Zimbabwe	Conservation agriculture	Soil type, labour availability, cattle ownership, disposable income, level of education, age, and family size	No
(K'Owino, 2010) Kenya	Conservation agriculture	Awareness, disposable income, and extension support	No
(Giller et al., 2011) Africa	Conservation agriculture	Slope, soils, livestock ownership, farming experience of farmers in cash cropping, secure tenure, markets, size of land and enabling environment	No
(Rusinamhodzi et al., 2011)	Maize	Soil texture, rainfall, resource availability, benefits, availability of inputs and practice of crop rotation	No
(Ojiem et al., 2011) Kenya	Legumes	Rainfall, temperature, solar radiation, photoperiod, soil type, soil nutrients, preferences, values, norms, attitudes, cash flow, inputs, extension support., profitability and markets	No
(Marongwe et al., 2011) Zimbabwe	Conservation agriculture	Soil, Labour availability, machinery, access to information, indigenous practices	No
(Kassam et al., 2011) World	Conservation agriculture	Awareness	No
(Mazvimavi, 2011) Southern Africa	Conservation agriculture	Rainfall, labour availability, practices, machinery, education, cash crop farmers, age, literacy, farming experience, gender, draft power, plot size, market, attitude, secure tenure,	No
(Milder et al., 2011)	Conservation agriculture	Climate, awareness, access to inputs, finances, farm size, profitability, labour availability and gender	No
(Nkala, 2011) Zimbabwe		Soil fertility, climate, awareness, extension support, technology, benefits, availability of inputs, experience, financial capital, livelihood assets	No
(Andersson and Giller, 2012) Zimbabwe	Conservation agriculture	Soils, climate, availability of inputs and livestock.	No

(Marongwe et al., 2012)	Conservation agriculture	Rainfall, soil type, livestock, availability of inputs, knowledge, labour demands, and technology	No
(Mavunganidze et al., 2013) Zimbabwe	Conservation agriculture	Age, education, extension services, labour, livestock availability and land size.	No
(Madyanga, 2014) Tanzania	Soil	Slope, land use, farming system, education, age, gender, access to land, technical assistance, farming experience, perceptions, and farm size	No
(Tesfaye et al., 2015) Ethiopia, Kenya, and Malawi	Conservation agriculture	Soil texture, slope, rainfall, market access, human and animal population densities	Yes Geospatial analysis using ArcGI
(Murage et al., 2015)	Conservation agriculture	Distance to market, access to information, gender, education, age, household size, farm size, livestock ownership, market, financial availability,	No
(Mlenga and Maseko, 2015) Swaziland	Conservation agriculture	Education and household size	No
(Pedzisa et al., 2015) Zimbabwe	Conservation agriculture	Rainfall, household size, farm size, experience, assets, education, inputs, and livestock ownership	No
(Thierfelder et al., 2015)	Conservation agriculture	Rainfall, soils, experiences, gender, inputs, labour demand, markets, and livestock ownership	No
(Baudron et al., 2015) Eastern and Southern Africa	Conservation agriculture	Labour availability and livestock ownership	No
(Gjengedal, 2016) Ethiopia	Conservation agriculture	Climate, biomass, soils, labour availability, inputs, extension services, and experience	No
(Umar, 2017) Zambia	Conservation agriculture	Climate and labour availability	No
(Li et al., 2017) Malawi	Conservation agriculture	Rainfall, temperature, slope, elevation, soil, land use and land cover	No
(Kunzekweguta et al., 2017) Zimbabwe	Conservation agriculture	Farm size, experience, distance to markets, livestock ownership, education, secure tenure, income, extension services, inputs	No
(Muriithi et al., 2018)	Conservation agriculture	Slope, soil fertility, distance to farm, gender, farm size and secure tenure	No
(Fisher et al., 2018) Malawi	Conservation agriculture	Rainfall, agro-ecological region, livestock ownership, market access, experience, education, gender, age, and labour availability	No
(Tambo and Mockshell, 2018) Sub Saharan Africa	Conservation agriculture	Age, gender, household size, dependency ration, livestock ownership, assets, income, and secure tenure	No
(Steward et al., 2018) World	Conservation agriculture	Soil type, temperature, rainfall, and solar radiation	No

(Komarek et al., 2019) Zambia	Conservation agriculture	Rainfall, soil texture, distance to markets, education, inputs, labour availability, assets, and livestock availability	No
(Ndah et al., 2020) Kenya	Conservation agriculture	Availability of inputs, knowledge, and financial availability	No
(Laborde et al., 2020) World	Conservation agriculture	Rainfall, soil, temperature, and experience	Yes machine-learning techniques
(Chineka, 2020)	Conservation agriculture	age, gender, household size and education, labour availability	No
(Umar, 2021) Zambia	Conservation agriculture	Gender, labour availability, availability of inputs and income	No
(Lee and Gambiza, 2022) Southern Africa	Conservation agriculture	Soil type, rainfall, availability of machinery, access to inputs, farm size, livestock ownership, infrastructure, knowledge, extension support, experience, and income.	No
(Oduniyi et al., 2022) South Africa	Conservation agriculture	Age, gender, extension support, access to input, experience, farm size, education, financial resources, and income	No
(Sayed, 2022) Egypt	Conservation agriculture and mechanization	Climate, labour availability, access to inputs, financial availability, farm size, education, experience, and markets	No
(Tufa et al., 2023) Southern Africa	Conservation agriculture	Cultivated land, location, age, gender, education, household size, secure tenure, inputs, livestock ownership, mobile phone, bicycle, motorbike, benefits, assets, and distance to market.	No

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