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Assessing Rangeland Suitability for Livestock Production in Pastoral Areas of Afar Ethiopia: Multi-Criteria Model Analysis in GIS and Remote Sensing

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ABSTRACT

Humans benefit significantly from rangelands in terms of both economic and environmental aspects. However, climate variability and anthropogenic causes can hurt rangeland production. Rangeland suitability analysis is a critical step in rangeland management. The study sought to analyze the feasibility of rangelands for livestock production in agro-pastoral areas of Afar, Ethiopia's pastoral regions. Natural pasture was the predominant feed source for animals, and feed shortage was the primary obstacle to livestock productivity, followed by drought in pastoral and agro-pastoral systems, respectively. The five suitability parameters assessed were altitude, land use or land cover, soil, water availability, and slope. ArcGIS 10.7.1 was used to process vector and raster data layers. Finally, suitability classes were determined by conducting a weighted overlay of spatial analysis, which relied on the reclassified raster layer incorporating all parameters, along with the outcomes of multicriteria analysis. The study's outcomes revealed that 1.20%, 8.49%, 20.08%, 69.26%, and 0.95% of the study area were categorized as highly suitable, moderately suitable, marginally suitable, presently unsuitable, and permanently unsuitable for cattle production, respectively.

INTRODUCTION

Rangelands, constituting around 50-70% of the Earth's land mass, are a fundamental and expansive component, encompassing 65% of Africa's land area. Over 50% of these lands are classified as arid and semi-arid agro-ecologies (Herlocker, 1999). These vast rangeland ecosystems play a crucial role in supporting a wide range of agricultural and non-agricultural activities, making them of utmost importance for global sustainability.

In many developing countries, rangelands serve as a vital source of sustenance and income for local communities. Livestock production in these areas contributes significantly to food security, poverty alleviation, and economic development (Coppock *et al.*, 2017). The availability of natural grazing resources allows pastoralists and agro-pastoralists to depend on rangelands for their livelihoods, thereby ensuring a sustainable supply of animal products such as meat, milk, and fibers (Tofu *et al.*, 2023). In addition to livestock production, rangelands offer a multitude of other valuable benefits. They serve as a habitat for a wide range of plant species with medicinal, industrial, and edible properties (O'Connor & van Wilgen, 2020). Moreover, rangelands contribute to carbon sequestration, acting as a sink for atmospheric carbon dioxide and mitigating the impacts of climate change.

East African countries, including Ethiopia, possess extensive rangeland areas. In Ethiopia alone, rangelands cover approximately 64% of the total area and situated in the eastern, southern, south-western, and western peripheries of the country (Alemayehu, 2006). The potential for rangeland and pastoralism in Ethiopia is

immense. With over 60 million cattle, sheep, goats, and camels, the country boasts the largest livestock population in Africa (Gelan, 2014).

Rangelands across the globe face significant challenges, with degradation increasingly becoming a cause for concern (Tongway & Ludwig, 2011). Pressures from climate change, unsustainable land management practices, and overgrazing are altering the delicate balance of these ecosystems, leading to declines in biodiversity and ecosystem services (Reid *et al.*, 2014). In Africa, where a substantial portion of the continent's landmass is comprised of rangelands, degradation is rampant due to uncontrolled grazing and land use changes (Snyman, 2011). Similarly, rangelands in Ethiopia and the Afar region face numerous challenges, which are critical to address for the sustenance of pastoral communities and the preservation of biodiversity. According to studies, these challenges stem from various factors including climate change, overgrazing, land degradation, and inadequate governance (Abate *et al.*, 2020; Lemma *et al.*, 2018).

Climate change has led to unpredictable rainfall patterns and prolonged droughts, exacerbating water scarcity and reducing forage availability for livestock (Alemayehu *et al.*, 2017). Overgrazing, intensified by population growth and land use changes, has resulted in soil erosion, loss of vegetation cover, and decreased productivity of rangelands (Yamane *et al.*, 2020). Land degradation further undermines the resilience of these ecosystems, threatening the livelihoods of pastoralists who rely on rangelands for their subsistence (Getachew *et al.*, 2016).

In addition to environmental challenges, governance

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issues play a significant role in exacerbating the vulnerability of pastoral communities. Limited access to markets, inadequate infrastructure, insecure land tenure, and conflicts over natural resources further constrain the adaptive capacity of pastoralists to cope with environmental stresses (Hassen *et al.*, 2019). Addressing these challenges requires holistic approaches that integrate climate-smart land management practices, community-based natural resource management initiatives, and policies that support the resilience of pastoral livelihoods (Asefa *et al.*, 2015; Lemma *et al.*, 2021). Moreover, empowering local communities and enhancing their participation in decision-making processes are essential for promoting sustainable rangeland management and improving the well-being of pastoralists in Ethiopia and the Afar region (Tessema *et al.*, 2019).

Rangeland suitability analysis is an essential tool for identifying the most appropriate land use for a particular area. It is used to determine the potential of an area to support livestock production, considering factors such as soil type, vegetation cover, topography, and climate (Piri Sahragard *et al.*, 2018). The importance of rangeland suitability analysis lies in its ability to identify areas suitable for grazing and those that are not. This information can be utilized to develop management plans that ensure the sustainable use of rangelands while minimizing environmental degradation. Therefore, the identification of suitable areas for livestock production using spatial models could offer a potential solution to mitigate this problem.

This study is focused on the Afar region, situated in Ethiopia's arid lands, characterized by low and erratic rainfall patterns (Kassie *et al.*, 2018). This region is predominantly inhabited by pastoral communities whose livelihoods depend on diverse assets and activities (Dejene

et al., 2019). However, the growing demand for arable land in the Afar region has resulted in the reduction of areas available for natural grazing and forage production (Lemma *et al.*, 2021). There have been some studies on rangeland conditions and pastoralism in the Afar region. Despite the region's vulnerability to environmental stresses and its significance for pastoral livelihoods, many studies conducted in the Afar region have not fully incorporated GIS-based approaches, thereby missing out on valuable opportunities to enhance understanding and decision-making in rangeland management.

Regional or local levels addressing the erosion of traditional wisdom regarding rangeland management for livestock sustenance among Ethiopian pastoralists require the utilization of GIS and remote sensing technology. This technology serves as a valuable tool for mapping and monitoring vegetation species, offering timely and relatively accurate information on the degradation of biological rangeland resources.

The objective of this study is to determine the suitability of land units for livestock production based on the evaluation of various factors such as soil type, vegetation cover, slope, and climate using a participatory GIS approach by combining empirical data collection with spatial analysis techniques. Ultimately, this research aims to provide practical recommendations for policymakers, land managers, and local communities to enhance the sustainable utilization of rangelands and promote the well-being of agro-pastoral communities in the Afar region.

MATERIALS AND METHODS

Description of the Study Area

The Afar region is home to one of the most populous pastoral communities in the Horn of Africa. It is found in the rangelands of northern Ethiopia, southern Eritrea,

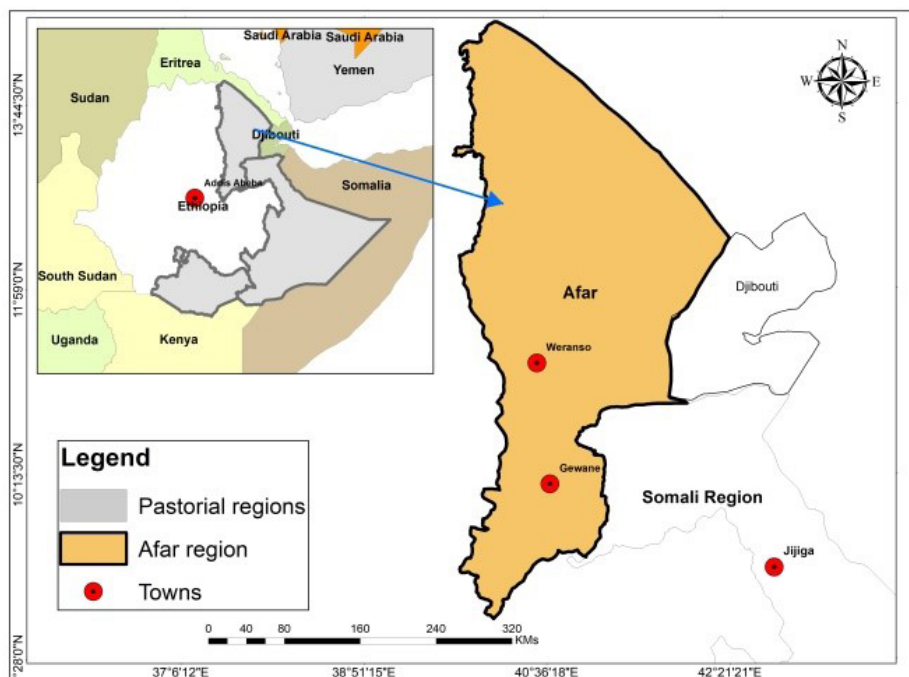


Figure 1: Study Area Map

and western Djibouti. The region is located between latitude 11° 49' N and longitude 41° 25' E and has an estimated area of 94,540 km². The region's altitude ranges from 116 meters below sea level to 1600 meters above mean sea level; its temperature ranges from 25 degrees Celsius to 48 degrees Celsius; and the average annual rainfall is 187.9 millimeters. It is the home of Erta Ale, an active volcano, and Lucy, Ardi, and Selam, the world's earliest hominid remains. According to the most recent census, the region has a population of 1,390,273, with 775,117 men and 615,156 women; urban residents make up 185,135 of the population, and 1,205,138 are pastoralists (Central Statistical Authority [CSA], 2012).

Materials

In this research work, the following software was used: These are Arc GIS 10.7.1, ERDASE Imagine 2015, Global Mapper, and Microsoft Excel.

METHODOLOGY

Data Collection and Types

In this study, both primary and secondary data were employed. Four environmental land factors land use/cover, soil, slope, and altitude were utilized. Additionally, one of the socioeconomic characteristics considered was access to safe drinking water.

Landsat Imagery

To extract LULC classes, a Landsat 8 Operational Land Imager (OLI) image from January 2020 with a resolution of 30 m was used. Cloud and haze-free Landsat pictures were obtained publicly from the United States Geological Survey (USGS) web page (<https://earthexplorer.usgs.gov>) during the dry season.

Digital Elevation Model

The Shuttle Radar Topography Mission (SRTM) collected digital elevation model (DEM) data, which was then utilized to extract slope data and subsequent derivations like elevation. Surface analysis tools in the spatial analysis category were employed to compute slope data and subsequent derivations such as elevation from the DEM.

Field Surveying

Ground reference data was gathered in order to appropriately assess the accuracy of remotely sensed image-based land use and land cover classification. Without the backing of field inquiry, land use/land cover classification analysis is likely to contain inaccuracies.

Table 1: Data Sources

Data	Sources
Soil type	FAO (FAO, 1997)
Land use/Land cover Map	Landsat 8 image
Altitude	SRTM
Slope	Derived from SRTM
Water Availability	USGS

Each land cover class's digital signature is determined by its spectral property. These signatures can then be utilized to train functions for accurate classification. As a result, primary data on the research area's dominant land-use/land-covers were gathered.

Multi-Criteria Decision Analysis (MCDA)

The multi-criteria Decision Analysis (MCDA) methodology simplifies prospective choices based on established criteria and weights, allowing for effective appropriateness analysis. Expert judgment and criterion assessment are primary components of MCDA to rate possible rangeland areas (Malczewski & Rinner, 2015). Not all criteria carry the same weight; varying with the objectives of the research, certain criteria hold considerable importance whereas others are of lesser significance (Aroge *et al.*, 2022). A weighted overlay analysis method was used to provide the overall study of suitability mapping. The MCDA method was applied to select the most potentially acceptable rangeland areas in the research area.

Analytic Hierarchy Process

One of the most thorough approaches to multicriteria decision analysis is the analytic hierarchy process (AHP) (Malczewski & Rinner 2015). The AHP approach consists of three major components. Internally, each layer was weighed depending on buffer minimum and maximum distances and needs. In the initial phase, the layers were standardized, and a thematic map of each criterion was created. The preference of each criterion compared to the rest of the criteria on rangeland site selection was reflected in the second phase by allocating weights. Analytical Hierarchical Process the Weight Derivation model was used to assess two criteria at the same time using expert opinion and a pair-wise comparison matrix. After giving external weights to each layer, the Weighted Linear Combination (WLC) technique was used to generate an overall rangeland site suitability map that included all of the criteria. The Weighted Linear Combination combined elements by assigning a weight to each and then averaging the results to produce a suitability map, as illustrated in equation 1.

$$s = \sum_{(i=1)}^n wixi \tag{1}$$

where S is suitability, wi is the weight of the factor i and xi are the criterion score of factor i. As stated in equation 2, this technique can be changed by multiplying the appropriateness obtained from the factors by the product of the constraints for Boolean constraints to apply.

$$s = \prod_{(j=1)}^m Cj \tag{2}$$

where C_j is the constraint j's criterion score. Several pair-wise comparisons of relative importance were used to produce the weights. Different weights were allocated to each parameter based on experience and potential impact on the surrounding environment. Weights were created using an analytic hierarchy technique. The restriction was used to narrow down the options under consideration, which were expressed as a Boolean logical map in 0 and 1

(Eastman, 2012; Shahabi *et al.*, 2013; Olusina & Shyllon, 2014). For Multi-Criteria Evaluation (MCE), apply Equation 3:

$$s = \sum_{(i=1)}^n w_i c_i * \prod_{(j=1)}^m r_j \quad (3)$$

where S is the appropriateness for a rangeland site, W_i is the weight of factor i , C_i is the criterion for factor i suitability, r_j is the criterion for constraint j suitability, and s is the product.

Table 2: Weighted and Ranked Thematic Layer Sub-Features

Thematic Layer	Classes	Weight (wi)	Rank
Altitude (Meter)	<500	0.1	2
	500-700		3
	700-1000		4
	1000-1700		5
Slope (%)	0-8	0.2	5
	8-16		4
	16-30		3
	>30		2
	<5	0.275	5
	5-7		4
	7-10		3
	>10		2
Water Availability (Km)	OGL	0.275	5
	OBGL,OSGL		4
	OSL, CL, OBL		3
	DSL, DBL		2
	WB,FR,BA		1
Soil	SNcc,VReu,VRpe	0.15	5
	CMcr,LVcr,CMeu,NTtro		4
	FLca,LPel,FLeu,CLha,Lp		3

Source: modified from (Abule, 2009)

Note: WB - water body, DSL- Dense shrubland, OGL- open grassland, FR- forest OSGL - open shrub grassland, BA- built-up areas.

Phase 1: Suitability Model

The first step was to reduce the decision-making problem into a hierarchical framework. A structural hierarchy built for the decision issue has numerous layers. Several criteria were developed to determine the hierarchy of the major aims of rangeland site selection, including environmental elements, socioeconomic issues, and restrictions. Weight Linear Combination (WLC) in conjunction with AHP was used to complete the task. The analytical hierarchy technique was utilized to capture components of the choice. It was utilized to compute the weights for various criteria by building a pair-wise comparison matrix. For the model, Equation 4 is used:

$$s = \sum_{(i=1)}^n w_i c_i \quad (4)$$

where s is suitability and w_i and c_i stands with the weight of each criterion considered.

Phase 2: Multi-Criteria Model

The matrices represent a series of pair-wise comparisons utilizing relative data, which were integrated with Weight

Linear Combination (WLC) to yield a final site selection using the equation:

$$s = \sum_{(i=1)}^n w_i c_i * \prod_{(j=1)}^m r_j \quad (5)$$

Factors of Suitability for Livestock Production

Several elements influence land suitability assessments, ranging from biophysical to socioeconomic. Four biophysical land parameters and one socioeconomic component were investigated in this study. Soil, terrain (slope), altitude, water availability, and land use/land cover are examples of these. All of the aforementioned factors were taken into account to identify suitable locations for livestock production and are plotted separately. Each criteria map depicts land suitability measured on an ordinal scale, which means that each parcel of land was assigned values of high, medium, and low appropriateness based on land parameters. The criteria maps serve as input data for the GIS-based decision-making process. The combination technique adheres to the standard scheme for GIS-based MCDA (Malczewski, 1996).

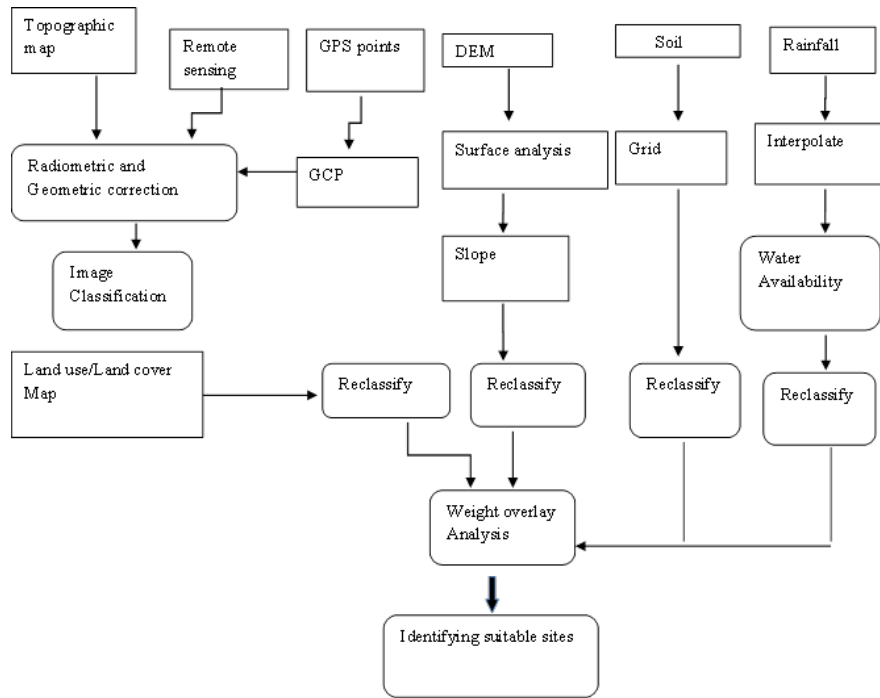


Figure 2: Methodology flowchart

Soil

It is one of the most important parameters used to assess the suitability of rangelands for livestock as a source of feed, a sleeping area, ease of trekking, and the occurrence of livestock diseases. Thus, the inclusion of soil parameters as a land quality criterion is critical for both

plants and animals. Physical features of soil, specifically textural classes, were evaluated for interpretation and analysis in this study. As shown in Figure 3, the principal soil types are Calcaric Fluvisol, Eutric Cambisol, Eutric leptosols, and others.

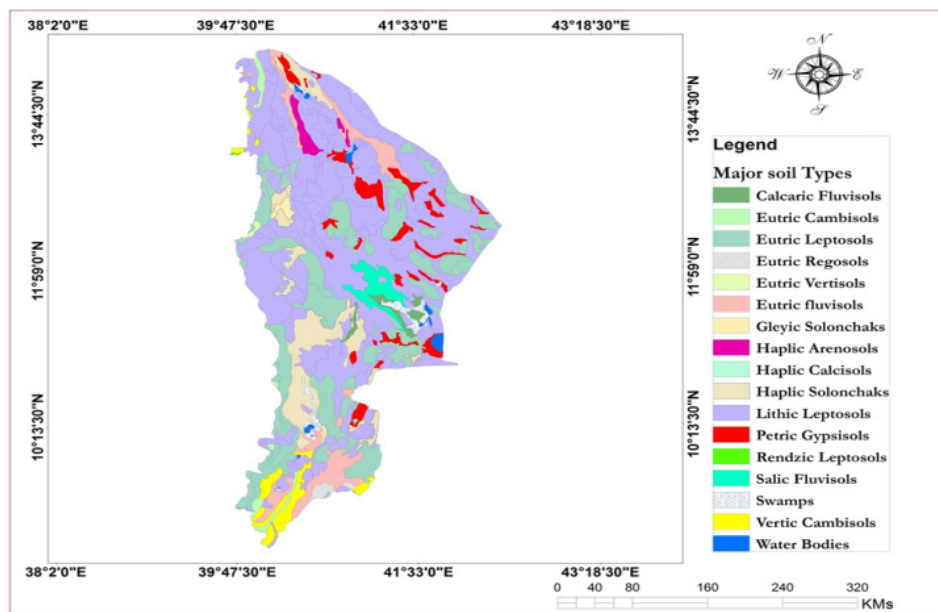


Figure 3: Soil Map of Afar region

Land Use/Land Cover

Certain vegetation types/covers are preferred by animals over others. As a result, various vegetation kinds within a pasture receive varying degrees of utilization. Cattle

prefer open pastures to densely forested places. The current land-use/land-cover analysis created nine classes: woods, bushland, swamps, shrubland, water bodies, grassland, state farmland, cultivated land, and bare land.

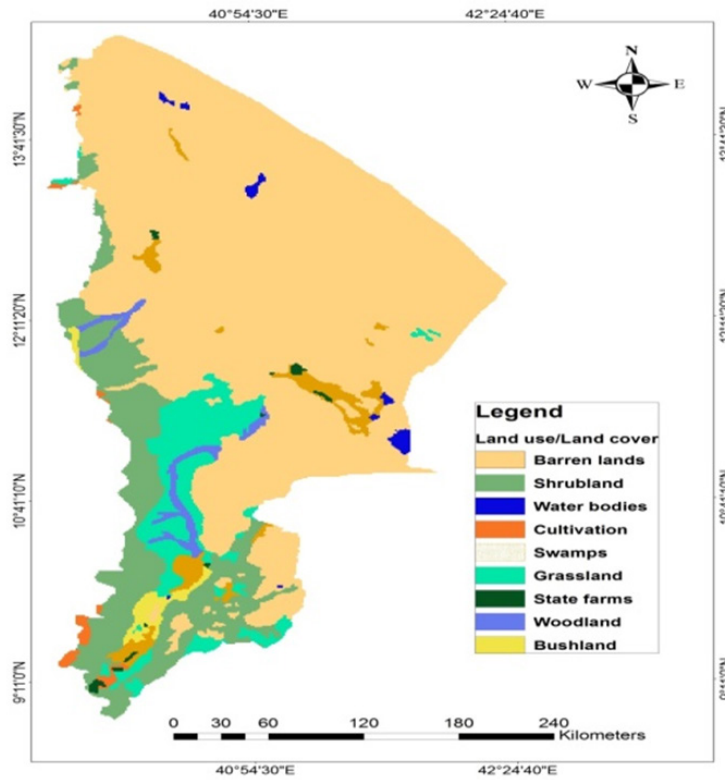


Figure 4: Land use/land cover map

Altitude

Altitude, is the most significant environmental variable contributing significantly to differences in the spatial distribution of both herbaceous and woody plant species. It influences the quantity and quality of feed for grazers

such as cattle and sheep, as well as browsers such as camels and goats (Ayana, 1999). The area ranges between 144 meters below sea level and 2390 meters above sea level, as shown in Figure 5 below.

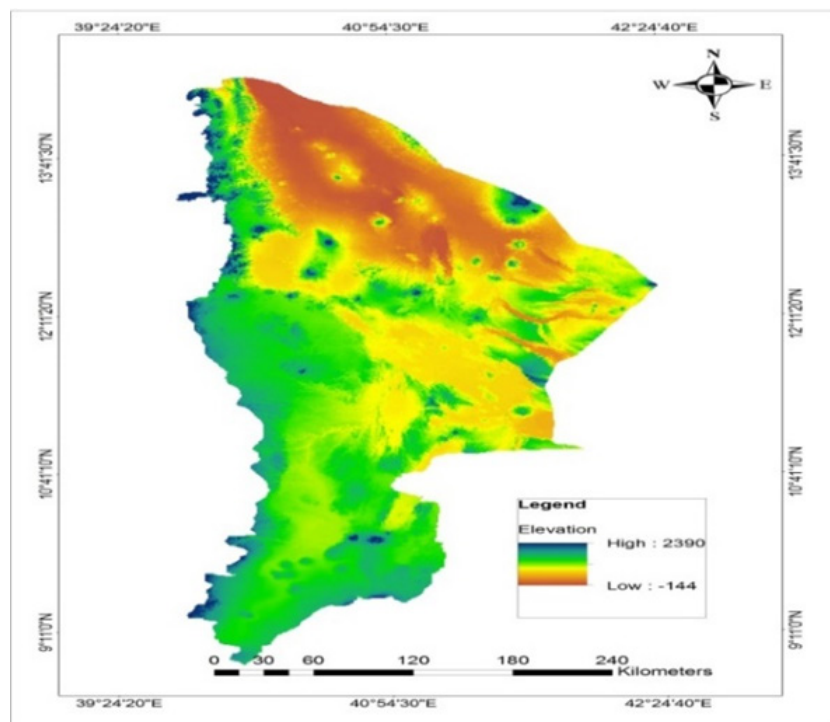


Figure 5: Altitude map

Slope

Slope was calculated from SRTM data in the GIS platform using the surface analysis approach of Geo-statistical Analyst. Rugged topography is one of the primary causes of poor cattle distribution on rangelands. The willingness of livestock to use steep terrain varies significantly. Large, hefty animals, such as adult cattle or camels, have difficulties

navigating steep, rocky hillsides. Cattle and camels, as a result, rarely use slopes with more than a 10% gradient. Sheep and goats use these places more frequently because of their tiny stature, higher agility, and surefootedness. Many rugged ranges are better suited to wild animals than livestock. Sheep can feed on steep hillsides where cattle and other large animals cannot (Abule, 2009).

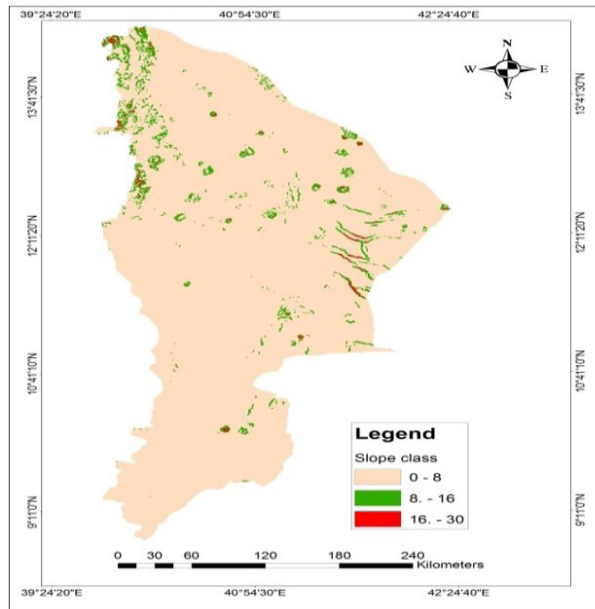


Figure 6: Slope map

Livestock Requirement

Land suitability for livestock production necessitates evaluation of a variety of elements, including the biophysical (environmental), infrastructural, and social aspects of the area under consideration. The second stage is to determine the factor ratings for each cattle species. Factor evaluations were classified into five categories: extremely suitable (S1), moderately suitable (S2), marginally acceptable (S3), temporarily not suitable

(N1), and permanently not suitable (N2). All of the above characteristics were taken into account in the analysis to determine acceptable regions for livestock production.

RESULTS AND DISCUSSION

RESULTS

Criteria Standardization

Standardization of criteria is a key step in developing rangeland suitability maps, ensuring that the many criteria

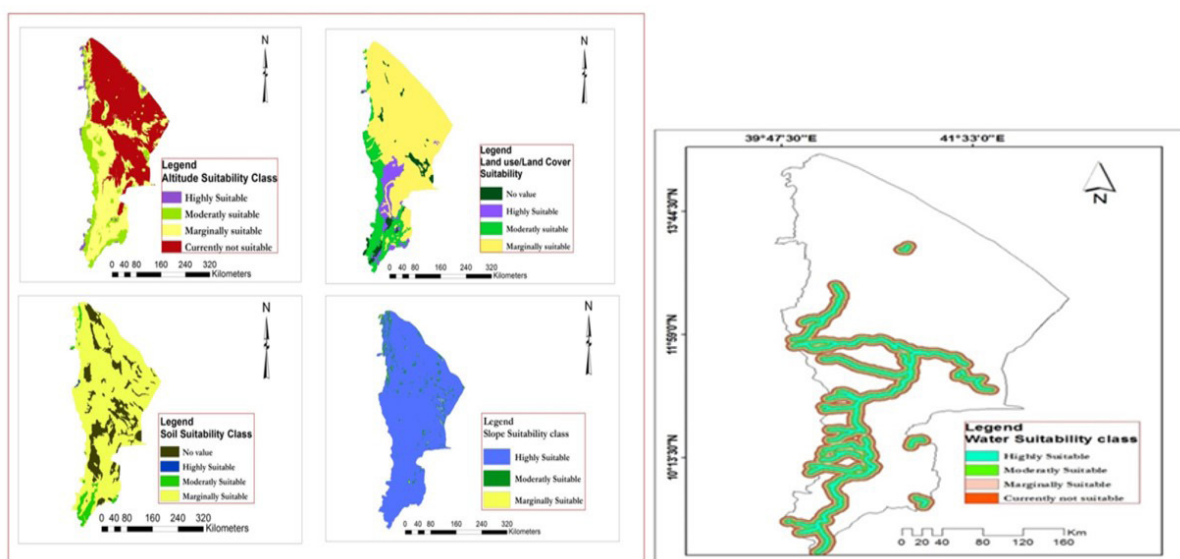


Figure 7: Standardized factor maps for cattle suitability analysis

employed in the study are equivalent and can be integrated to provide a final suitability map. The raster layers utilized in this study were classified into five classes (S1, S2, S3, N1, and N2) with values ranging from 1 to 5, where 1 represents the most acceptable and 5 represents the least suitable for all parameters studied.

Criteria standardization is a multi-step procedure. First, the various criteria employed in the study are identified. As shown in Figure 7, the requirements include height, land use/cover cover, soil, slope, and water availability. Following that, each criterion is standardized using

a common scale. Once all of the criteria have been standardized, they are combined to create a final suitability map.

Land Suitability Analysis

The suitability map (Figure 8) was created using weighted overlay spatial analysis based on the AHP weights. The weighted overlay of the parameters that affect cattle output was used to analyze land suitability. Table 3 shows the findings of the physical environment appropriateness analysis for cattle.

Table 3: Final land suitability classes for cattle with areas of coverage

Suitability class	Area	
	(Km ²)	%
Highly suitable (S1)	1137.48	1.20
Moderately suitable (S2)	8032.70	8.49
Marginally Suitable (S3)	18984.99	20.08
Currently not suitable (N1)	65480.58	69.26
Permanently not suitable (N2)	904.27	0.95
Total	94540.02	100

The results indicated that the areas for land suitability for Afar region were 1137.48 km² (1.20%), 8032.70 km² (8.49%), 18984.99 km² (20.08%), 65480.58 km²

(69.26%) and 904.27 km² (0.95%) for S1, S2, S3, N1 and N2 respectively. Distribution of physical environment suitability of cattle is presented in Figure 8.

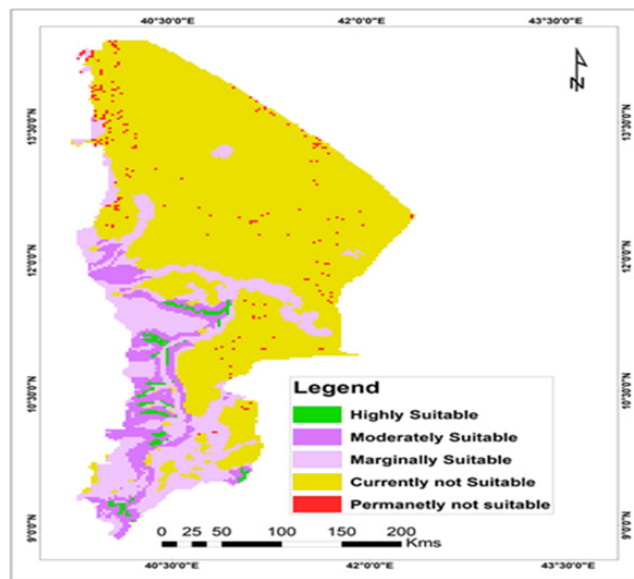


Figure 8: Land suitability classes for cattle in the Afar region

To establish rangeland suitability, knowledge of environmental criteria such as water resources, soil, slope, altitude, and land use land cover is required. The majority of the lands in the research region were determined to be currently unsuitable (N1) or moderately acceptable (S3). As a result, the region is at risk of rangeland degradation and land use change. Rangeland has deteriorated as a result of several human-caused and environmental change issues.

DISCUSSION

The weight of each parameter that impacts suitability assessment is a crucial stage in the land suitability evaluation (Jayasinghe *et al.*, 2019). Because the criteria are of unequal relevance, multiple factors influence the land suitability evaluation (Elsheikh *et al.*, 2013). A multicriteria decision-making technique that blends AHP with biophysical and remote sensing parameters was employed in this investigation.

The majority of the land in the Afar region is unsuitable for livestock raising for a variety of reasons. This could be due to an inadequate soil type, slope, or altitude, as well as the most crucial aspects, such as water availability. The environmental parameters utilized in this study reveal a mixed picture of suitability for livestock production in the Afar region. While parameters such as slope and altitude are favorable, others like water availability and soil quality pose significant limitations.

Water availability emerges as one of the most critical environmental factors impacting livestock production in the region. Arid and semi-arid conditions, with erratic rainfall patterns and limited surface water sources characterize the Afar region. This scarcity of water directly affects the hydration and survival of livestock and restricts the growth of essential grazing vegetation. The reliance on seasonal rains and the absence of reliable water infrastructure exacerbate the challenges faced by pastoralists in maintaining healthy livestock populations (Teshome *et al.*, 2020).

Furthermore, the poor quality of soil presents another significant environmental constraint in the Afar region. The predominant sandy and rocky soil types are not conducive to vegetation growth, leading to limited forage availability for livestock. Soil erosion and degradation further reduce the suitability of the land for grazing, posing long-term challenges for sustaining livestock populations and exacerbating food insecurity among pastoral communities (Lemma, S., *et al.*, 2021).

Despite the low-altitude plains and rugged terrain seemingly offering opportunities for extensive grazing, they also present challenges. Steep slopes limit accessibility and pose risks of erosion, while low-altitude plains are susceptible to extreme temperatures, exacerbating heat stress in livestock. The rugged landscape and climatic variability present challenges for effective herd management and livestock productivity (Gebremeskel *et al.*, 2019).

Previous studies have also confirmed these findings. According to the Afar National Regional Rural Strategy (2008), approximately 25.7% of the total land of the Afar region is suitable for grazing. According to the current study, approximately 70.9% of the region's total land is denuded and devoid of vegetation that is unsuitable for livestock production. The climate in the region is usually hot, desert-like, and partly dry. The land is usually deteriorated (rocky/stony), and temperatures can be extremely high or low. Because the soil types accessible in the region are sandy and rocky, the majority of the overall area of the region has been denuded, with only about half of this area used for grazing for a brief period of time during the sparse short rainy season. Apart from that, this enormous plot of land serves no purpose. Several other issues have also contributed to the area's unsuitability for rangeland. These include a lack of forecasted climate information, a scarcity of watering points, and transportation limits.

CONCLUSION

The present study delineated a novel methodology for identifying suitable rangeland areas within the Afar region of Ethiopia by integrating Geographic Information Systems (GIS), satellite remote sensing, and Analytic Hierarchy Process (AHP). Rangeland assessment poses recurrent challenges for stakeholders engaged in livestock management, environmental conservation, and land administration. Our investigation revealed that a significant portion of the Afar rangelands exhibited unsuitability for cattle rearing. Consequently, it is imperative for diverse stakeholders, including governmental bodies and environmental agencies, to prioritize the utilization of viable rangeland areas and enact regulations to support pastoralist communities. Additionally, ongoing monitoring of land-use dynamics within the Afar rangelands is paramount, with the findings of our study serving as a valuable tool for such surveillance. However, it is essential to acknowledge the limitations encountered in establishing research-derived suitability evaluation parameters. Future endeavors should concentrate on enhancing these parameters and refining the rating methodologies. Factors such as the palatability of various vegetation components for diverse livestock species warrant detailed investigation and integration into suitability assessments. Moreover, understanding the influence of specific soil parameters on suitability for different livestock species is crucial. Further refinement of parameters should entail comprehensive studies encompassing aspects such as livestock diseases and market dynamics. It is noteworthy that our analysis solely focused on biophysical factors (including altitude, land use/land cover, water availability, slope, and soil characteristics). Future investigations ought to broaden the scope by incorporating additional environmental parameters and socio-economic considerations, such as income levels and livestock preferences. Furthermore, infrastructural factors like the availability of veterinary services and livestock markets should be integrated into future analyses to provide a comprehensive understanding of rangeland suitability and management dynamics in the Afar region.

REFERENCES

- Afar National Regional State. (n.d.). *Rural land use and administration policy. Food and Agriculture Organization*. Retrieved from <https://faolex.fao.org/docs/pdf/eth165071.pdf>
- Abule, E. (2009). *Rangeland suitability evaluation for livestock production in Laga-Wata/Laga-Sura, Dawa, and Rift Valley sub-basins of the Borana Zone of Oromia, Southern Ethiopia* [Unpublished report]. Oromia Water Works Design and Supervision Enterprise, Addis Ababa.
- Alemayehu, T., Bekele, T., & Mengistu, A. (2017). Impacts of climate change on land use and land cover changes in Kobo watershed, Ethiopia. *Environment and Ecology Research*, 5(6), 457-465.

- Alemayehu, M. (2006). *Range management for Eastern Africa: Concepts and practices*. Addis Ababa University Printing Press.
- Aroge, S. K., Adewole, B. E., Amoo, N. B., & Adeleke, J. S. (2022). Combination of GIS, MCDA, and AHP for the selection of the most suitable location for primary health care facilities. *American Journal of Geospatial Technology*, 2(1). <https://doi.org/10.54536/ajgt.v2i1.1820>
- Ayana, A. (1999). The ecological impact of bush encroachment on the yield of grasses in Borana rangeland ecosystem. *African Journal of Ecology*, 43, 14-20.
- Coppock, D. L., Booth, D. B., Butterbach-Bahl, K. D., & Antle, J. M. (2017). Rangeland systems in developing nations: Conceptual advances and societal implications. In D. Briske (Ed.), *Rangeland systems* (pp. 407-434). Springer. https://doi.org/10.1007/978-3-319-46709-2_17
- Dejene, A., Abebe, S., & Yitafaru, B. (2019). Impacts of climate variability and change on rangeland condition in Amibara District, Afar Region, Ethiopia. *International Journal of Environmental Science and Technology*, 16(11), 7477-7490.
- Eastman, R. (2012). GIS and multicriteria decision analysis. In D. Richardson & N. Castree (Eds.), *The Sage handbook of geographical knowledge* (pp. 273-288). Sage Publications.
- Elsheikh, R., Shari, A. R. B. M., Amiri, F., Ahmad, N. B., Balasundram, S. K., & Soom, M. A. M. (2013). Agriculture land suitability evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. *Computers and Electronics in Agriculture*, 93, 98-110.
- Food and Agriculture Organization. (1997). *The Digital Soil and Terrain Database of East Africa (SEA)* [CD-ROM, Version 1.0]. Rome, Italy.
- Gebremeskel, Y. M., Berhe, T. H., Gebremichael, G. G., & Gebreyesus, M. W. (2019). Climate variability and its impact on livestock production in Afar Region, Ethiopia. *International Journal of Agriculture, Forestry and Life Sciences*, 3(1), 40-54.
- Gelan, D. (2014). Pastoral rangelands policy and institutional concerns in Ethiopia. SSRN. <https://ssrn.com/abstract=2524948> or <http://dx.doi.org/10.2139/ssrn.2524948>
- Getachew, W., Suryabhagavan, K. V., Nigussie, D., & Tegegne, A. (2016). Effect of grazing pressure on vegetation dynamics and soil properties in Afar Region, Ethiopia. *International Soil and Water Conservation Research*, 4(4), 282-290.
- Hassen, A. S., Assen, M., Hunde, F., & Tesfaye, A. (2019). Livelihood strategies of pastoral and agro-pastoral households in the Afar region, Ethiopia: The role of environmental, social, and human capitals. *Pastoralism*, 9(1), 7.
- Herlocker, D. J. (1999). *Rangeland ecology and resource development in Eastern Africa*. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).
- Jayasinghe, S. L., Kumar, L., & Sandamali, J. (2019). Assessment of potential land suitability for tea (*Camellia sinensis* (L.) O. Kuntze) in Sri Lanka using a GIS-based multi-criteria approach. *Agriculture*, 9(7), 148.
- Kassie, B. T., Assen, M., & Tesfaye, A. (2018). Assessment of rainfall variability, trend analysis, and its implication for crop production in Awash Basin, Ethiopia. *Weather and Climate Extremes*, 19, 39-51.
- Lemma, B., Bräuning, A., & Fichtler, E. (2018). Assessing the impact of climate variability and human activities on vegetation dynamics in pastoral rangelands of Borana, Southern Ethiopia. *International Journal of Environmental Research and Public Health*, 15(1), 52.
- Lemma, S., Smith, J., Johnson, A., et al. (2021). Spatiotemporal dynamics of vegetation and its relationship with climate variability in Afar Region, Ethiopia. *Theoretical and Applied Climatology*.
- Malczewski, J. (1996). GIS-based approach to multiple criteria group decision-making. *International Journal of Geographic Information Science*, 10, 955-971.
- Malczewski, J., & Rinner, C. (2015). Multicriteria decision analysis in geographic information science. In L. J. Bracken & M. G. H. Bell (Eds.), *Geographic information science and technology body of knowledge* (pp. 1-24). University Consortium for Geographic Information Science.
- O'Connor, T. G., & van Wilgen, B. W. (2020). The impact of invasive alien plants on rangelands in South Africa. In B. van Wilgen, J. Measey, D. Richardson, J. Wilson, & T. Zengeya (Eds.), *Biological invasions in South Africa* (pp. 283-306). Springer. https://doi.org/10.1007/978-3-030-32394-3_16
- Piri Sahragard, H., Ajorlo, M., & Karami, P. (2018). Modeling habitat suitability of range plant species using random forest method in arid mountainous rangelands. *Journal of Mountain Science*, 15, 2159-2171. <https://doi.org/10.1007/s11629-018-4898-1>
- Reid, R. S., Fernández-Giménez, M. E., & Galvin, K. A. (2014). Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annual Review of Environment and Resources*, 39, 217-242.