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*Research Article*

# Identification of Suitable Land for Livestock Production Using GIS-Based Multicriteria Decision Analysis and Remote Sensing in the Bale Lowlands, Ethiopia

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Rangeland resources of the Bale lowlands have been degraded due to climate change, human factors, lack of sufficient environmental and rangeland policies, disaster mitigation strategies, and good management. The study identified suitable rangeland for cattle, sheep, goat, and camel production in the Bale lowlands using GIS-Based Multicriteria Decision Analysis and remote sensing techniques. Land-use and land-cover, rainfall, water accessibility, slope, and soil types were used for the suitability analysis. The study showed that an area of 4112, 16311, 6643, and 9820 $km^2$ was highly suitable for cattle, sheep, goats, and camels, respectively. The results of the study also indicated that an area of 40099, 30925, 41981, and 36802 $km^2$ was moderately suitable for cattle, sheep, goats, and camels, respectively. In addition, an area of 7644, 4671, 3630, and 5632 $km^2$ was marginally suitable for cattle, sheep, goats, and camels, respectively. On the other hand, an area of 399 and 346 $km^2$ was not suitable for cattle and sheep, respectively. The study is important for improving livestock production and mitigating the impacts of traditional livestock mobility on local communities. The study can also provide insights for government authorities to formulate environmental and rangeland policies to identify rangeland types and separate the rangeland for each livestock category.

## 1. Introduction

Rangeland is a type of land characterized by nonforest and native vegetation [1]. Land cover types of rangelands include grasslands, shrub land, and savannas. Rangeland is an area that serves as grazing land for domestic animals and wildlife [2–4]. It has crucial value in environmental, social, and economic aspects. Besides, rangeland is very significant, particularly for pastoralists, since it is used for forage and water for their livestock. Although rangeland has positive contributions to environmental and social aspects, it has been degraded due to land-use and land cover (LULC) change [5–9]. Rangeland degradation causes low livestock production and seasonal mobility [8, 10, 11].

Pastoralists lack knowledge of livestock mobility. As a result, they do not know the appropriate location to mobilize and predict the challenges, which may be faced during mobility. Therefore, pastoralists need strategic plans to mobilize their livestock from place to place. Commonly, pastoralists' decisions to mobilize their livestock are often based on imprecise information and informed traditionally. Such kind of ineffective livestock mobility and wrong decisions cause livestock starvation and death. This leads to loss of livelihood and famine in pastoral communities [8, 12]. Mobility strategies for different landscapes are still the main grazing management techniques used by pastoralists to mitigate the impacts of climate change, utilize rangeland wisely, and improve livestock production, particularly in arid and semiarid rangelands [10, 11, 13–16]. Hence, pastoralists have to access information about socio-spatial heterogeneity, animals' behavior and performance, carrying capacity, spread of disease, quality and quantity of different plant species, water availability, and land-use types during livestock mobility. Therefore, a depth understanding of how pastoralists manage their grazing resources and the nature of the environment, how they determine their mobility strategies, and what factors they consider when making daily and seasonal mobility are very essential [8, 17].

In the Bale lowlands of Ethiopia, limited rangeland resources and a lack of sufficient environmental policies for sustainable use of rangelands are the main problems for pastoralists. Besides, the combined factors of LULC change, frequent drought, and irregular rainfall cause rangeland depletion [8]. As a result, mobility is the most important pastoralist adaptation strategy to enhance livestock production. In the Bale lowlands, tribal leaders and experienced herders have been collecting information about pastoral lands, plant species, and the appearance of some insects to evaluate rangeland conditions and distribute information among the entire community. These methods of information acquisition may not be successful, especially in areas where there are frequent variations in weather, climate, and land degradation. Pastoralists also did not regularly monitor and evaluate the situation of rangeland before mobilizing their livestock. Although indigenous knowledge about livestock mobility and traditional information-based decisions are very significant, they are not effective in the Bale lowlands due to irregular rainfall availability, distribution, and extreme temperatures. Therefore, the local knowledge-based decision on livestock mobility should be aided by flexible resource analysis and management practices. Moreover, advanced rangeland suitability analysis is very essential to minimize pastoralists' vulnerability to unplanned mobility and identify suitable rangeland for livestock production.

Recently, studies have been conducted on historical rangeland dynamics and their impact on the environment, livelihoods, and various management practices on forage production [8, 18–21]. However, little attention was given to rangeland suitability analysis for livestock production and mobility. Besides, the problem under investigation is the main challenge to the livelihood and sustainable development of pastoral areas in Ethiopia in general and Bale lowlands in particular [8].

A GIS-Based Multicriteria Decision Analysis (MCDA)-based spatial analysis is a fundamental approach for evaluating and managing different complex criteria and making an effective spatial decision for sustainable rangeland management [22, 23]. Besides, MCDA is an effective technique for comparing multifaceted factors used for rangeland suitability analysis [24–27]. Assessing suitable rangeland for livestock production using GIS-based MCDA is essential to improve livestock productivity and the livelihoods of the pastoral community. Moreover, remote sensing is a very crucial technology that aims to monitor LULC change, biodiversity, and ecosystems. Rangeland degradation can be monitored using remote sensing to improve livestock productivity and make a scientific decision on livestock mobility. In this context, this study aimed to identify a suitable rangeland for cattle, sheep, goat, and camel livestock production in the Bale lowlands using GIS-based MCDA and remote sensing techniques. Environmental factors such as LULC, rainfall, water accessibility, slope, and soil type were considered for rangeland suitability analysis. However, the study did not consider socio-economic criteria such as veterinary service, market center, and plant types and composition. The study did not consider veterinary service and market center as criteria because there was not well organized center due to the remoteness of the area. The study was also not included plant types and composition as a factor for this rangeland investigation because the study used Landsat image which is unable to discriminate the type plant species and their composition. Therefore, further study can be done by incorporating these and other gaps into the study. Finally, this study is important for providing better mobility decisions and improving livestock production to the local community in the Bale lowlands. Besides, the study is useful to regional and national government authorities for implementing feasible policies and strategies. Moreover, this study may provide new insights to the wider community worldwide.

## 2. Materials and Methods

*2.1. Description of the Study Area.* The study was conducted in the lowlands of the Bale zone. Geographically, it extends from 5° 20′ 58″ N to 8° 9′ 29″ N and 39° 12′ 37″ E to 42° 14′ 6″ E (Figure 1). The study area includes the districts of Berbere, Dawe Kachen, Dawe Serer, Delo Mena, Ginir, Gura Damole, Lege Hida, Madda Walabu, Rayitu, and Seweyna. The topography of the Bale lowlands is dominated by deep gorges, river valleys, flat plains, hills, and ridges. The elevation of the study area varies between 400 and 1500 m above mean sea level. The main vegetation types in the Bale lowlands include alpine vegetation, coniferous, podocarps, broad-leafed, juniper forest, woodland, savanna, and grasslands. The major soil types found in the study area are Arenosols, Calcisols, Cambisols, Fluvisols, Gypsisols, Leptosols, Luvisols, Nitosols, and Vertisols. Pastoralism is the dominant economic activity of Bale lowland communities. In the Bale lowlands, the livestock population of cattle, sheep, goats, and camels was estimated at 1575554, 352696, 3471105, and 264449, respectively. Of the total livestock population (6280396), cattle, sheep, goats, and camels together constitute about 5663804, and the remaining are donkeys, mules, and horses. Besides, crop farming is a source of livelihood. Some communities also practice both crop and

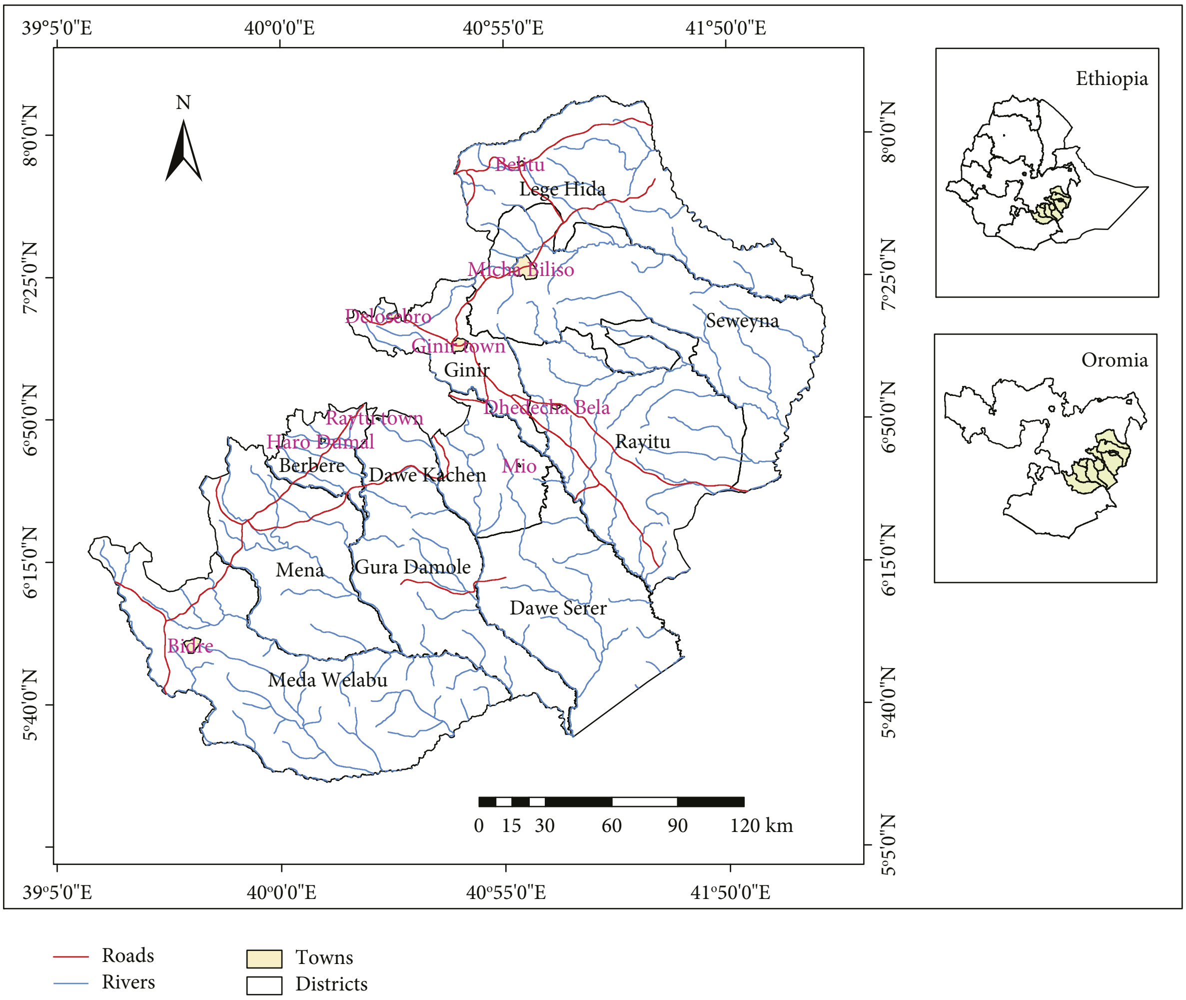


Figure 1: Location of the study area.

livestock agriculture as a source of income. Recurrent drought and uneven rainfall amounts and patterns are the main characteristics of the study area.

*2.2. Factors of the Study.* The study used LULC, rainfall, water resource accessibility, slope, and soil type to evaluate rangeland for livestock production. Assessing these parameters is important to provide crucial information about the suitable rangeland for livestock productivity and mobility.

*2.2.1. Land-Use and Land Cover.* A Landsat 8 Operational Land Imager (OLI) image of January 2020 with a 30 m resolution was used to extract LULC classes. Cloud and haze-free Landsat images were freely acquired during the dry season from the United States Geological Survey (USGS) web page (https://earthexplorer.usgs.gov). Basic image preprocessing such as atmospheric correction and image enhancement were done in ENVI 5.1 to improve the accuracy of image classification. A supervised maximum likelihood classifier was applied to extract LULC classes. Accordingly, forest, shrub land, bushland, grassland, farmland, and settlement were the main LULC types of Bale lowlands in 2020. Ground coordinate points were collected from the field using GPS to validate the accuracy of the classified LULC classes. The overall accuracy and kappa statistics of the classification were 88.24% and 0.8712, respectively.

*2.2.2. Rainfall.* Rainfall data were obtained from the USGS early warning web page (https://earlywarning.usgs.gov) to derive the annual rainfall factor. The data have a spatial resolution of 0.25° by 0.25°, which covers an area extending from 40° S to 50° N and 40° S to 50° N. The data were processed and extracted with the study area boundary, and rainfall values were reclassified to generate thematic layers for rangeland suitability. Rainfall was considered in this study because it influences the pasture and forage development in the rangeland.

*2.2.3. Water Resource Accessibility.* Water resources, mainly river factors, were extracted from ASTER DEM using ArcGIS 10.5 environment. Hydrological analysis was applied to extract rivers from DEM. Euclidean

Table 1: Rangeland evaluation criteria and their suitability classes for cattle, sheep, goat, and camel.

| Livestock category | Criteria | Range of suitability | | | |
|---|---|---|---|---|---|
| | | S1 | S2 | S3 | N1 |
| Cattle | LULC | GL | BL, SL | FL | FOR, SETT |
| | Rainfall (mm) | >800 | 500–800 | 300–500 | <300 |
| | Water accessibility (km) | <8 | 8–15 | 15–20 | >20 |
| | Slope (%) | 0–8 | 8–16 | 16–25 | >25 |
| | Soil types | VRe, CLp, VRk | CLh, CMx, LPq, LPe, GYh, LPk, FLe, LP, GYp | ARb, CMe, CMx, LVx, NTh, CM | |
| Sheep | LULC | GL | BL, SL | FL | FOR, SETT |
| | Rainfall (mm) | >800 | 500–800 | 300–500 | <300 |
| | Water accessibility (km) | <5 | 5–7 | 7–10 | >10 |
| | Slope (%) | 0–16 | 16–30 | 30–40 | >40 |
| | Soil types | CLh | CMx, ARb, CMe, VRe, CLp, GYh, VRk, LVx, NTh, CM | LPq, LPe, LPk, FLe, LP, GYp | |
| Goat | LULC | SL | GL, BL | FL | FOR, SET |
| | Rainfall (mm) | 600–800 | 400–600 | 250–400, >800 | <250 |
| | Water accessibility (km) | <5 | 5–7 | 7–10 | >10 |
| | Slope (%) | 0–16 | 16–35 | 35–50 | >50 |
| | Soil types | CMe, CMx, CM | CLh, ARb, LPq, LPe, VRe, CLp, Gyh, LPk, VRk, LVx, NTh, FLe, Lp, GYp | | |
| Camel | LULC | SL | GL, BL | FL | FOR, SET |
| | Rainfall (mm) | 450–700 | 350–450 | 200–350 | <200,>700 |
| | Water accessibility (km) | <10 | 10–20 | 20–25 | >25 |
| | Slope (%) | 0–8 | 8–16 | 16–25 | >25 |
| | Soil types | CMe, CMx, CM | CLh, ARb, LPq, LPe, VRe, CLp, Gyh, LPk, VRk, LVx, NTh, FLe, Lp, GYp | | |

SL: shrub land, GL: grassland, BL: bushland, FL: farmland, FOR: forest, SET: settlement; CMe: Eutric cambisols, CMx: Chromic Cambisols, CM: Cambisols, CLh: Happlic Calcisols, ARb: Cambic Arenosols, LPq: Lithic Leptosols, LPe: Eutric Leptosols, VRe: Eutric Vertisols, CLp: Petric Calcisols, GYh: Haplic Gypsisols, LPk:Rendizic Lpeptosols, VRk: Calcic Vertisols, LVx: Chromic luvisols, NTh: Haplic Nitosols, FLe: Eutric Fluvisols, Lp: Lpeptosols, and Gyp: Petric gypsisols

distance was used to assess water accessibility for livestock mobility. The maximum Euclidean distance of the perennial river in the study area was 84 km. Water accessibility was evaluated to minimize the distance traveled by pastoralists for watering.

*2.2.4. Slope.* The slope is also another factor used in this study. It was extracted from the ASTER DEM using surface analysis in ArcGIS 10.5. A slope suitability analysis was conducted to identify the nature of the landscape and the topography of the environment. The slope of the study area varies from 0 to 58% and the thresholds were identified based on the nature of the topography and the capacity of animals to easily move in the area.

*2.2.5. Soil Types.* Soil data collected from the Ministry of Agriculture were used to extract soil types in the ArcGIS 10.5 environment. Soil types were analyzed to identify the most suitable soil for rangeland development since it determines the growth of tree plants, grass, mangroves, and other vegetation types.

*2.3. Criteria Rating and Standardization.* The aforementioned factors were independently evaluated to prepare the thematic layers. The factors were reclassified in the ArcGIS 10.5 environment to rate the criteria and make each thematic layer suitable for overlay analysis. Furthermore, before the weights were assigned, each factor was standardized into four suitability classes, such as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N1), based on the Food and Agriculture Organization (FAO) (2007). Criteria weights were assigned based on the literature [28, 29] and the nature of the environment under investigation. Besides, different weights were assigned to the variables that were used for rangeland suitability analysis because their influence may not be similar in the four livestock categories. Besides, the study needs to identify suitable rangeland areas for cattle, sheep, goat, and camel livestock types and remommends separating rangeland types for improving livestock productivity and managing pastoralist mobility.

*2.4. Factor Reclassification.* All factors were resampled to a 30 m resolution to conduct overlay analysis. Besides, the factors that are used for livestock rangeland suitability are

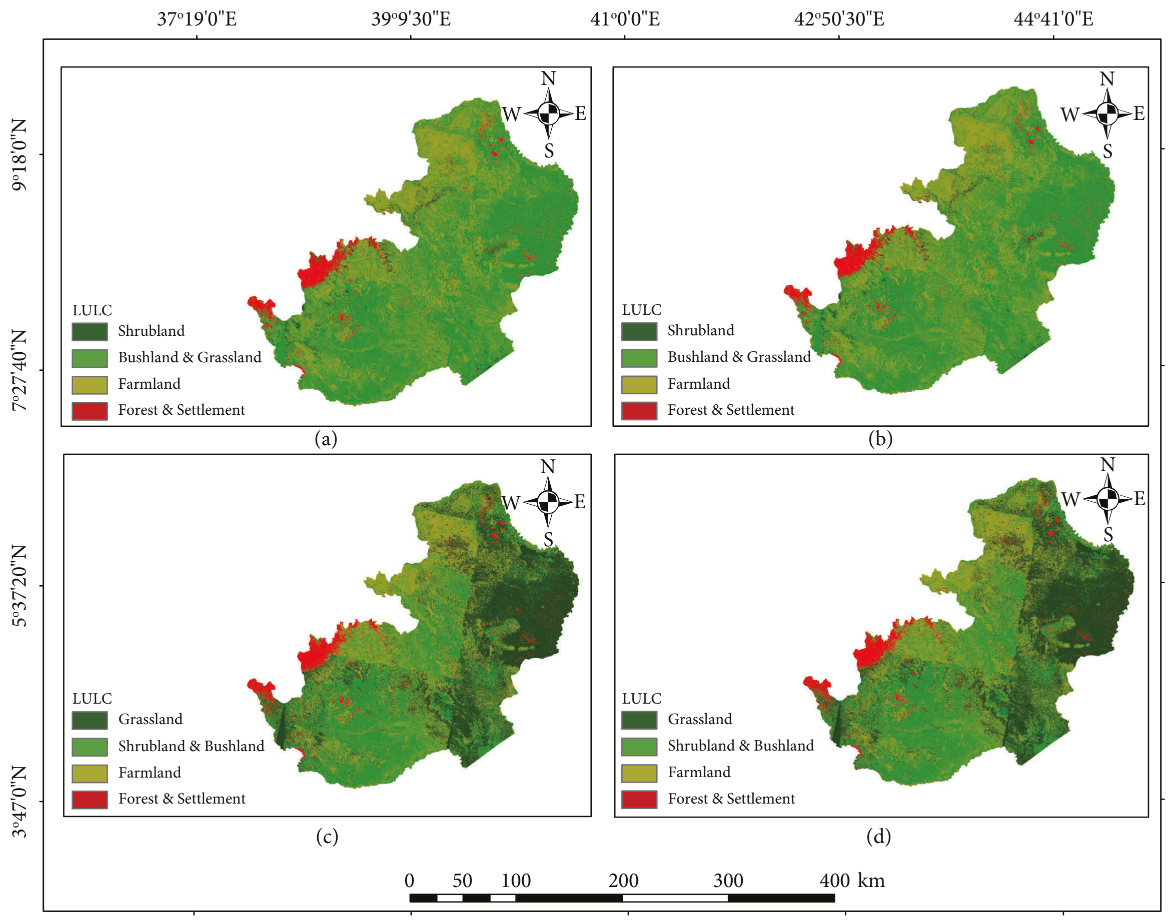


Figure 2: LULC factor livestock production map for (a) goat, (b) camel, (c) sheep, and (d) cattle.

reclassified and standardized into four suitability classes as shown in Table 1. LULC types were reclassified into four different classes to evaluate their suitability for cattle, camels, sheep, and goats (Table 1 and Figure 2). This classification was done based on the rangeland suitability classification done by Ebro [28]. Moreover, factors such as rainfall (Table 1 and Figure 3), slope (Table 1 and Figure4), and soil type (Table 1 and Figure 5) were classified into highly, moderately, marginally, and not suitable classes according to previous studies [28,29]. Reclassification analysis was also conducted to extract water access suitability classes (Table 1 and Figure 6), which were classified according to the previous studies [30,31]. The study was mainly focused on rangeland suitability classification for livestock categories specifically for cattle, sheep, goat, and camel. Such a classification of rangeland types is very significant for proper rangeland management and increases livestock productivity and improves the livelihoods of the communities. In reality, cattle, sheep, goat, and camel did not require the same types of rangeland. To implement this reality and improve livestock productivity and minimize the impacts of improper livestock mobility, this study analyzed rangeland suitability for four livestock categories based on five criteria (Table 1).

*2.5. Assigning Criteria Weights.* A GIS-based MCDA model was used to analyze the factors employed in this study (Figure 7). The model has three basic procedures. In the first stage of the model, each criterion was reclassified in ArcGIS, and the map was standardized to a common scale. Accordingly, the factors of LULC, rainfall, water accessibility, slope, and soil type were reclassified into four classes (S1, S2, S3, and N1). In the second stage, criteria weights were computed from a pairwise comparison matrix in the IDRISI 17 AHP environment, and the consistency ratio was derived from the matrix (Table 2). AHP is one of the most commonly used approaches for multi-criteria evaluation, which used for spatial suitability analysis and sound decision making. The evaluation process has components of goal, criteria, alternative solutions, experts, and decision making and expected decision outcomes [32]. The AHP is very capable of managing different and complex criteria and enabling us to make better decisions [33,34]. However, the AHP approach has some subjectivity in ranking criteria and determining weights for the criteria. Therefore, to minimize the effect of subjectivity and achieve better weighted evaluation of this study, the AHP model was guided by the goals of the problem to be achieved, alternative solutions, experience, knowledge, and skills of researchers, the realities of the environment of the study area,

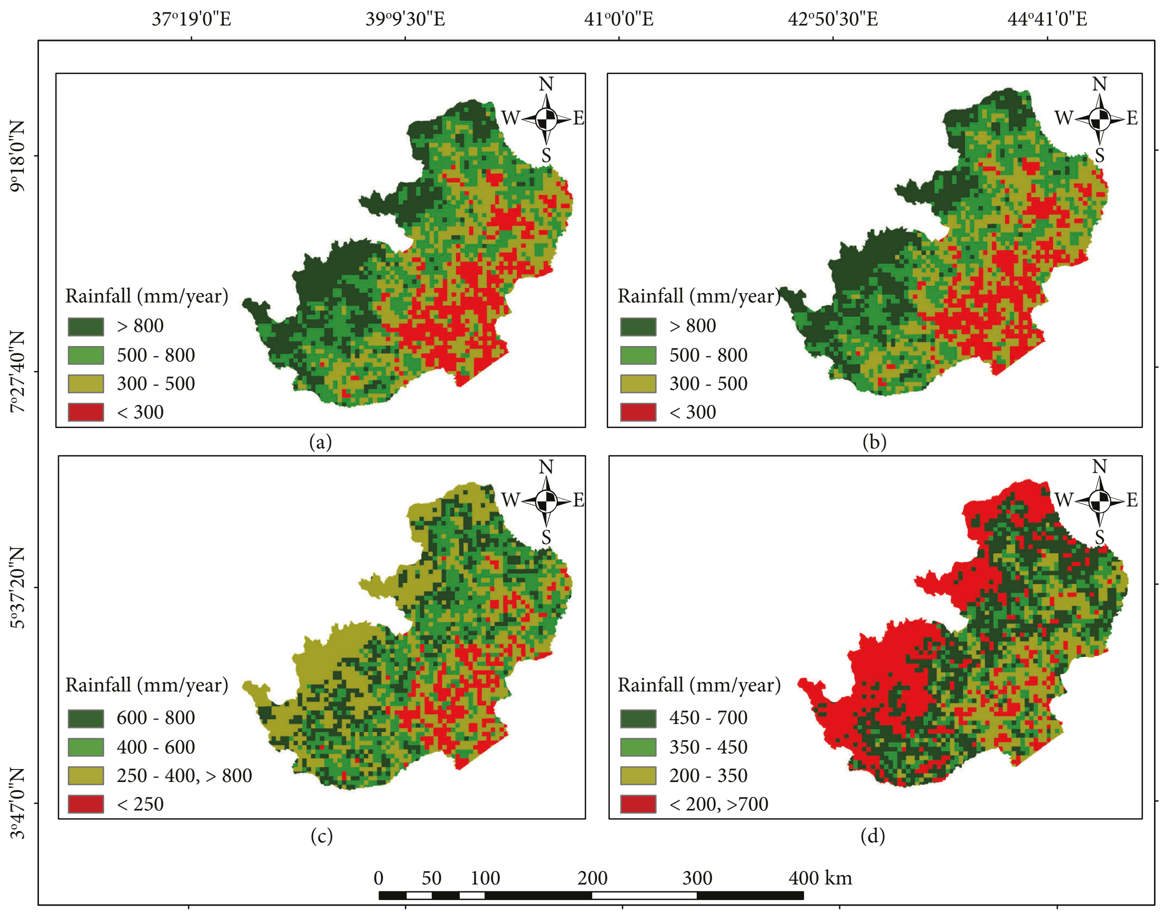


Figure 3: Rainfall factor map for livestock production: (a) cattle, (b) sheep, (c) goat, and (d) camel.

and researchers' experience in the study area. In the third stage, the standardized criteria maps and their weights were combined in the weighted overly analysis as explained in the following equation:

$$S = \sum_{i=1}^{n} W_i * C_i * \prod_{j=1}^{m} r_j. \quad (1)$$

This GIS-based MCDA model can be explained as follows:

$$S = ((LUw \times LUc) + (Rw \times Rc) + (WAw \times WAc) + (SLw \times SLc) + (STw \times STc)) \times (LUr \times Rr \times WAr \times SLr \times STr), \quad (2)$$

where $C_i$ represents criterion, $r$ is the rate of criterion, $w$ is the weight of criterion, $\prod$ is the product, LU (LULC), R is the rainfall, WA is the water accessibility, SL is the slope, and ST is soil types.

The overall methodological procedures of this study are presented in Figure 7. The figure indicates that five criteria (LULC, slope, rainfall, soil type, and water accessibility) were used as input parameters. And, different GIS analyses were implemented to obtain criteria suitability maps and a final rangeland suitability map.

## 3. Results

### 3.1. Factor-Wise Rangeland Suitability

*3.1.1. Soil Types.* The result of soil type suitability analysis showed that 8923.12 and 1643.72 km$^2$ areas were highly suitable for cattle and sheep production, respectively, whereas 25377 and 32274.14 km$^2$ areas were moderately suitable for cattle and sheep production, respectively (Table 3). Based on the soil factor results, the places found in north Delo Mena, Berbere, Lege Hida, and northwest Ginir were highly suitable, while the south and southeast Delo Mena and Meda Welabu were moderately suitable for cattle

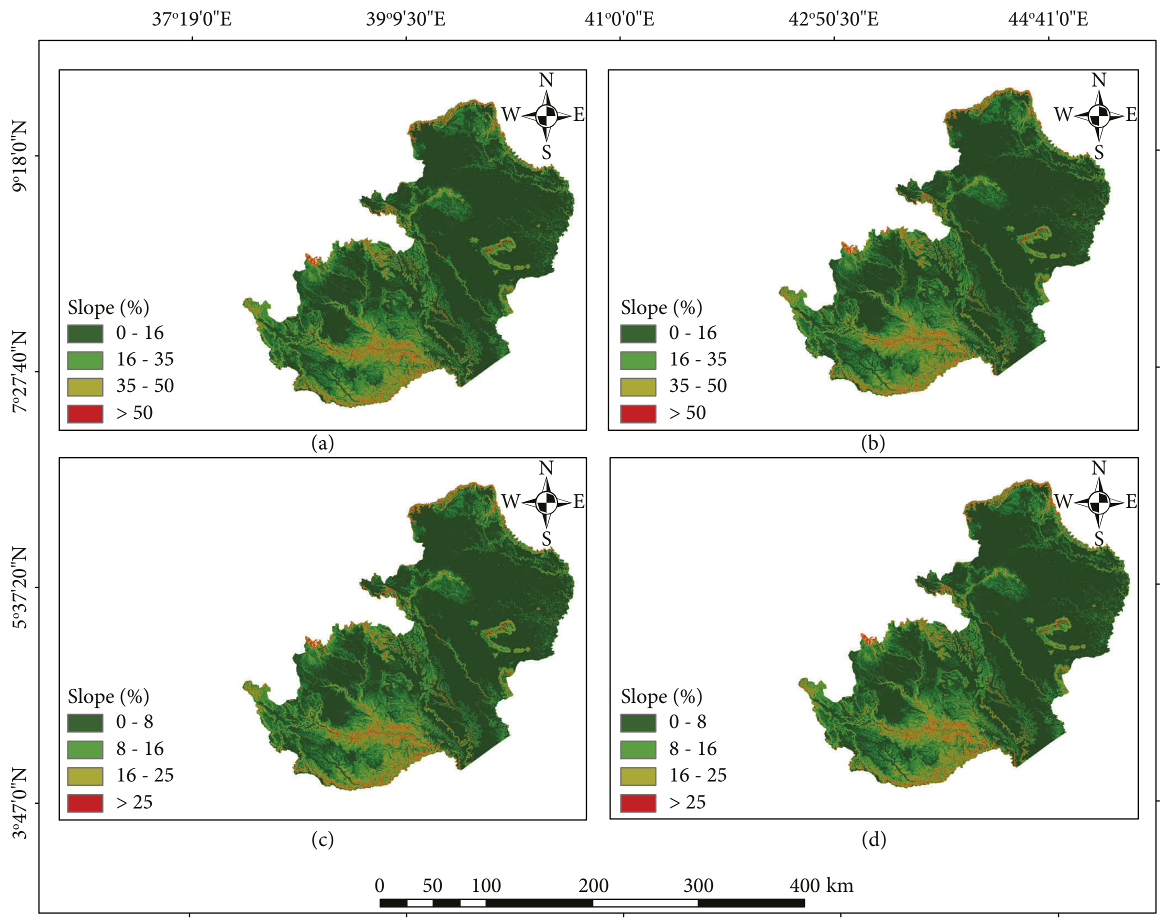


Figure 4: Slope factor map for livestock production: (a) goat, (b) sheep, (c) camel, and (d) cattle.

productivity (Figure 8(a)). Most places in north-south and central Bale lowlands were moderately suitable for sheep productivity (Figure 9(a)). Moreover, all soil types found in the study area were highly and moderately suitable for goat and camel productivity (Figures 10 and 11(a)).

*3.1.2. Rainfall.* The statistical results of rainfall suitability indicated that 1085.42, 1085.42, 8099.91, and 17988.82 km$^2$areas of the lowlands were highly suitable for cattle, sheep, goat, and camel production, respectively (Table 3). Based on the result of the rainfall factor, the places found in north Meda Welabu, Delo Mena, Berbere, Ginir, and Lege Hida were highly and moderately suitable for cattle and sheep productivity while southeast places were not suitable (Figures 8 and 9(b)). Moreover, the results of rainfall suitability analysis showed that arid and semi-arid areas were not suitable for cattle and sheep mobility and production. On the other hand, mountainous areas and places that received high rainfall such as the north and northwest of the Bale lowlands were not suitable for camels because such areas may affect their movement and consume more energy to travel (Figure 11(b)). Besides, very arid areas that were dominated by erratic rainfall were not suitable for goat mobility and production (Figure 10(b)).

*3.1.3. Slope.* The slope suitability analysis of the study showed that 39362.52 km$^2$ areas were highly suitable for cattle and camel production whereas the 45855.34 km$^2$ area of the Bale lowlands was highly suitable for sheep and goat production (Table 3). In addition, the results indicated that most places of the Bale lowlands were highly and moderately suitable, while the gorge and escarpment areas were not suitable for cattle, sheep, goat, and camel productivity (Figures 8 and 11(c)).

*3.1.4. Water Accessibility.* The results of the study on water accessibility indicated that 22586.79, 16969.89, 16969.74, and 25054.69 km$^2$ of the Bale lowlands were highly suitable for cattle, sheep, goat, and camel production, respectively (Table 3). Most places in the Bale lowlands that are very close to perennial rivers are highly and moderately suitable for cattle, sheep, goat, and camel productivity because the livestock may not lose their energy in traveling long distances whereas areas dominated by gorges and escarpments were not suitable for livestock production even though sufficient water was available in such areas because the livestock cannot move easily in those places (Figures 8 and 11(d)).

*3.1.5. Land-Use and Land Cover.* The results of LULC revealed that the majority of the area (41439.16 km$^2$) was highly suitable for cattle and sheep production (Table 3).

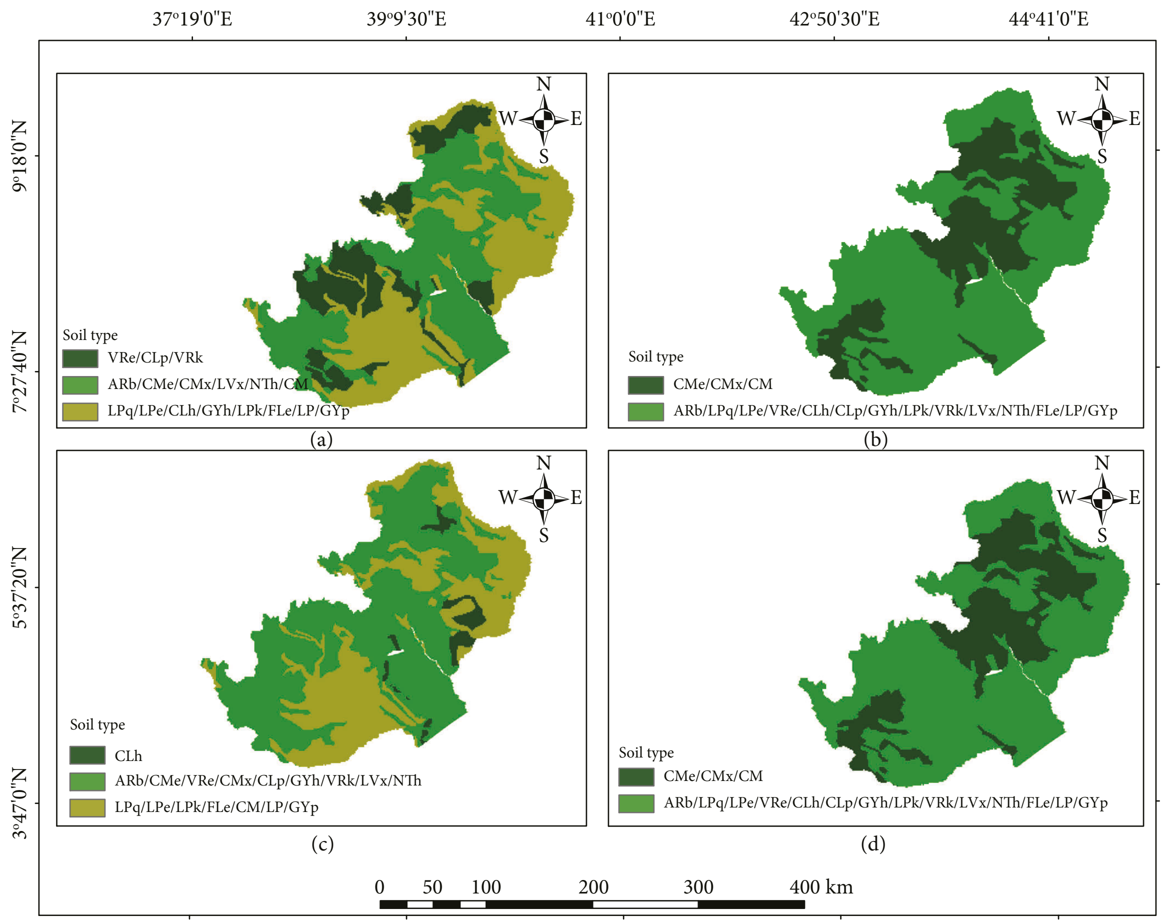


Figure 5: Soil factor map for livestock production: (a) cattle, (b) goat, (c) sheep, and (d) camel.

Most places found in south, southeast, and east of the Bale lowlands were highly suitable for cattle and sheep production whereas the northwest Ginir and the west Lege Hida places were marginally suitable for cattle and sheep production. On the other hand, a few places in northwest Meda Welabu, north Delo Mena, and north Berbere were not suitable for cattle and sheep production (Figures 8 and 9(e)). According to the results of the LULC factor, some places in the Bale lowlands were highly suitable for goat and camel production whereas most areas of the Bale lowlands (41628.64 km$^2$), mainly east, south, southeast and central places were moderately suitable for goat and camel production. Browser animals such as goats and camels were productive in shrub land-dominated areas (Figures 10 and 11(e)). The results of this study indicated that areas that are very good in pasture and tree cover are very decisive for cattle and sheep mobility and production.

*3.2. Final Rangeland Suitability.* The study revealed that 4112.5 km$^2$ of the Bale lowlands was highly suitable for rangeland for cattle production whereas moderately, marginally, and not suitable rangeland for cattle livestock population covered an area of 40099.26, 7644.3, and 399.1 km$^2$, respectively. Apart from this, 16311.42, 30925.93, 4671.73, and 346.1 km$^2$ of the Bale lowlands were highly, moderately, marginally, and not suitable for rangeland and sheep productivity, respectively. Besides, 6643.57, 41981.25, and 3630.36 km$^2$ of the study area were highly, moderately, and marginally suitable for goat production, respectively. Rangelands of the Bale lowlands which were highly suitable for camel production covered about 9820.5 km$^2$ whereas 36802.67 and 5631.97 km$^2$ areas were moderately and marginally suitable for camel production, respectively (Table 4 and Figures 12(a)–12(d)).

## 4. Discussion

*4.1. Rangeland Suitability Analysis for Livestock Mobility and Production.* Livestock agriculture is the main economic activity and source of livelihood for pastoral communities, particularly in the lowland areas of Ethiopia. It serves as a source of export earnings for the country [35]. The country has a huge potential for livestock production though it is not utilized properly due to the lack of proper policies for land-use planning and the low attention of the government. Livestock productivity in Ethiopia is also very low because of a lack of separating rangelands for each livestock type. However, feasible policies and legislation are very fundamental for the scientific use of rangeland and proper

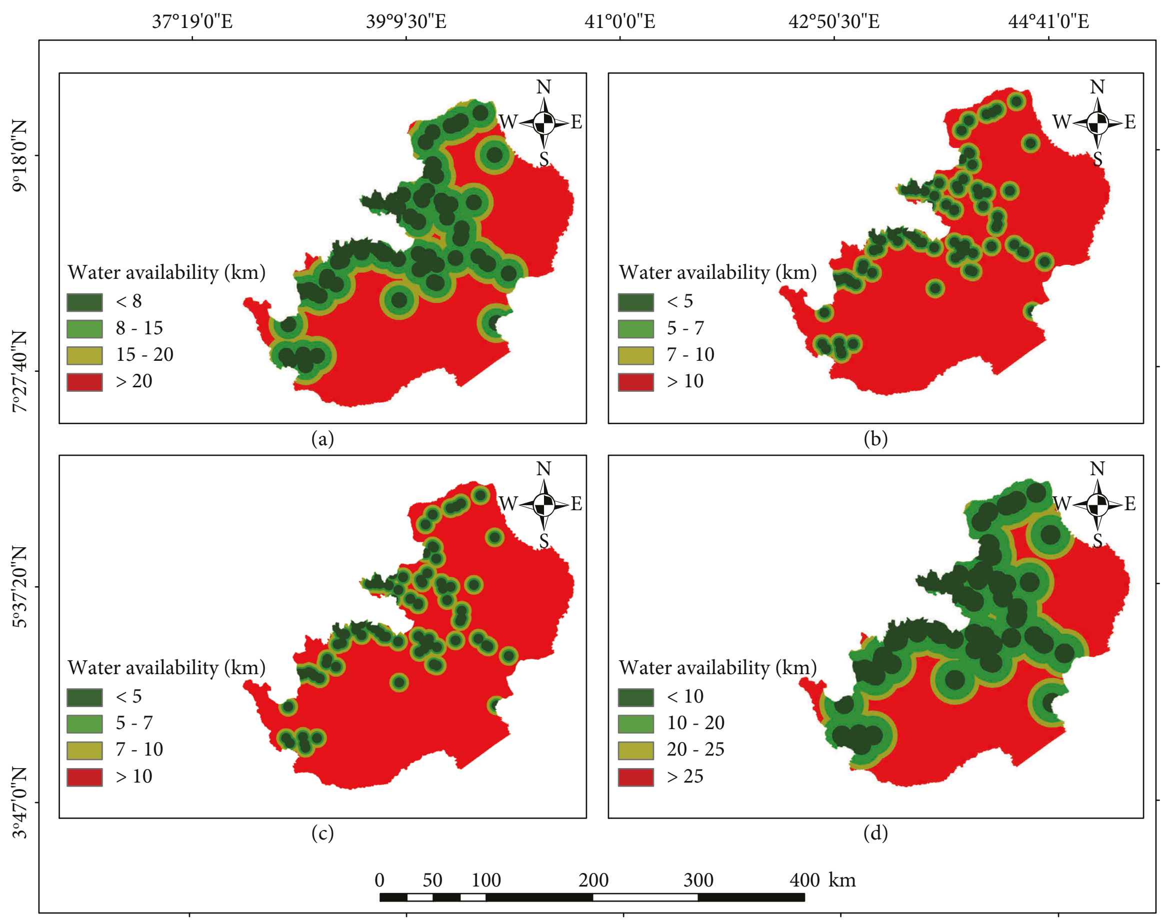


Figure 6: Water accessibility factor map for livestock production: (a) cattle, (b) sheep, (c) goat, and (d) camel.

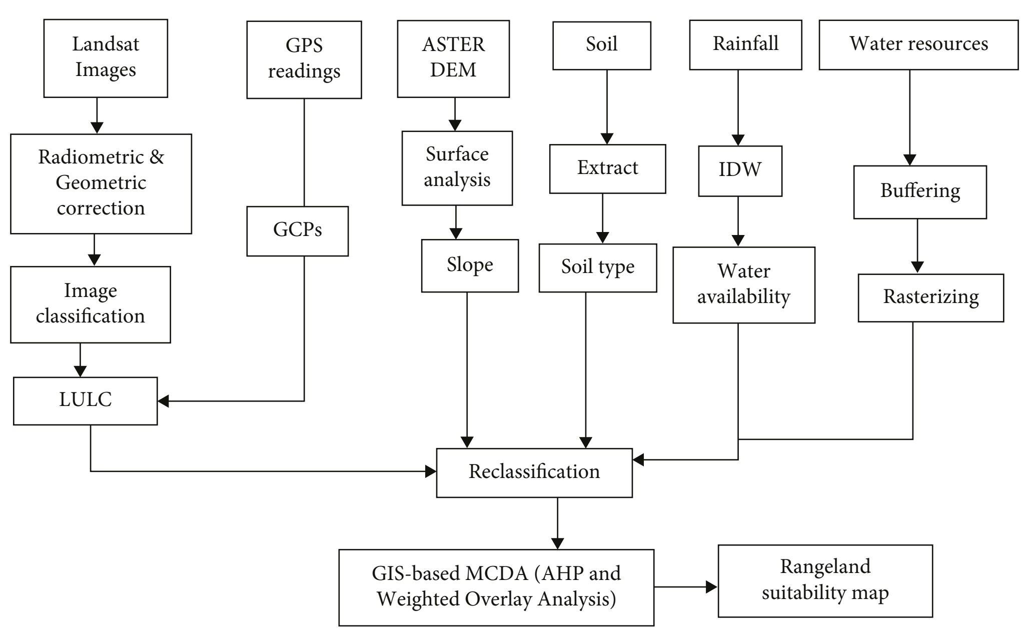


Figure 7: Methological flow diagram of the study.

decisions regarding livestock mobility and productivity [8, 36]. Therefore, scientific rangeland evaluation has a key role in improving livestock production and reducing the risks of livestock mobility by identifying rangeland types for different livestock categories. GIS-based MCDA models have been contributing to advanced rangeland suitability analysis, which is based on different physical and socio-economic factors.

Table 2: Criteria weights of the pair-wise comparison matrix.

| Factors | Cattle Weight | Sheep Weight | Goat Weight | Camel Weight |
|---|---|---|---|---|
| LULC | 0.3375 | 0.5405 | 0.3278 | 0.3415 |
| Rainfall | 0.3375 | 0.1782 | 0.3278 | 0.2710 |
| Water accessibility | 0.1665 | 0.0967 | 0.1445 | 0.1834 |
| Slope | 0.1049 | 0.1282 | 0.1093 | 0.1834 |
| Soil type | 0.0536 | 0.0563 | 0.0906 | 0.0903 |
| Consistency ratio | 0.05 | 0.07 | 0.03 | 0.04 |

Table 3: Rangeland suitability evaluation factors and their suitability classes and aerial extent.

| Livestock | Suitability | Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LULC ($Km^2$) | % | RF ($Km^2$) | % | WA ($Km^2$) | % | SL ($Km^2$) | % | ST ($Km^2$) | % |
| Cattle | S1 | 41439.16 | 79.3 | 1085.42 | 2.08 | 22586.79 | 43.22 | 39362.52 | 75.37 | 8923.12 | 17.08 |
| | S2 | 4574.84 | 8.75 | 11713.61 | 22.42 | 12789.67 | 24.48 | 7100.86 | 13.6 | 25377 | 48.56 |
| | S3 | 5250.18 | 10.05 | 23759.92 | 45.47 | 8127.94 | 15.55 | 3741.69 | 7.16 | 17955.06 | 34.36 |
| | N1 | 990.99 | 1.9 | 15696.24 | 30.04 | 8750.78 | 16.75 | 2020.1 | 3.87 | — | — |
| Sheep | S1 | 41439.16 | 79.3 | 1085.42 | 2.08 | 16969.74 | 32.47 | 45855.34 | 87.75 | 1643.72 | 3.15 |
| | S2 | 4574.84 | 8.75 | 11713.61 | 22.42 | 8124.85 | 15.55 | 3741.69 | 7.16 | 32274.14 | 61.76 |
| | S3 | 5250.18 | 10.05 | 23759.92 | 45.47 | 9241.76 | 17.69 | 1844.81 | 3.53 | 18337.31 | 35.09 |
| | N1 | 990.99 | 1.9 | 15696.24 | 30.04 | 17918.83 | 34.29 | 813.34 | 1.56 | — | — |
| Goat | S1 | 4385.35 | 8.39 | 8099.91 | 15.5 | 16969.74 | 32.47 | 45855.34 | 87.75 | 37285.24 | 71.35 |
| | S2 | 41628.64 | 79.66 | 20767.05 | 39.74 | 8124.85 | 15.55 | 3741.69 | 7.16 | 14969.94 | 28.65 |
| | S3 | 5250.18 | 10.05 | 18163.68 | 34.76 | 9241.76 | 17.69 | 1844.81 | 3.53 | — | — |
| | N1 | 990.99 | 1.9 | 5224.54 | 10 | 17918.83 | 34.29 | 813.34 | 1.56 | — | — |
| Camel | S1 | 4385.35 | 8.39 | 17988.82 | 34.42 | 25054.69 | 47.95 | 39362.52 | 75.33 | 37285.24 | 71.35 |
| | S2 | 41628.64 | 79.66 | 10994.7 | 21.04 | 13808.77 | 26.43 | 7100.86 | 13.56 | 14969.94 | 28.65 |
| | S3 | 5250.18 | 10.05 | 7944.48 | 15.2 | 6961.83 | 13.32 | 3741.69 | 7.16 | — | — |
| | N1 | 990.99 | 1.9 | 15327.18 | 29.33 | 6429.89 | 12.3 | 2050.1 | 3.92 | — | — |

LULC: land-use and land cover, RF: rainfall, WA: water accessibility, SL: slope, and ST: soil type.

The present study identified potential rangelands for livestock such as cattle, sheep, goat, and camel mobility and productivity in the Bale lowlands. This rangeland suitability investigation was done based on LULC, rainfall, water accessibility, slope, and soil type parameters. Because these criteria strongly influence the forage production, livestock mobility, and their productivity, improper land and environmental management cause low livestock production and food insecurity.

LULC is the main controlling factor of rangeland because it is a unit of land that directly affects forage availability and production. The majority of areas of the Bale lowlands, which are covered by grassland, are highly suitable for cattle and sheep while very few areas which are covered with settlements and forest were unsuitable for rangeland production. Areas that are covered by bushland and shrub land were moderately suitable for cattle and sheep production. On the other hand, the area, which is covered by shrub land, was highly suitable for goat and camel production. Besides, the farming areas were marginally suitable for cattle, sheep, goats, and camels because it is very hard for forage production and difficult for grazing. Places which are dominated by bushland and shrub land were moderately suitable for cattle and sheep production. The study also revealed that grassland areas are highly suitable for cattle and sheep production because such land type has high grass species diversity and is very suitable for grazing. Terfa and Suryabhagavan [31] stated that a place that is dominated by grass is highly suitable for cattle and sheep. Whereas shrub land and bushland are more suitable for goat and camel production because these animals are browsers and can easily get their food from such kind of land cover types.

Rainfall is also the main factor that affects rangeland suitability since it controls water availability for rangeland plant growth and their greenness [22,31]. It also determines soil moisture, which in turn affects grass and plant growth. The very dry areas of the Bale lowlands, which receive very low rainfall, were not suitable for rangeland and livestock production. Places with steep slopes were not suitable for cattle and sheep because it affected their possibility of feed and water. It also affects surface runoff and soil erosion, which affects forage production [22]. On the other hand, places having flat slopes were highly suitable for rangeland because they are suitable for grazing [22,31].

Soil type is also important in any rangeland evaluation process because it influences the quality and quantity of forage [22]. Areas that are dominated by very deep soils were highly suitable for rangeland and livestock production because such soils are good for plant and grass development. Moreover, accessibility to surface water resources

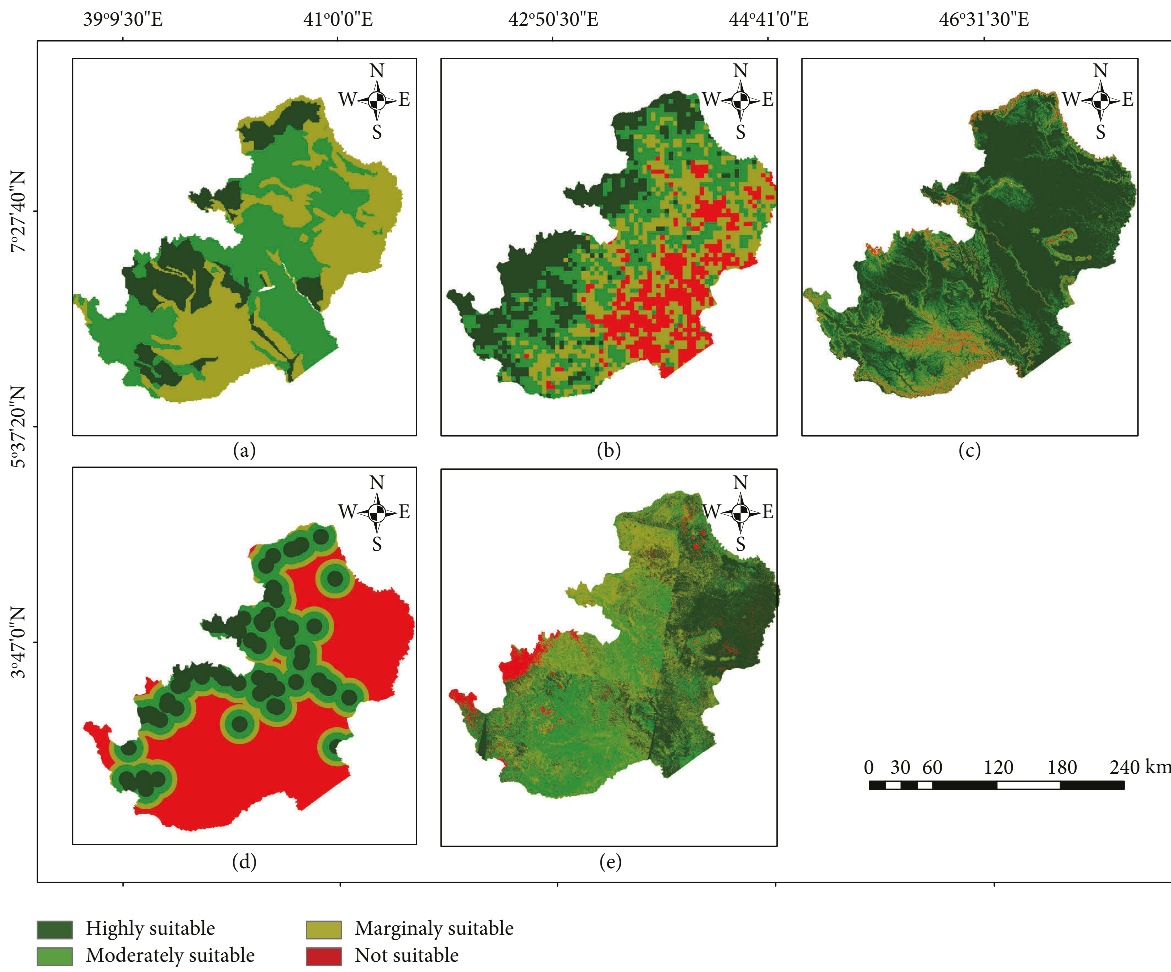


Figure 8: Factor suitability map for cattle mobility: (a) soil type, (b) rainfall, (c) slope, (d) water accessibility, and (e) LULC.

such as springs, rivers, and streams is essential for rangeland suitability. Areas which have high access to water resources were suitable for rangeland and livestock production because it reduces the time and energy of transport and minimizes the possible risk of mobility [22]. However, places that have low access to water resources were not suitable for livestock production since it increases the cost of mobility and causes different risks. According to Gavili et al. [30] and Terfa and Suryabhagavan [31], the water sources within the 5 km range were highly suitable for livestock production. The study confirmed that most of the areas of the Bale lowlands were moderately suitable for rangeland and livestock production. The study also revealed that some places in the Bale lowlands were highly suitable for rangeland and livestock production.

Based on the result of the study, the Bale lowlands have potential rangeland that enables them to improve the productivity of cattle, sheep, goat, and camel. However, there is no separate rangeland for these livestock types in the study area. Therefore, there should be a separated rangeland management system in the lowland area of the Bale zone to increase livestock productivity. Moreover, Ethiopia should exercise a separate rangeland system based on the livestock categories and formulate policies to manage rangeland even though there is no identified and separated rangeland for each livestock type in most African countries.

*4.2. Impact of Rangeland Degradation on Livestock Productivity.* Currently, rangeland has been degraded due to different human-induced problems and environmental changes. The extreme rangeland dynamics have been affecting livestock productivity and pastoralists' livelihoods. Therefore, GIS-based MCDA and remote sensing approaches to suitable land evaluation through considering different biophysical, environmental, and socio-economic

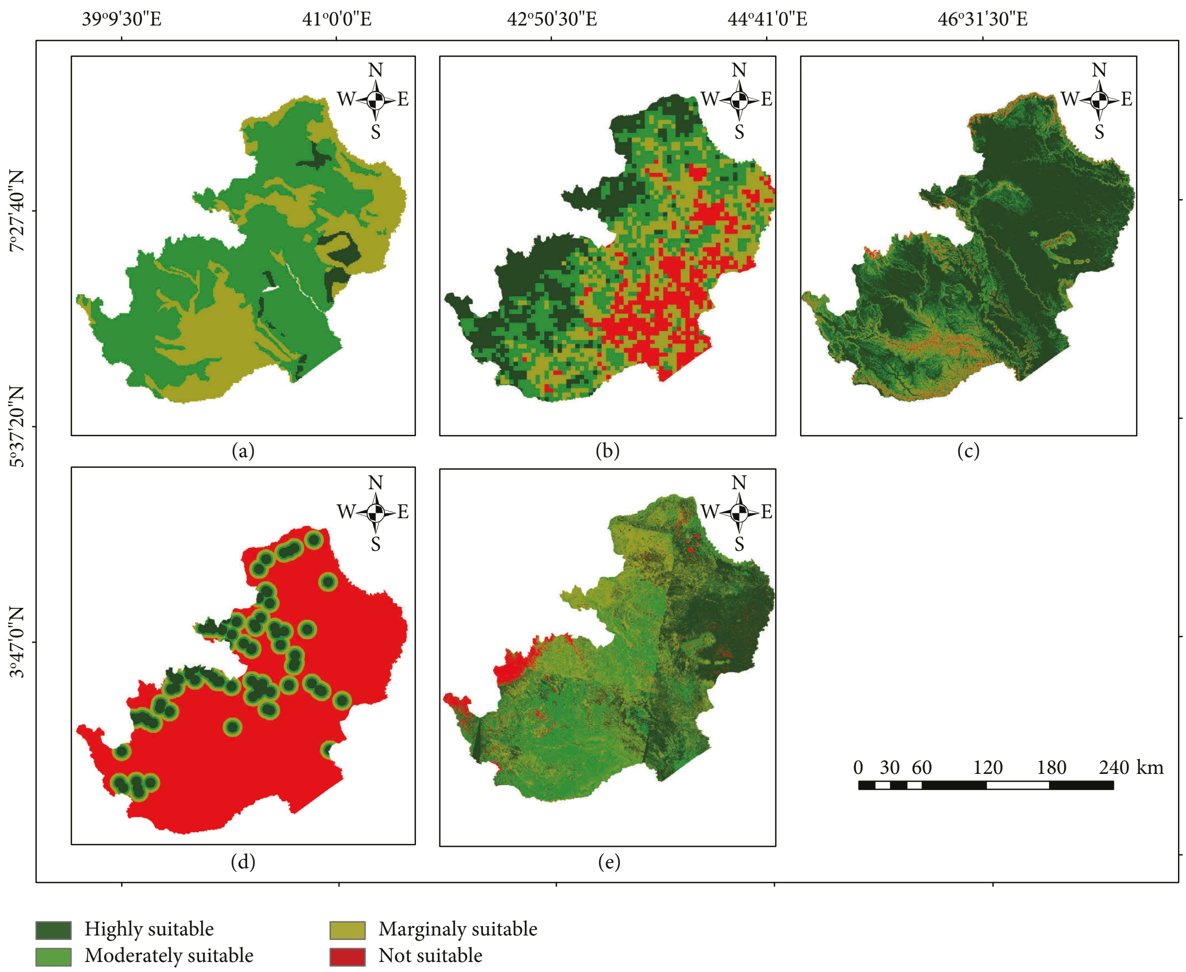


FIGURE 9: Factor suitability map for sheep mobility: (a) soil type, (b) rainfall, (c) slope, (d) water accessibility, and (e) LULC.

criteria are vital to mitigate the impacts of rangeland degradation [24, 39, 40]. Understanding ecosystem health, rangeland dynamics, and their indicators in rangeland systems enables us to assess livestock productivity. Analyzing current and future LULC types is very essential to identify suitable land for livestock production and mobility. Thus, land suitability analysis is an integral part of spatial analysis for deciding different land-use plans [24, 25, 27, 41] and evaluating future land-use conditions.

Therefore, rangeland degradation and its effects on livestock productivity should be spatially and temporally monitored based on different indicators such as vegetation cover, species composition, soil, and livestock conditions (health and products) [42,43]. The intensification of crop farming due to rapid population growth aggravates rangeland depletion and reduces livestock productivity. Besides, it reduces forage species and composition such as grassland, woody vegetation, shrub land, bushland, and open pastoral land. The study conducted by Legese and Balew [8] found that crop farming in the Bale lowlands was expanded at the expense of vegetation cover and open grazing lands. This leads to a decline in the type, composition, quality, and quantity of forage plants and grasses. Moreover, this problem is very serious in the dry season when there is a lack of forage species and soil moisture. Therefore, the degradation of rangeland causes a considerable decline in

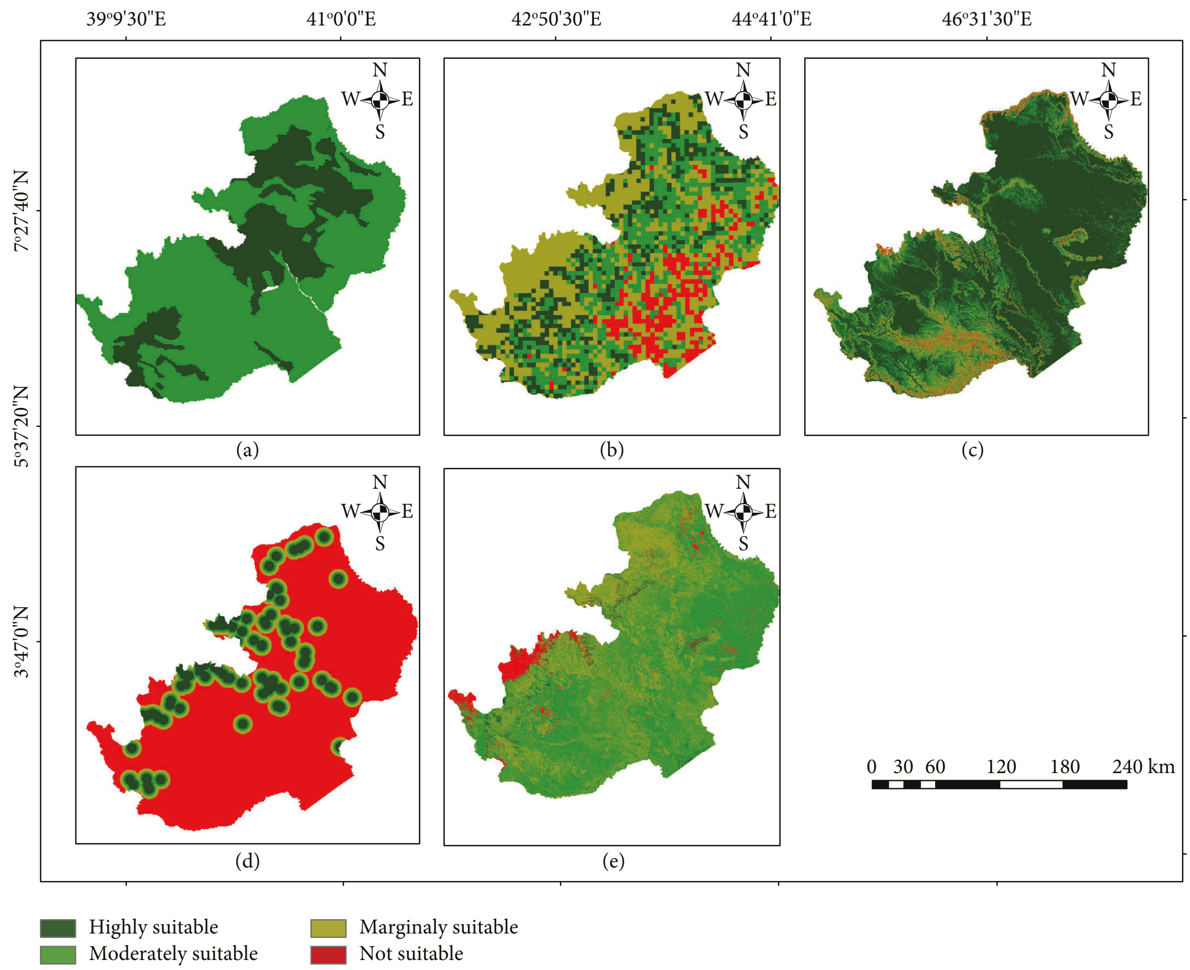


Figure 10: Factor suitability map for goat mobility: (a) soil type, (b) rainfall, (c) slope, (d) water accessibility, and (e) LULC.

livestock production such as milk, meat, and calving rate, which affects animals' health and brings hunger and death. Such problem affects the livelihood of the pastoral communities and causes famine and poverty. Due to extreme rangeland degradation and its interrelated problems, pastoralists in the Bale lowlands were forced to mobility to other areas to search for forage for their livestock. However, their mobility was not well understood and studied in terms of the condition of vegetation composition and type, soil moisture, season and landscape structure, and water availability. Thus, pastorals have to evaluate rangeland performance against livestock

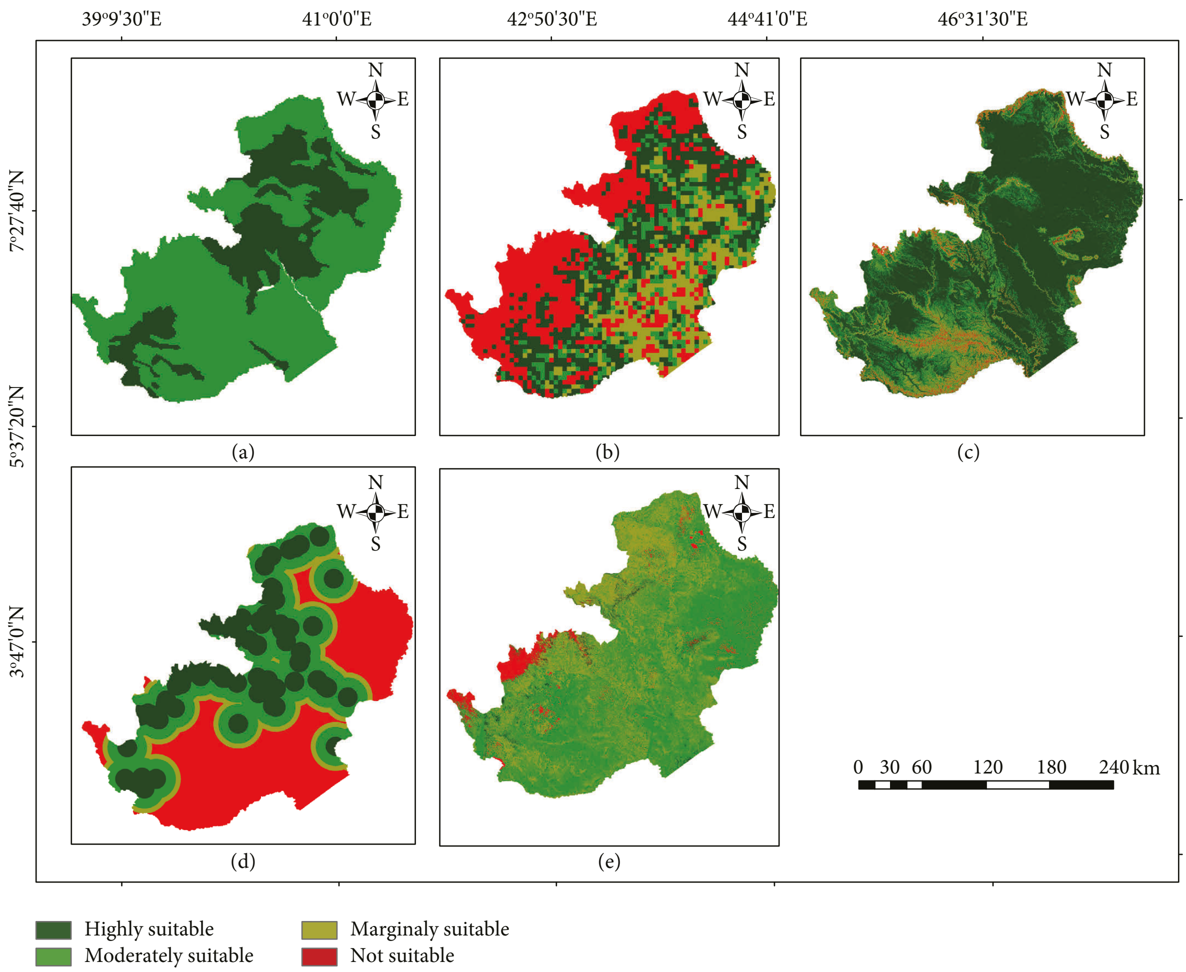


Figure 11: Factor suitability map for camel mobility: (a) soil type, (b) rainfall, (c) slope, (d) water accessibility, and (e) LULC.

Table 4: Rangeland suitability class for livestock with respective area coverage.

| Suitability classes | Livestock category | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cattle | | Sheep | | Goat | | Camel | |
| | Area (km$^2$) | Area (%) | Area (km$^2$) | Area (%) | Area (km$^2$) | Area (%) | Area (km$^2$) | Area (%) |
| S1 | 4112.5 | 7.87 | 16311.42 | 31.21 | 6643.57 | 12.71 | 9820.5 | 18.79 |
| S2 | 40099.26 | 76.74 | 30925.93 | 59.18 | 41981.25 | 80.34 | 36802.67 | 70.43 |
| S3 | 7644.3 | 14.63 | 4671.73 | 8.94 | 3630.36 | 6.95 | 5631.97 | 10.78 |
| N1 | 399.1 | 0.76 | 346.1 | 0.66 | — | — | — | — |

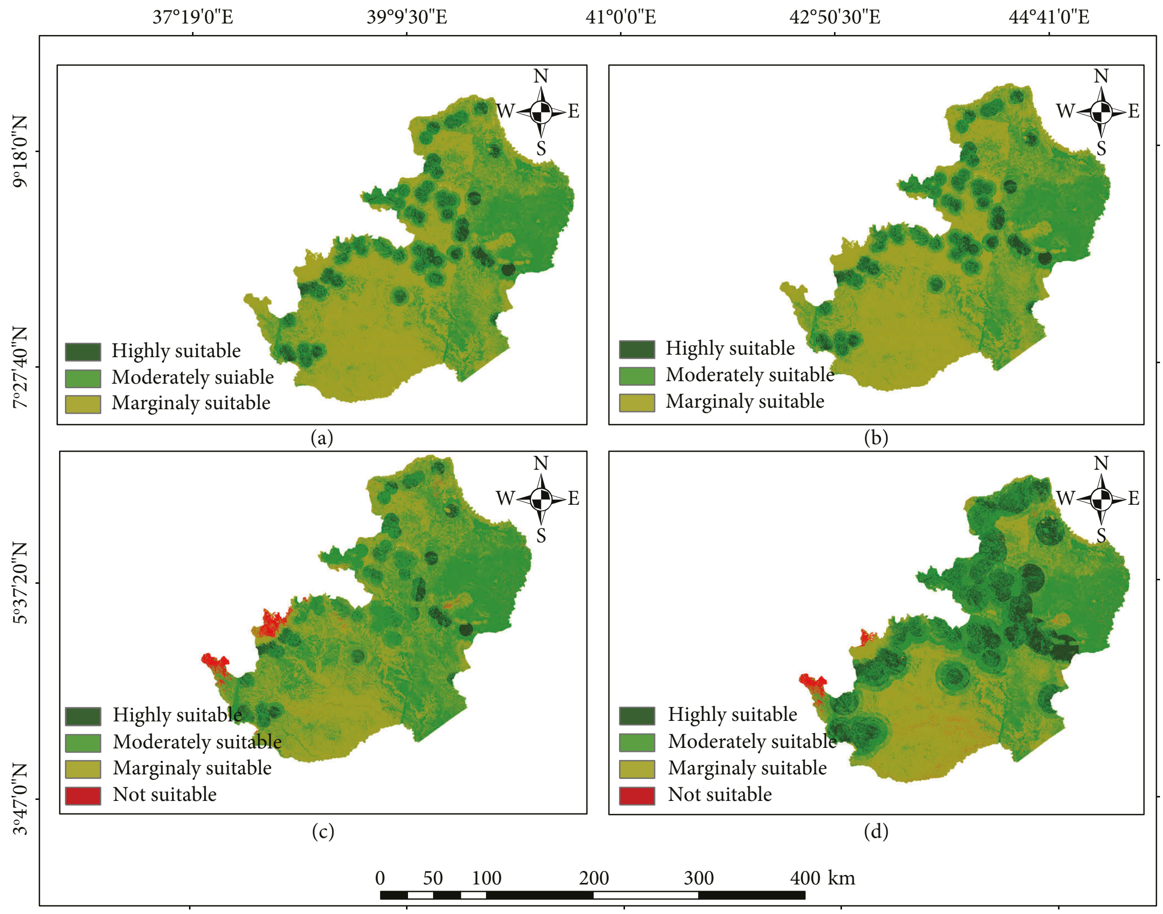


Figure 12: Rangeland suitability map for (a) camel, (b) goat, (c) sheep, and (d) cattle.

productivity through their local knowledge and scientific studies.

## 5. Conclusions

The rangelands of the Bale lowlands have been degraded due to climatic and human-induced problems. This affects the rangeland system and the ecosystem as a whole. Rangeland degradation brings different environmental and socio-economic problems such as rangeland change, famine, food insecurity, and land degradation. Therefore, land evaluation based on different criteria is vital to improving the quality of the rangeland ecosystem, livestock productivity, and livelihood of the pastoralists. A GIS-based MCDA and remote sensing approach has been used to investigate different environmental resources. The approaches are mainly important for processing and managing different spatial datasets to evaluate rangelands. LULC, rainfall, water accessibility, slope, and soil type were the main criteria that were used for livestock productivity in the Bale lowlands. The result of the study revealed that most parts of the Bale lowlands were moderately and highly suitable for livestock production whereas very few areas, mainly gorge, valleys, escarpment and arid and semi-arid places that are dominated by irregular rainfall and extreme temperature were not suitable for cattle, sheep, goat, and camel livestock production. The study confirmed that the Bale lowlands have huge potential rangeland for improving livestock production. The study recommended that pastorals should move their livestock to areas with better forage products such as dense grassland, woodland, and shrub land. Besides, pastoralists should not travel very long distances, particularly during the dry season, because they may be vulnerable to different risks, and instead, they have to search for water sources in their temporarily settled areas. Governments and environmental managers should give great attention to using the potential rangeland and develop policies for supporting pastoralists. Moreover, the study recommended that the government should formulate a rangeland policy to improve pastoral livelihoods. Finally, rangelands are mixed in Africa, particularly in Ethiopia. However, there should be separate rangelands for each livestock type to improve productivity.

## Data Availability

The data associated with the paper are available with principal investigator.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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