*Agriculture, Forestry and Fisheries*
2024, Vol. 13, No. 6, pp. 276-286
https://doi.org/10.11648/j.aff.20241306.17

Research Article

# Land Suitability Evaluation for Agroforestry Using Geospatial Techniques in Genale Sub-basin Oromia, Ethiopia

**Getachew Haile***

Natural Resource Directorate, Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

## Abstract

Agroforestry is a sustainable agricultural method that integrates trees, crops, and/or livestock within a unified land space, promoting ecological balance and resource efficiency which has been widely used for centuries due to its social, economic, and environmental advantages, despite its numerous advantages, it has not achieved substantial global acknowledgment. This research investigates the land units within the Genale sub-basin to assess their suitability for agroforestry practices, focusing on the factors that significantly impact tree and crop growth as well as productivity. Conducting a land suitability analysis is essential for designating particular areas for specific agricultural purposes. The study employs an integrated approach utilizing Geographic Information Systems (GIS), Remote Sensing (RS), and the Analytical Hierarchical Process (AHP) model, along with a weighting function, to assign suitability weights to the criteria and sub-criteria influencing plant growth, ultimately producing a predictive map of agroforestry cultivation suitability. Soil fertility parameters (soil nitrogen (N), potassium (K), organic carbon (C), phosphorus (P) and pH), Climatic (rainfall) and Topographic (Elevation and Slope) were considered in the model as a significantly determinant of agroforestry factors. Each of criteria/factor layers were classified (not suitable, less suitable, suitable and highly suitable) based on reviewed literature and expert level judgement. The Analytical Hierarchical Process indicated that the most influential variable determining agroforestry practice were, Soil nutrient availability, Slope, The Normalized Difference Water Index (NDWI), Mean annual rainfall and Elevation, respectively with 5% consistency index. The model results showed that approximately 0.6% (19,072.80 ha) of sub-basin area has optimal growth conditions, 67.83% (2,193,368 ha) suitable, 30.8% (995,382 ha) less suitable and 0.77% (24,841.60 ha) Not suitable conditions for agroforestry practice. The findings indicate that the integration of Geographic Information Systems (GIS) and Remote Sensing (RS) with the Analytic Hierarchy Process (AHP) model, incorporating a weight function, proves to be effective in identifying and assessing land units suitable for agroforestry practices aimed at optimizing production yields. This study's outcomes provide valuable insights for land-use policymakers and farmers, facilitating informed decision-making concerning agroforestry cultivation in the Genale sub-basin and similar watershed regions.

## Keywords

Genale Sub-basin, GIS, RS, AHP, Agroforestry

*Corresponding author: boqolo@gmail.com (Getachew Haile)

**Received:** 31 October 2024; **Accepted:** 15 November 2024; **Published:** 9 December 2024

# 1. Introduction

Agroforestry and Agroforestry practices has been defined in numerous ways [1]. Currently The Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) defined Agroforestry as a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit. The integration can be either in a spatial mixture or in a temporal sequence [2].

Agroforestry is a centuries-old practice that involves growing trees alongside crops and enables farmers to optimize their land use. The implementation of agroforestry systems is diverse across the globe, encompassing practices such as alley cropping in Africa and silvopasture in Central America. These methods offer a range of social, economic, and environmental advantages, including timber production, carbon sequestration, and the provision of habitats for various wildlife species. However, despite its numerous benefits, agroforestry has not yet gained significant global recognition, and there is a pressing need to increase awareness regarding its potential to tackle critical issues facing humanity today, such as food insecurity and the mitigation of climate change.

Agroforestry represents a sustainable agricultural approach that synergistically combines trees, crops, and/or livestock within a single land area [3]. This method leverages the advantages of both forestry and agriculture, enabling the production of diverse outputs from a single plot. Through agroforestry, farmers can enhance their income streams by cultivating food crops alongside tree-derived products such as timber, fruits, nuts, and medicinal plants. Additionally, this practice improves soil fertility by increasing organic matter, which in turn mitigates erosion resulting from wind and water runoff. The incorporation of trees also plays a crucial role in carbon dioxide sequestration, thereby contributing to climate change mitigation. Moreover, agroforestry creates habitats for wildlife, thereby supporting biodiversity within ecosystems. Given its numerous ecological and economic benefits, agroforestry has become increasingly favored by small-scale farmers in both developed and developing nations as a practical strategy to bolster food security while promoting the conservation of natural resources.

In Ethiopia, Agroforestry farming practice which is the integration of trees and shrubs into agriculture was emerged around 7000 years ago [4, 5], and has developed during subsequent millennia into number of distinct indigenous agroforestry systems [6]. Agroforestry is a major component of Ethiopian farming systems and recently taken as one of the development objectives of national development policy of the country [7, 8]. Parkland agroforestry is practiced in most part of Genale sub-basin The Fabaceae species is the predominant group of woody species, representing approximately 41.2% of the total species. The most commonly encountered multipurpose woody species in the study area were Croton macrostachyus Hochst., Faidherbia albida, Cordia africana Lam., Acacia abyssinica Hochst., Juniperus procera Hochst., and various Acacia species [9].

# 2. Materials and Methods

## 2.1. Description of the Study Area

From the total area of Genale basin which is 11,380,300 ha, the Gunale sub-basin covered under this study is about 3,232,664 ha (28.4% of the Genale basin). It is situated in Bale, East Bale and Guji zones. It totally covers Districts of Mada Walabu, Berbere, Haranabuluk, Dalomana, Guradhamole from Bale Zone and Girja from Guji Zone. It also partially covers districts of Goba, Goro, Dawe Kachen, and Dawe Sarar from East Bale Zone and Bore, Anna Sora, Adola Rede, Wadera, Gorodola, and Liban from Guji Zone. Its geographical location is extended from West to East is $38^{o}$33’51.55” to $41^{o}$39’0.33” East and South to North $4^{o}$37’34.63” to $7^{o}$9’5.32” North. Figure 1 below shows the map of the Sub-Basin.

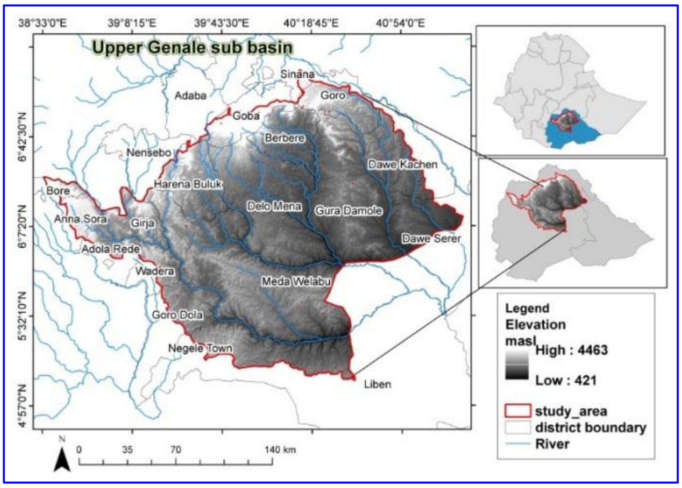


*Figure 1. Location map of Genale Sub-Basin.*

## 2.2. Data Used

In this study, both primary and secondary data were used to prepare factors (Figure 2). A resolution of 30 meters remote sensing data of Landsat 8/9 satellite imagery for LULC of path and row of 166:055, 166:056, 166:057, 167:055, 167:056, 167:057, 168:055, 168:056 and 168:057 were acquired from the United States Geological Survey Global Visualization Viewer website, with geographic reference set to UTM zone 38, WGS 84, digital evaluation models (DEM) for topographic (Elevation and Slope) factor, soil lab result data (soil nitrogen, phosphorus, potassium, organic carbon and pH) were derived from both field surveys and laboratory analyses conducted by the Oromia Irrigation Development Authority and climate data (Annual mean rainfall) were used for the land evaluation and site selection for agroforestry practice were used by interpolated mean annual rainfall data from 15 meteorological stations spanning 31 years (1990-2022) which is obtained from the National Meteorological Agency of Ethiopia.

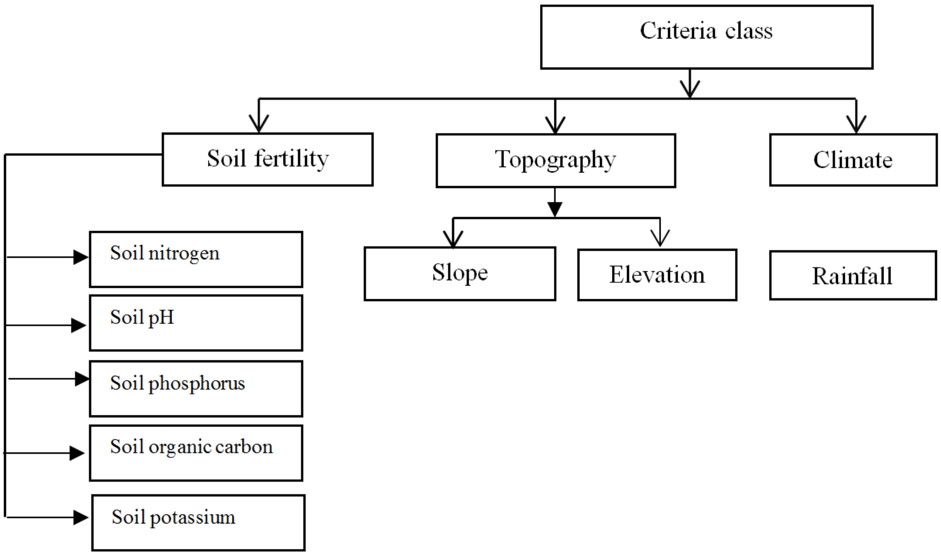


***Figure 2.*** *Methodological flow chart of the analysis.*

## 2.3. Data Analysis

*The Analytical Hierarchical Process (AHP) Model*

Weighting each criterion and factors is an important step in establishment of the model. In this research The AHP model is used which is a common method for criteria-weighting that was developed by Saaty [10]. The Analytical Hierarchical Process (AHP) Model comprises three main steps:

1) Calculating the criteria weights: This involves determining the importance or relevance of various criteria that will be used to evaluate different options or alternatives.
2) Comparing alternatives: For each criterion, you assess and compare the different options available to see how well they perform based on that specific criterion.
3) Ranking the Criteria: After evaluating the alternatives, you organize the criteria based on their calculated weights, which helps to prioritize which criteria are most important in the decision-making process [11].

Preferences value for the development of suitable site selection modeling is conducted with consideration of the evaluation criteria that are incorporated into the decision model, reflecting the relative significance of each criterion. The preference value assigned to an evaluation criterion serves to establish and signify its importance in relation to the other criteria being assessed. All criteria were systematically categorized, ranked, and rated based on a review of the literature and expert judgment, utilizing a pair-wise comparison method to determine their relative importance. [12, 13]. Relative weights were developed by making a pair-wise comparison matrix at each level of the hierarchy [14]. According to Saaty [15] the intensity of importance is 1 if both parameters are of equal importance, 3 for moderate importance, 5 for strong, 7 for very strong and 9 for extreme importance whereas the reciprocals are values for inverse comparison (Table 1 and Table 2).

***Table 1.*** *Saaty 1 to 9 Scale.*

| **1** | **3** | **5** | **7** | **9** |
|---|---|---|---|---|
| Equal | Moderately | Strongly | Very strong | Extremely strong |

***Table 2.*** *Pairwise comparison matrix.*

| **A** | **$C_1$** | **$C_2$** | **$C_3$** | **…** | **$C_n$** |
|---|---|---|---|---|---|
| $C_1$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | … | $a_{1n}$ |
| $C_2$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | … | $a_{2n}$ |
| … | … … | … … … | … … … | … … … | … … … |
| $C_n$ | $a_{n1}$ | $a_{n2}$ | $a_{n3}$ | $a_{n3}$ | $a_n$ |

The pairwise comparison square matrix is defined for main-criteria and sub-criteria to determine the weights. The diagonal element of the comparison matrix is 1. Each element of the comparison matrix is divided by the sum of its own column sum to generate a normalized matrix with Formula 1.

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (1)$$

Each column of the normalized matrix sum is equal to 1. Then, each row sum of the normalized matrix is divided by the matrix order. The average of the sum represents the weights of each criterion in pairwise comparison matrix (Formula 2).

$$w_{i} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} a_{ij}, (i, j = 1,2,3, \ldots., n) \quad (2)$$

The evaluation of the consistency of the pairwise comparison matrix is essential for determining whether the criteria and comparisons are coherent. The assigned preference values are aggregated to establish a ranking of the pertinent factors, represented numerically as the weights of each parameter. Consequently, the eigenvalues and eigenvectors of the square pairwise comparison matrix are computed, providing significant insights into the underlying patterns within the data matrix [14]. One approach to assess the consistency coefficient of the pairwise comparison matrix is through the Consistency Index (CI), which is derived using Formula 3 [16].

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

Calculating consistency index depends on the λmax value with Formula 4 [14].

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \left[\frac{\sum_{j=1}^{n} a_{ij} w_j}{w_i}\right] \quad (4)$$

In addition to this, the Random Index (RI) value must be calculated to determine the consistency index. After calculating the CI and RI, consistency ratio (CR) can be calculated with Formula 5. In the AHP approach, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding CR is less than 10%, If CR exceeds 0.1, based on expert knowledge and experience, recommends a revision of the pairwise comparison matrix with different values [10].

$$CR = \frac{CI}{RI} \quad (5)$$

## 3. Result and Discussion

### 3.1. Agroforestry Suitability Mapping Parameters

Based upon the experimental and practical results gained from various research activities on the selected sub-basin and region of agroecological zone, the parameters/factors which contribute potentially for the agroforestry farming system are soil nutrient availability [17], annual rainfall [18], wetness [19], slope [20] and elevation [21] Ranks and weights were assigned for different thematic maps were chosen based on pair-wise comparison (Table 3). These parameters have the potential for delineating intensive suitable area for various crops. The above approach helped in assessing the land suitability for dominant crops in the country/region and in the selected sub-basin [22].

***Table 3.*** *Weight matrix for parameters for agroforestry suitability mapping.*

| **Agroforestry factor** | **Weights** | **Value/Description** | **Class/Rank** | **Suitability** |
|---|---|---|---|---|
| Soil nutrient availability | 35 | Four categories based on weighted average output | 1 | Low |
| | | | 2 | Medium |
| | | | 3 | High |
| | | | 4 | Very high |
| Slope | 30 | >9 | 1 | Low |
| | | 7-9 | 2 | Medium |
| | | 4-7 | 3 | High |
| | | <4 | 4 | Very high |

| Agroforestry factor | Weights | Value/Description | Class/Rank | Suitability |
|---|---|---|---|---|
| Wetness factor | 15 | <0 | 1 | Low |
| | | 0 – 1.5 | 2 | Medium |
| | | 1.5-2 | 3 | High |
| | | >2 | 4 | Very high |
| Rainfall | 12 | <600mm | 1 | Low |
| | | 600mm-800mm | 2 | Medium |
| | | 800mm-1200mm | 3 | High |
| | | >1200mm | 4 | Very high |
| Elevation | 8 | >1500m | 1 | Low |
| | | 1000m-1500m | 2 | Medium |
| | | 500m-1000m | 3 | High |
| | | <500m | 4 | Very high |

### 3.1.1. Soil Nutrients Availability Parameters and Mapping

The National Regional State of Oromia Rural Land Administration and Use Bureau of Oromia soil laboratory data was used and projected to the specific study area of sub-basin which was soil samples is taken an Auger observation conducted along the roads at 2 km intervals in most of the areas, and 1.5 km intervals in potential areas, to check and delineate soil types. Additional traverse auger observations were made in some complex soil patterned areas to check variability. About 1 to 2 pits were dug in each soil units/types and described in detail following FAO pit description guidelines. In addition, mini pits of about 0.50-0.60 m depth were dug, in some areas where the soil units are found to be heterogeneous, in order to develop more confidence and select soil variability relevant to identification of potential development areas. Therefore, to generate the nutrient availability map by assigning equal weights to all soil nutrient parameter making it as a whole to 100%. They were chosen based upon the experts/researcher's level judgements, FAO standards towards plant growth and findings of various related works of nutrient suitability [22]. Based on the capability and importance of soil fertility and plant growth for food security; soil nitrogen (N), potassium (K), organic carbon (C), phosphorus (P) and pH parameters are used for producing nutrient availability map Figure 3 and Figure 4. Weights and Class/ranks were assigned for mapping different thematic maps (Table 4).

*Table 4. Weight matrix for parameters and ranking for nutrient availability mapping.*

| Nutrient factor | Weights (%) | Value/Description | Class/rank | Suitability |
|---|---|---|---|---|
| Soil Nitrogen | 20 | <200kg/ha | 1 | Low |
| | | 201kg/ha-280kg/ha | 2 | Medium |
| | | 281kg/ha-560kg/ha | 3 | High |
| | | >560kg/ha | 4 | Very high |
| Soil Potassium | 20 | < 100 kg/ha | 1 | Low |
| | | 101kg/ha-200kg/ha | 2 | Medium |
| | | 201kg/ha-280kg/ha | 3 | High |
| | | >280kg/ha | 4 | Very high |
| Soil Organic Carbon | 20 | <0.5 | 1 | Low |
| | | 0.5-0.7 | 2 | Medium |

| Nutrient factor | Weights (%) | Value/Description | Class/rank | Suitability |
|---|---|---|---|---|
| | | 0.7-0.75 | 3 | High |
| | | >0.75 | 4 | Very high |
| Soil Phosphorus | 20 | <10kg/ha | 1 | Low |
| | | 11 kg/ha -15kg/ha | 2 | Medium |
| | | 16 kg/ha-25 kg/ha | 3 | High |
| | | > 25kg/ha | 4 | Very high |
| Soil pH($H_2O$) | 20 | <5OR >8 | 1 | Low |
| | | 5.1-5.5 OR 8-8.3 | 2 | Medium |
| | | 7.4-8.4 OR 6.5-5.6 | 3 | High |
| | | 6.6-7.3 | 4 | Very high |

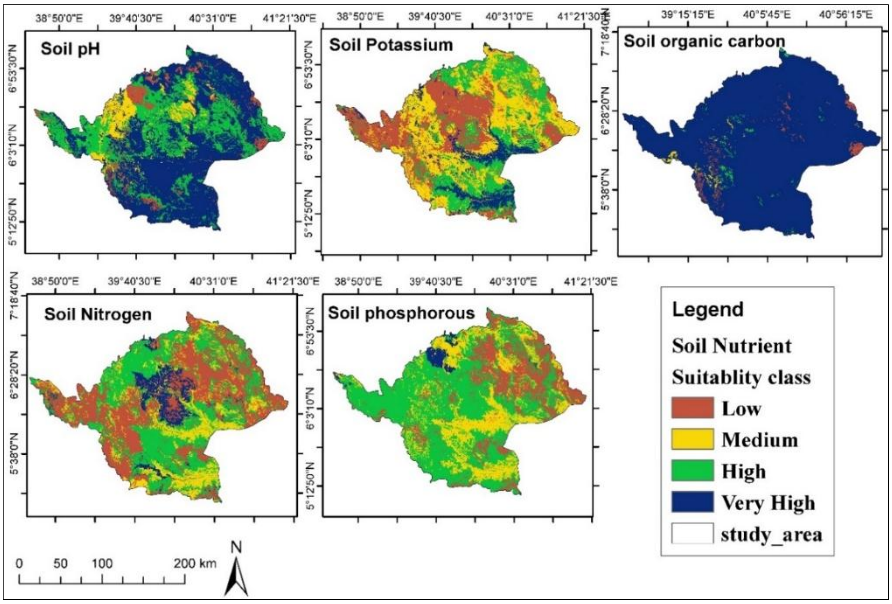


***Figure 3.*** *Reclassified Soil pH, Potassium, Organic Carbon, Nitrogen and Phosphorous availability maps.*

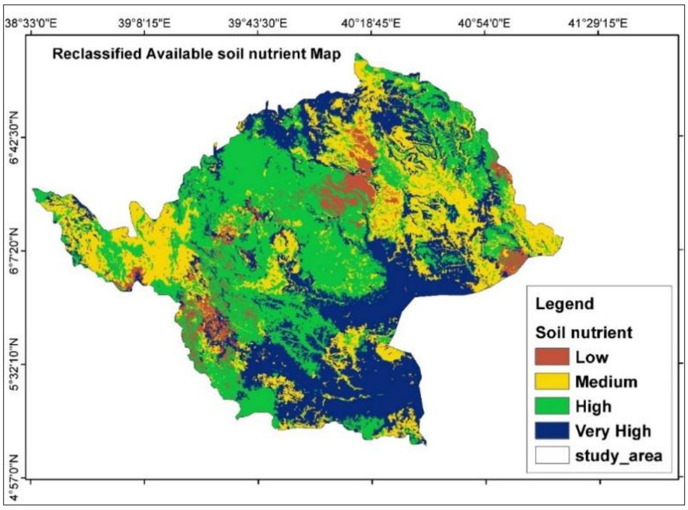


***Figure 4.*** *Overlayed and Reclassified soil nutrient availability map.*

### 3.1.2. Slope

Slope percentage plays a significant role in influencing plant growth. Steeper slopes facilitate the rapid movement of water, which can lead to increased soil erosion and loss of soil nutrients. Conversely, areas with gentler slopes tend to retain water for longer periods, thereby providing sufficient moisture for the soil, which is conducive to plant development. Consequently, regions characterized by low slopes are generally more advantageous for agroforestry compared to those with steep inclines. The slope data was derived from the Aster Digital Elevation Model (DEM) and subsequently categorized into four classifications: less than 4%, between 4% and 7%, between 7% and 9%, and greater than 9%. These categories were assigned ranks of 4, 3, 2, and 1, corresponding to very high, high, medium, and low suitability for plant growth, respectively (Figure 5B).

### 3.1.3. Elevation

Altitude, or elevation, is recognized as a critical factor in the mapping of agroforestry suitability [23], with tree growth exhibiting a decline at higher altitudes [24]. As altitude increases, both temperature and vegetation tend to diminish. Trees are unable to thrive beyond the tree line or timber line due to the lower air pressure and decreased levels of carbon dioxide, which are essential for plant metabolism and growth. The elevation map was subsequently reclassified into four categories, with new values assigned based on agroforestry potential. These categories were ranked as 4, 3, 2, and 1, corresponding to very high, high, medium, and low potential, respectively (Figure 5A).

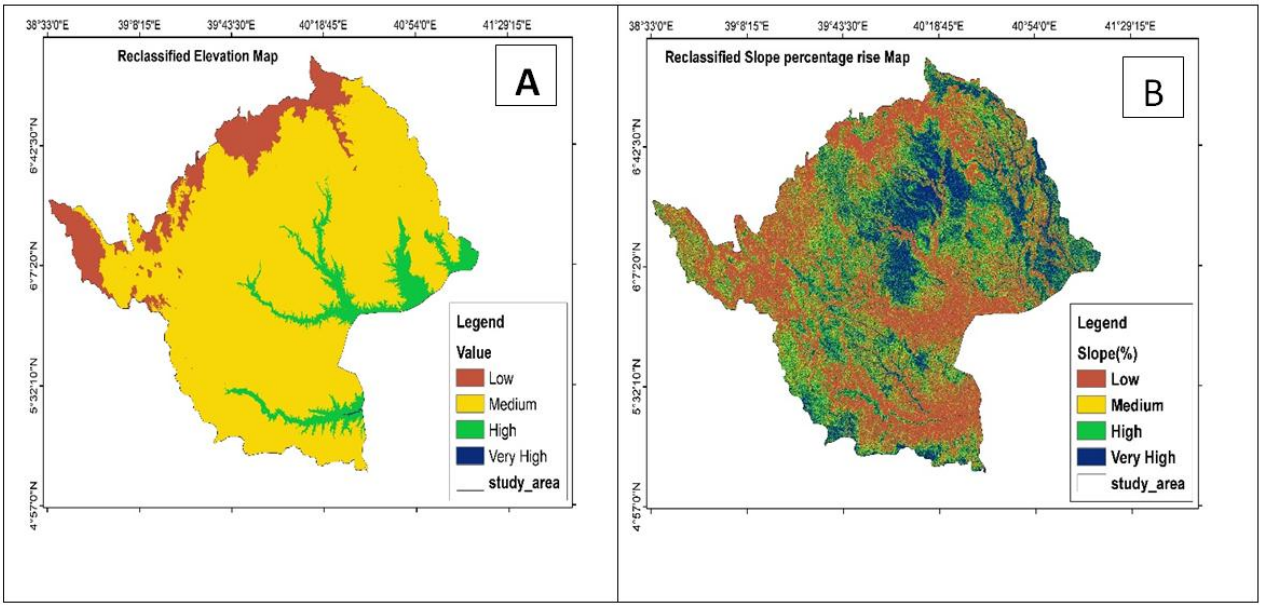


***Figure 5.*** *Reclassified A) Elevation and B) Slope Suitability Map.*

### 3.1.4. Wetness/NDWI Factor

Soil moisture/wetness is a critical factor influencing plant growth across various species. Sufficient moisture levels enhance the absorption of nutrients by plants, making it a vital consideration in the implementation of agroforestry practices. [25] introduced a methodology for calculating soil wetness by deriving distinct coefficients from Landsat-8 imagery, which has gained considerable acceptance within the scientific community. In terms of agroforestry suitability, the resulting wetness map was categorized into four distinct classes: values less than 0, 0 to 1.5, 1.5 to 2 and values greater than 2. These classes were subsequently ranked as 1, 2, 3and 4, corresponding to low, medium, high and very high wetness levels, respectively (Figure 6).

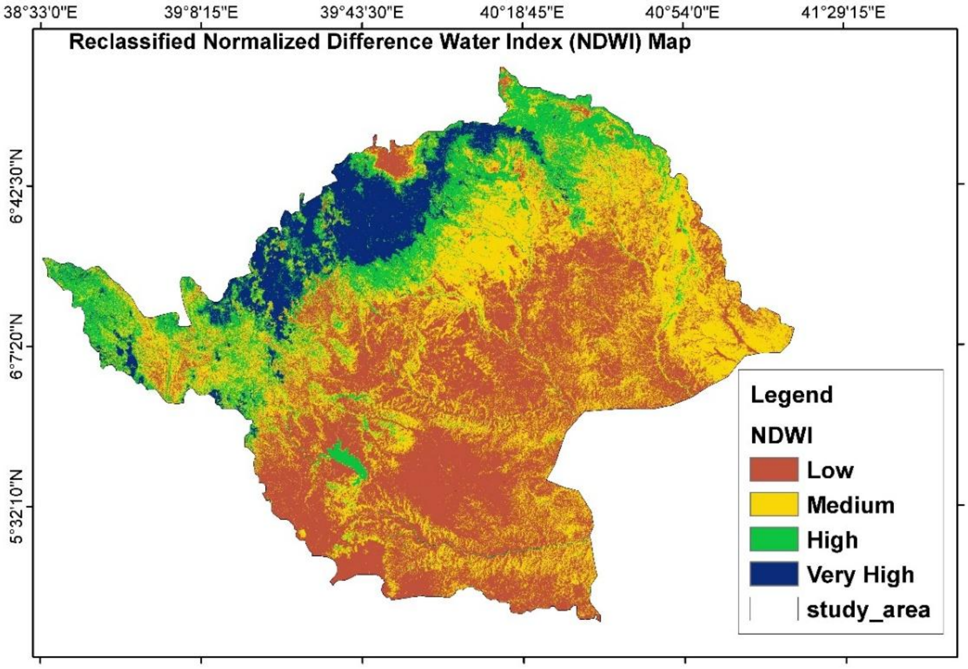


*Figure 6. Reclassified Water Availability (Normalized Difference Water Index) Suitability map.*

### 3.1.5. Rainfall Intensity

Rainfall intensity and its spatial distribution are recognized as significant climatic factors influencing crop and tree growth. An increase in rainfall is positively correlated with plant growth and is commonly utilized in mapping agroforestry suitability [22]. Three decadal annual rainfall data from 1993 to 2023 was employed to create a spatial rainfall pattern (continuous surface) using the kriging interpolation technique in ArcGIS software. Based on the potential for agroforestry, the rainfall map was categorized into four classes (<600mm, 600-800mm, 800mm-1200mm, >1200 mm), which were assigned ranks of 1, 2, 3, and 4, corresponding to low, medium, high and very high rainfall levels, respectively (Figure 7).

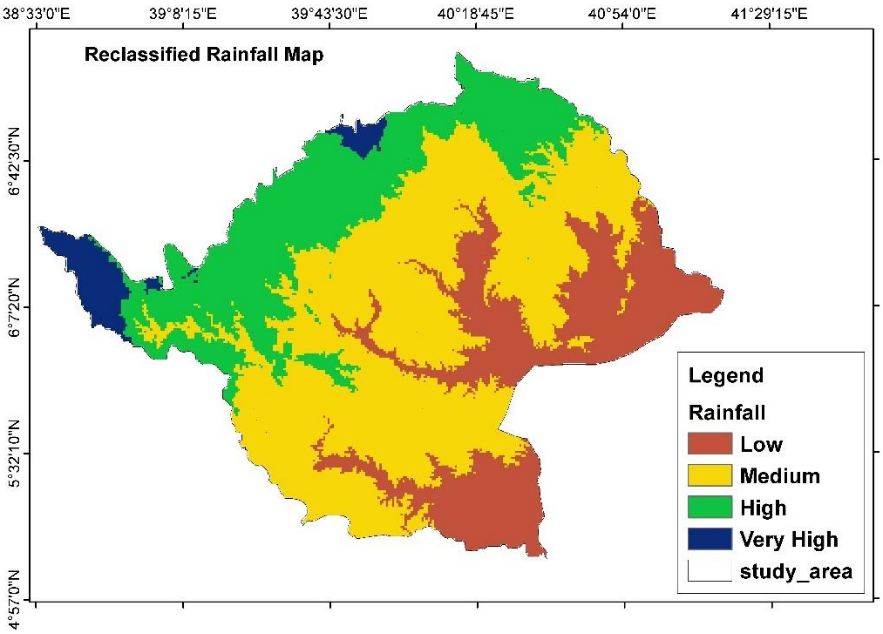


*Figure 7. Reclassified Mean annual rainfall Suitability map.*

### 3.2. Weighted Overlay

In this research, weights for specific parameters and factors were established utilizing the AHP model. The relative significance of the factors influencing the growth of the Agroforestry practice was determined through a pair-wise comparison matrix. In this matrix, the values above the diagonal were assigned based on comparisons with the corresponding column parameter. Each parameter's values were allocated according to their impact on the growth and productivity of Agroforestry farming practice. The values below the diagonal for each parameter represent the reciprocals of those above the diagonal. Following the assignment of relative importance values for the upper diagonal and their reciprocals, normalization of each cell value was performed.

Normalization is achieved by dividing each cell value by the total of its respective column for each parameter. This process was undertaken to establish criteria weights for each parameter. The criteria for each parameter were determined by summing the values across each row. Based on the criteria weights, the elevation parameter is identified as critically important for the Agroforestry (Tree and Crop). The consistency ratio for all parameters was calculated to verify the accuracy of the computed values. A consistency ratio greater than 0.10 suggests inconsistent judgments, while a ratio of 0.10 or lower indicates an acceptable level of consistency in the pair-wise comparisons. In this instance, the calculated consistency ratio is 0.05, reflecting a reasonable level of consistency within the matrix. (Table 5).

***Table 5.*** *Analytical Hierarchical Process Comparison Matrix.*

| Criteria | Nutrient availability | Slope | Wetness factor | Rainfall | Elevation | AHP weight | % |
|---|---|---|---|---|---|---|---|
| Nutrient availability | 1 | 2 | 2 | 3 | 3 | 0.345 | 34.5 |
| Slope | 0.5 | 1 | 2 | 3 | 6 | 0.295 | 29.5 |
| Wetness factor | 0.5 | 0.5 | 1 | 2 | 4 | 0.189 | 18.9 |
| Rainfall | 0.33 | 0.33 | 0.5 | 1 | 2 | 0.105 | 10.5 |
| Elevation | 0.33 | 0.166 | 0.25 | 0.5 | 1 | 0.065 | 6.5 |

### 3.3. Proportions of Suitability Result and Validation

The agroforestry suitability map for a specific delineated watershed was assessed through comparison with previously done field assessment and characterization of Agroforestry practice on some parts the sub-basin [9], Google Earth imagery, and field verification. The result of this analysis shows that most part of sub-basin found in Goba, Harena Buluk, Gora and Delo Mena districts classified under Suitable class (Figure 8). Similarly, the above validation methods reveal that parkland agroforestry is dominantly practiced with dominated seventeen woody plant species. The study identified several multipurpose woody species that were frequently encountered, including Croton macrostachyus Hochst., Faidherbia albida, Cordia africana Lam., Acacia abyssinica Hochst., Juniperus procera Hochst., and various Acacia species. Less suitable area dominantly found in Gura damole, Mede welabu and Gurja districts where high slope areas found, most studies have indicated that the aspect of a slope significantly influences various aspects of soil development, including microbial activity and diversity, biomass generation, soil organic matter content, hydrological processes, and the regulation of microclimates. These elements play a crucial role in determining the physicochemical characteristics of the soil. Additionally, the slope aspect can affect surface runoff and erosion as a result of its impact on microclimatic conditions which highly influence plant growth and crop production (Table 5).

***Table 6.*** *Land Suitability class and area coverage of Genale sub-basin for Agroforestry.*

| Suitability class | Area (ha) | Area (%) |
|---|---|---|
| Highly suitable | 19,072.80 | 0.6 |
| Suitable | 2,193,368 | 67.83 |
| Less suitable | 995,382 | 30.8 |
| Not suitable | 24,841.60 | 0.77 |
| Total | 3,232,664.33 | 100 |

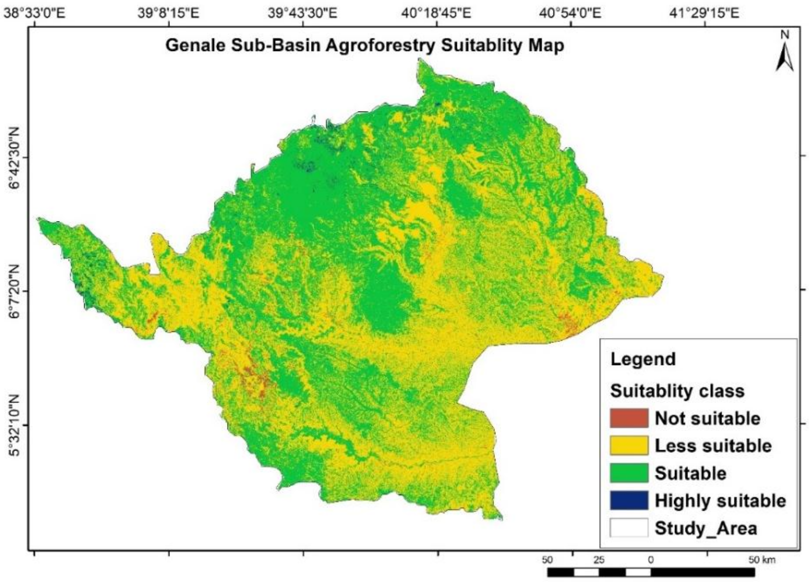


*Figure 8. Land Suitability Class for Agroforestry of Genale sub-basin.*

## 4. Conclusion

Agroforestry is preferable management approach that synergistically integrates agricultural practices with tree cultivation to meet conservation objectives while enhancing the economic viability and climate resilience of farms, ranches, and communities in the sub-basin. Genale sub-basin is potential land for Agroforestry which offers a range of ecological and economic advantages. The practice increases soil fertility through nitrogen fixation, stabilization of microclimates, and enhanced water infiltration in the soil. Additionally, trees serve as windbreaks, mitigating soil erosion, and function as living barriers that protect crop areas.

By implementing agroforestry techniques, stakeholders can harmonize productivity and profitability with environmental conservation, leading to the establishment of robust and sustainable agricultural systems that are capable of being inherited by future generations. This study highlights the capabilities of geospatial technology in identifying appropriate locations for the Evaluation land for agroforestry practices.

The integration of supplementary data sets and their representation as thematic layers within the Geographic Information system (GIS) and Spatial Analytical Hierarchical Process (SAHP) which is applied in this research can significantly enhance the mapping and allocating land for specific purpose ultimately benefiting local villagers, farmers, government and non-government organizations.

## Abbreviations

| | |
|---|---|
| GIS | Geographical Information System |
| RS | Remote Sensing |
| AHP | Analytical Hierarchical Process |
| SAHP | Spatial Analytical Hierarchical Process |
| NDWI | Normalized Difference Water Index |
| DEM | Digital Evaluation Model |
| CR | Consistency Ratio |

## Author Contributions

Getachew Haile is the sole author. The author read and approved the final manuscript.

## Conflicts of Interest

The authors declare no conflicts of interest.

## References

[1] Nair PKR. 1989. Agroforestry defined. P. 13-18. In: PKR Nair (ed) Agroforestry Systems in the tropics, Dordrecht, Netherlands: Kluwer Academic Publishers.

[2] Sanchez PA. 1995. Science in agroforestry. Agroforestry Systems 30: 5-55.

[3] Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A.,... Bayala, J. (2010). Evergreenagriculture: A robust approach to sustainable food security inAfrica. Food Security, 2, 197–214.

[4] Brandt, A. S. 1984. New perspective on the origins of food production in Ethiopia. In: Clark, J. D. & Brandt, A. (Eds.). From hunters to farmers: the case and consequence of food production in Africa. p. 173−190.

[5] Edmond, N., Yakam-Simen, F., Tadesse, K. K. & Romeij, P. 2000. Gedeo Zone Mapping Project. Phase 2. Final Report. Treemail, Heelsum, the Netherlands, Privateers N. V. and the Agricultural Bureau for Gedeo Zone. http://www.treemail.nl/download Accessed 24 March 2009.

[6] Kanshie, T. K. (2002). Five thousand years of sustainability? A case study on Gedeo land use (Southern Ethiopia). PhD Dissertation, Wageningen Agricultural University.

[7] FDRE (Government of the federal democratic republic of Ethiopia) (2003) Rural development policy and strategies. Ministry of Finance and Economic Development Economic Policy and Planning Department. Addis Ababa.

[8] Teshome Amidissa (2006) Agriculture, Growth and Poverty Reduction in Ethiopia: Policy Processes around the New PRSP (PASDEP). A paper for the Future Agricultures Consortium workshop, Institute of Development Studies.

[9] Hirpha, A., Mengistu, B., Mengistu, W. X., Dibaba, Z., Bultuma, B. (2024). Assessment and Characterization of the Traditional Parkland Agroforestry Practices in Mid and Lowlands of Bale: In the Case of Goro and Ginnir Districts. World Journal of Agricultural Science and Technology, 2(2), 32-45. https://doi.org/10.11648/j.wjast.20240202.11

[10] Saaty, T. L. (1980) The Analytic Hierarchy Process, New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000), Pittsburgh: RWS Publications.

[11] Qaddah, A., & Abdelwahed, M. (2015). GIS-based site-suitability modeling for seismic stations: Case study of the northern Rahat volcanic field, Saudi Arabia. Computers & Geosciences.

[12] Shimelis s., (2020). Suitablity Analysis for Moringa Oleifera Tree Production in Ethiopias- Spatial Moedlling Approach.

[13] Firoz A, Laxmi G, Abdul Q. Natural Resource Mapping Using Landsat and Lidar towards Identifying Digital Elevation, Digital Surface and Canopy Height Models. Int J Environ Sci Nat Res. 2017; 2(1): 555580. https://doi.org/10.19080/IJESNR.2017.02.555580

[14] Saaty T L (1994). Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. RWS Publications, Pittsburgh, Pa.

[15] Saaty T. L., 1977. A scaling method for priorities in hierarchical structures. J Math Psychol 15: 231–281.

[16] Saaty, T. L. and Vargas, L. G. (1991) Prediction, Projection and Forecasting, Boston: Kluwer Academic.

[17] Yedage AS, Gavali RS, Jarag AP (2013) Land Assessment for Horticulture (Pomegranate) Crop Using GIS and Fuzzy Decision Analysis in the Sangola Taluka of Solapur District. Int J Remote Sens GIS 2: 104-113.

[18] Sarkar A, Ghosh A, Banik P (2014) Multi-criteria land evaluation for suitability analysis of wheat: a case study of a watershed in eastern plateau region, India. Geospatial Inf Sci 17: 119-128. https://doi.org/10.1080/10095020.2013.774106

[19] Ahmad F, Goparaju L (2016) Urban Forestry: Identification of Suitable sites in Ranchi city, India using Geospatial Technology. Ecol Quest 24: 45-58.

[20] Kihoro J, Bosco NJ, Murage H (2013) Suitability analysis for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. Springerplus 2: 265. https://doi.org/10.1186/2193-1801-2-265

[21] Ritung S, Wahyunto FA, Hidayat H (2007) Land Suitability Evaluation with a case map of Aceh Barat District. Indonesian Soil R. Institute and World Agro Centre, Bogor, Indonesia.

[22] Ahmad F, Goparaju L. Geospatial Approach for Agroforestry Suitability Mapping: to Enhance Livelihood and Reduce Poverty, FAO Based Documented Procedure (Case Study of Dumka District, Jharkhand, India). Biosci Biotech Res Asia 2017; 14(2).

[23] Bijalwan, A., Upadhyay, A. P. and Dobriyal, M. J. R. (2015). Tree-crop Combinations, Biomass and Carbon Estimation in Conventional Agrisilviculture (Agroforestry) System along Altitude and Aspects in the Hills of Uttarakhand Himalaya, India. Int. J. Curr. Res. Biosci. Plantbiol, 2(6): 214-217.

[24] Coomes, D. A., & Allen, R. B. (2007). Effects of Size, Competition and Altitude on Tree Growth. Journal of Ecology, 95, 1084-1097. http://www.jstor.org/stable/4496061

[25] Baig, M. H. A., Zhang, L., Shuai, T., & Tong, Q. (2014). Derivation of a tasselled cap transformation based on Landsat 8 at-satellite reflectance. Remote Sensing Letters, 5(5), 423–431. https://doi.org/10.1080/2150704X.2014.915434