Land suitability evaluation using GIS and multicriteria decision analysis for cashew cultivation, Ethiopia: A systematic review

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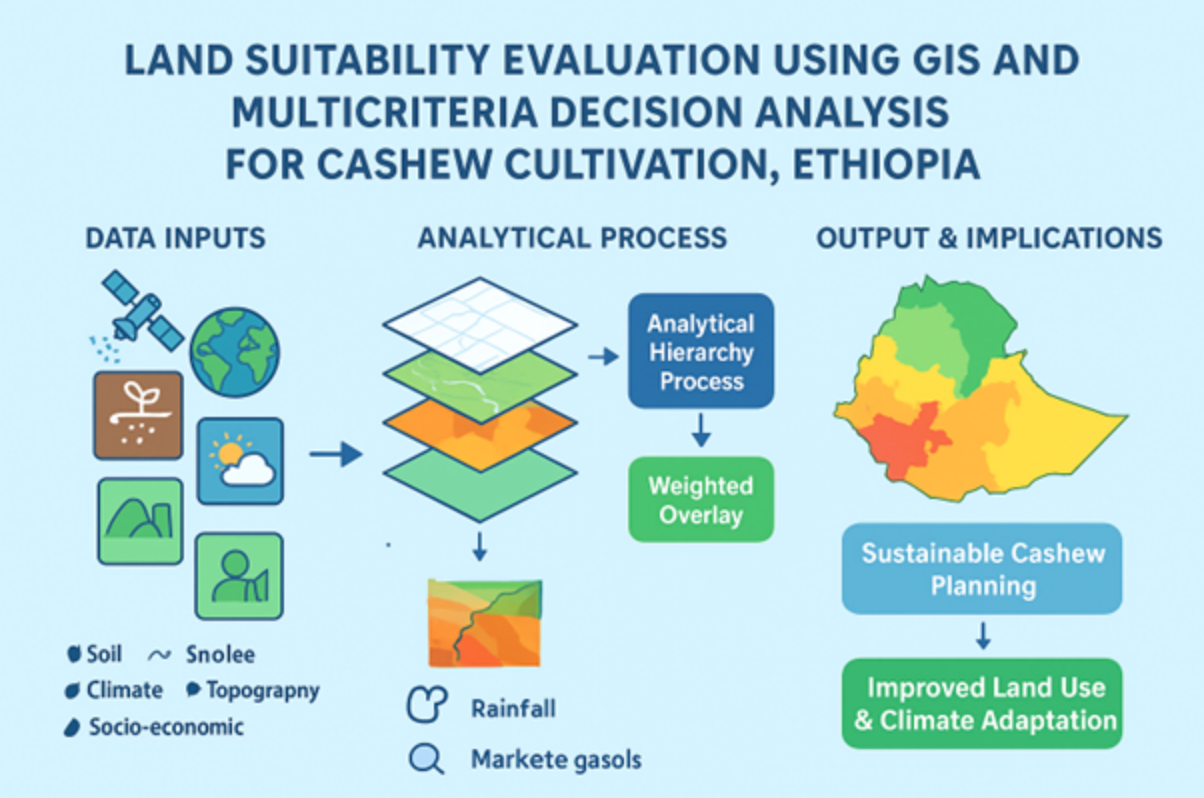
Graphical Abstract



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Abstract

Land selection for crops is crucial for sustainable production and economic development in tropical regions. Climate play a significant role in determining suitable areas for crop growth. Land selection for cultivation in Ethiopia is evaluated using GIS-based multi-criteria decision analysis, combining weighted thematic layers of soil, climate, topography, and socioeconomic factors to classify land into four suitability classes. A systematic literature review was conducted using studies conducted primarily in Ethiopia detail a consistent approach for evaluating land suitability that readily extends to crop cultivation in the Abaya-Chamo watershed. All studies prepare layered data on soil, climate, topography, socio-economic factors, and current land use. Nine of ten relied on Geographic Information Systems to integrate this information, and five employed the Analytical Hierarchy Process to weight selected criteria. The common procedure involved: (1) Prepared thematic layers from sources such as Landsat imagery, digital elevation models, and soil surveys. (2) Combined these layers through spatial overlay techniques (including weighted overlays) to classify land into four suitability classes from highly (or optimally) suitable to not suitable. (3) Employed expert judgment and literature review to select relevant criteria for the target crop or agricultural use. The specific crop foci ranged from rice and wheat to sesame and agroforestry systems, the integration of numeric and categorical criteria using GIS-based multi-criteria decision analysis provides a replicable framework. The methods described by the studies support the application of these procedures to assess land suitability for crop cultivation in a watershed, relying on consistent quantitative criteria and mapping techniques.

Keywords: Crop Cultivation; Runoff Coefficient;Evaluation; Land Suitability; Analytical Hierarchy Process

1 Introduction

Land suitability evaluation for crop cultivation is crucial for sustainable production and economic development in tropical regions, as noted by Wekesa (2018). Climate and soil factors play a significant role in determining suitable areas for cashew growth, according to Vinca (2021). A global study by Gruter et al., (2022) found that long dry seasons, extreme temperatures, and annual precipitation are the primary climatic constraints for cashew cultivation, while low soil pH, unfavourable soil texture, and steep slopes are the main soil-related limitations. Climate change is expected to impact the suitability of cashew-growing regions, as highlighted by Kourgialas et al., (2022). Although some areas may become more suitable due to increasing minimum temperatures at higher latitudes and altitudes, Gruter et al., (2022) reported that most major producing countries are likely to experience a decrease in highly suitable areas. This highlights the need for adaptation strategies in cashew cultivation.

A comprehensive land suitability evaluation for cashews should consider both climatic and soil factors, as well as potential climate change impacts, according to Eshetu et al., (2021). Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) are commonly used to evaluate land suitability for various crops, including cashew (Gomathi et al., 2019; Parihari et al., 2021). These methods integrate multiple criteria such as soil properties, topography, irrigation, and socio-economic factors to create suitability maps (Chowdhuri et al., 2022; Khatri et al., 2024). The use of advanced tools such as GIS-based procedures and remote sensing data can enhance the accuracy of land suitability assessments, as demonstrated by Pulighe and Lupia (2016). Integrating molecular diversity studies of cashew genetic resources, as suggested by Guterres et al., (2023), with land suitability evaluations could lead to the development of more resilient and productive cashew varieties adapted to specific environmental conditions. The FAO approach defines land suitability as the aptitude of a given type of land to support a defined use, according to Temesgen et al., (2016). To manage land resources properly, a land suitability assessment is often conducted to determine which type of land use is most appropriate for a particular location (Chandio et al., 2013). Land suitability analysis allows the identification of the main limiting factors of a particular crop (Abebe et al., 2023) and enables decision-makers to develop crop management systems for increasing land productivity (Chen et al., 2022; Zhang et al., 2022).

Researchers have employed techniques like Fuzzy-AHP, weighted overlay analysis, and multi-criteria spatial analysis to assign weights to different parameters and generate suitability classes (Akinci et al., 2013; Chaube et al., 2024; Leal et al., 2020; Pant et al., 2024; Parihari et al., 2021; Pattnaik et al., 2021; Salifu et al., 2022; Yalew et al., 2016). The resulting suitability maps can categorize land into different classes, such as highly suitable, moderately suitable, and marginally suitable, providing valuable information for farmers and decision-makers to optimize crop selection and land-use planning (Gomathi et al., 2019; Khatri et al., 2024).

By addressing the specific biophysical, socio-economic, and environmental requirements of crops, this research contributes to the growing body of knowledge on agricultural planning in Africa and beyond, as emphasized by Sreenivasan et al., (2023). The results have practical implications for policymakers, international donors, agricultural planners,

and local communities aiming to enhance food security and climate-resilient farming systems, thereby contributing to the achievement of the SDGs by 2030.

2 Methodology

2.1 Paper Search and Screening

Used a research question "Methodology for the research topic Land suitability evaluation using GIS and multicriteria decision analysis for cashew cultivation in the Abaya-Chamo Watershed, Ethiopia." We retrieved the 50 papers most relevant to the query from the Semantic Scholar corpus. We screened in papers that met these criteria: (a) does the study focus on land suitability evaluation for agriculture, with methodology applicable to cashew cultivation? (b) does the study employ and clearly describe GIS and/or multicriteria decision analysis methods? (c) does the study analyze comprehensive physical land characteristics including soil, climate, and topography? (d) is the study conducted in tropical/subtropical regions or agro-ecological zones similar to Ethiopia? (e) does the study examine land suitability at watershed-level or regional scale (beyond plot-level)? (f) is the study a primary research study, systematic review, or meta-analysis with practical applications? (g) does the study incorporate socio-economic factors in its land suitability analysis? (h) does the study focus on pre-cultivation land suitability rather than only post-cultivation management? We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

2.2 Eligibility Criteria

This review included research that directly examined the Behavioural-based safety and workplace culture approaches construction industries. The eligible articles included original research, observational studies, and review articles that were published in English Language. The research should present factual data and a concise description of the behavioural-based safety components and workplace culture that were investigated. The review omitted sources that were not focused on construction industries, lacked empirical data, or were published in languages other than English.

2.3 Flowchart Visualization

To provide a clear visual representation of the process, we developed a flowchart shown on Figure 1. This flowchart outlines each step, from the initial identification of studies to the final inclusion of the 50 works, illustrating the systematic approach taken in the study.

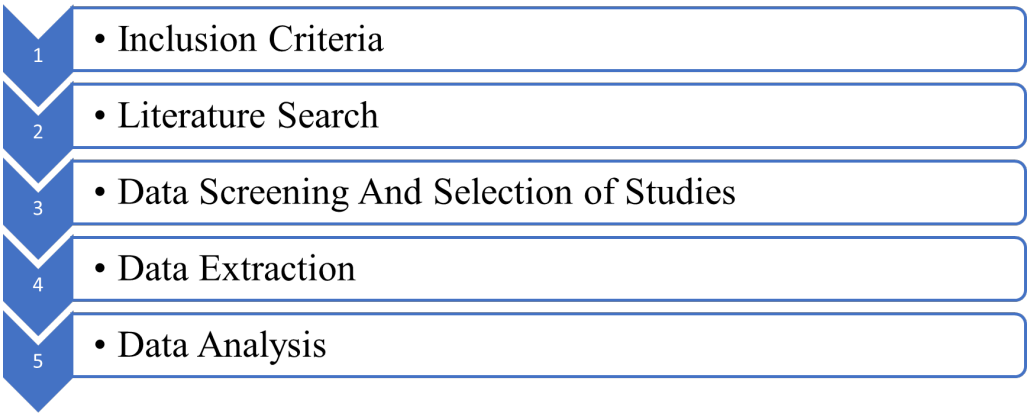

Figure 1: Flowchart of the systematic review process. Source: Authors' construct, 2023.

2.4 Data Extraction

2.4.1 Methodology for Land Suitability Evaluation

Identified and described the specific methodology used for land suitability evaluation on each paper. Specific GIS techniques used, Multicriteria decision analysis approach (AHP, Fuzzy AHP). Software or tools used (ArcGIS, specific decision analysis software), Detailed steps of the methodology, and if multiple methodological approaches were described.

2.4.2 Input Parameters and Criteria

Listed ALL parameters or criteria used in the land suitability evaluation. Categorized parameters by type (soil, climate, topography, infrastructure), Specified the exact parameters (soil pH, slope, soil depth). Noted how each parameter was measured or assessed and recorded the number of parameters used. If parameters were weighed, note the weighting method and specific weights for each parameter.

2.4.3 Geographic Study Area

Specified the Exact location (watershed, district, zone, region), the Total area of study site in hectares (ha). Specific geographic coordinates if provided, and Relevant geographic characteristics (elevation, climate zone), and if multiple geographic details were provided.

2.4.4 Crop or Land Use Focus

Identified the Specific crop(s) or land use type being evaluated, and the Purpose of the land suitability assessment (irrigation, crop production). Any specific agricultural context or goals and if multiple crops or uses were considered.

2.4.5 Suitability Classification Results

Recorded the Suitability classification categories used (highly suitable, moderately suitable, marginally suitable, not suitable), the Exact area (in hectares or percentage) for each suitability category and any specific spatial distribution of suitability classes. Ensured percentages or areas sum (total) to 100% of the total study area. If they do not, note this discrepancy.

3 RESULTS

3.1 Evaluation Method

Based on the information provided in the papers in Table 1 shown below. Geographic Information Systems (GIS)-based approaches were the most common, mentioned in 9 studies. Other methods included Analytical Hierarchy Process (AHP) 5 studies, Multi-Criteria Evaluation (MCE) 4 studies, Remote Sensing 1 study, Weighted Overlay 1 study, and Geospatial technology 1 study. Many studies used multiple methods in combination.

3.1.1 Crop Focus

The studies covered a diverse range of crops. Wheat and Sesame were each the focus in 2 studies. Groundnut was also studied in 2 studies. Other crops (Rice, Mung Bean, Barley) and agricultural systems (Agroforestry, Surface irrigation, General cropland/agriculture) were each the focus of 1 study. Some studies focused on multiple crops.

3.1.2 Geographic Information Systems (GIS)-Based Analysis Methods

Studies used various data sources to create thematic layers for each criterion, (Ayenew, 2020) used remotely sensed data (Landsat images), digital elevation models, and soil data to prepare the necessary layers. Weighted overlay analysis was a frequently used technique for combining multiple criteria layers, (Hussien et al., 2019) specifically mentioned using the Weighted Overlay tool in ArcGIS. All studies produced suitability maps as their final output, classifying land into different suitability categories, (Haile, 2024) classified land into four categories: optimal growth conditions, suitable, less suitable, and not suitable.

3.1.3 Multicriteria Decision Analysis Framework

The integration of Multi-Criteria Evaluation (MCE) techniques with Geographic Information Systems (GIS) was a key feature of all studies. Criteria were selected based on literature reviews, expert opinions, and their relevance to the specific crop or land use being evaluated. For instance, Yalew et al. (2016) identified nine criteria for agricultural land suitability evaluation.

The Analytical Hierarchy Process (AHP) was the predominant method for assigning weights to different criteria. This technique involves pairwise comparisons to determine the relative importance of each criterion. Merga et al. (2021) applied AHP to derive weights for their criteria.

The weighted criteria were then typically combined using GIS overlay techniques to produce final suitability maps. For example, Ayehu et al. (2015) employed the weighted sum overlay tool in ArcGIS to construct suitability map layers.

Table 1: Characteristics of Included Studies

Study	**Study Location**	**Evaluation Method**	**Criteria Used**	**Crop Focus**
(Ayehu & Besufekad, 2015)	West central highlands of Amhara Region, Ethiopia	Geographic Information Systems (GIS)-based, Multi-Criteria Decision Approach, Analytical Hierarchy Process (AHP)	Soil, climatic conditions, topography	Rice
(Ayenew, 2020)	Wollo part of the Amhara Regional state, Ethiopia	Geographic Information Systems (GIS)-based, Multi-Criteria land suitability analysis, Analytical Hierarchy Process (AHP)	Soil texture, soil depth, rainfall, temperature, altitude, slope	Mung Bean
(Haile, 2024)	Genale sub-basin, Oromia, Ethiopia	Geographic Information Systems (GIS), Remote Sensing (RS), Analytical Hierarchy Process (AHP)	Soil fertility (N, K, C, P, pH), rainfall, elevation, slope, Normalized Difference Water Index (NDWI)	Agroforestry
(Tilahun et al., 2019)	Watershed, East Harerge Zone, Ethiopia	Geographic Information Systems (GIS)-based, multi-criteria land suitability evaluation, Weighted Overlay tool	Soil pH, slope, soil drainage, soil depth, AWSC, type, texture, EEC, CEC, phase, surface carbon, distance classes, obstacles to land use, land cover, slope, distance from river	Surface irrigation for crop production
(Tigistu Enyew, 2021)	South Gondar, Ethiopia	Geographic Information Systems (GIS)-based land suitability analysis	Slope, soil depth, soil drainage, soil texture, temperature requirements, rainfall requirements	Wheat
(Aytenew & Ab, 2021)	Woreja District, East Gojjam Zone, Amhara Regional State, Western Ethiopia	Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE), Analytical Hierarchy Process (AHP)	Soil texture, soil depth, soil slope, soil drainage, soil fertility, rainfall	Sesame and Groundnut

Continued on next page

Table 1 – *Continued from previous page*

Study	Study Location	Evaluation Method	Criteria Used	Crop Focus
(Mekuanint, 2022)	Dang, Amara Region, Western Ethiopia	Geographic Information Systems (GIS) and multi-criteria evaluation	Rainfall, slope, elevation, soil depth, road network, market accessibility	Sesame and Groundnut
(Tilahun et al., 2022)	National (review paper)	Multi-criteria evaluation (MCE) techniques integrated with geospatial technology	Economic condition, infrastructure, irrigation, existing land use/land cover, environmental aspects	General agriculture sustainability
(Yalew et al., 2016)	Abbay (Upper Blue Nile) basin, Ethiopia	Geographic Information Systems (GIS)-based analysis, Analytical Hierarchy Process (AHP)	Soil type, soil depth, soil water content, soil stoniness, slope, elevation, proximity to towns, roads, water sources	General agriculture
(Yohannes & Soromessa, 2018)	Andit Tid watershed, Ethiopia	Geographic Information Systems (GIS)-based multi-criteria approach	Soil depth, texture, temperature, slope, erosion hazard	Wheat and Barley

3.2 Land Suitability Parameters

The Table 2 presents five main parameter categories for land suitability assessment: soil, climate, topography, socio-economic factors, and land use. Each category was associated with specific criteria, measurement methods, and relevance to land suitability.

3.3 Specific Criteria

Soil properties were texture, depth, pH, fertility, organic carbon, and drainage. Climate factors were rainfall and temperature. Topography criteria were slope, and elevation. Socio-economic criteria were proximity to roads, and markets. Land use was current land use/land cover

3.4 Measurement Methods and Relevance

2/5 categories used Geographic Information Systems (GIS)-based methods. Other methods included field surveys and laboratory analysis for soil, meteorological data and climate models for climate, and remote sensing and land use maps for land use. 2/5 categories (soil and climate) were relevant to plant growth factors. 2/5 categories (topography and land use) were relevant to land management. 1/5 category (socio-economic) was relevant to economic factors. The Table 2 below demonstrates a comprehensive approach to land suitability assessment, incorporating physical, climatic, topographic, socio-economic, and

current land use factors. Each parameter category contributed unique information to the overall assessment of land suitability for cultivation.

Table 2: Main categories of evaluation criteria used across the studies

Parameter Category	**Specific Criteria**	**Measurement Method**	**Relevance**
Soil	Texture, depth, pH, fertility (N, P, K), organic carbon, drainage	Soil surveys, laboratory analysis	Determines water retention, nutrient availability, and root growth potential
Climate	Rainfall, temperature	Meteorological data, climate models	Affects crop water requirements and growth conditions
Topography	Slope, elevation	Digital Elevation Models (DEM)	Influences erosion risk, mechanization potential, and microclimate
Socio-economic	Proximity to roads, markets	Geographic Information Systems (GIS) analysis of infrastructure data	Affects accessibility and economic viability of cultivation
Land use	Current land use/land cover	Remote sensing, land use maps	Indicates current utilization and potential for conversion

3.5 Suitability Classification Methods

Most studies applied a four-class suitability scheme: *highly suitable*, *moderately suitable*, *marginally suitable*, and *not suitable*. Some variations existed; for example, Haile et al. (2024) used the term "optimal growth conditions" instead of "highly suitable."
There was limited information on validation methods across the studies in the available full texts or abstracts. Several studies identified different limiting factors for land suitability. For instance, Yohannes et al. (2018) highlighted soil depth, texture, temperature, slope, and erosion hazard as the main limiting factors.

4 Discussion

4.1 The characteristics of soils

The suitability of soils for cashew cultivation in a watershed depends on several physical characteristics that influence the crop's growth and productivity (Peterson, 2000). Soil texture plays a crucial role in determining land suitability for cashews (Pradhan et al., 2024). Cashew trees prefer well-drained soils with good water holding capacity. Sandy soil, which are prevalent in many parts of Africa, can be challenging for cashew cultivation due to their low water retention capacity (Viana et al., 2023).

However, the distribution of coarse and fine sand fractions within the soil profile can significantly impact its physical and hydric attributes. Higher coarse sand content increases

soil hydraulic conductivity and macroporosity, while fine sand content can improve water retention in subsurface layers (Viana et al., 2023). For cashew cultivation, a balanced distribution of sand fractions is desirable to ensure adequate drainage while maintaining sufficient water availability. Soil depth is another critical factor for cashew cultivation (Tantuoyir et al., 2025). Deep soil(s) are preferred as they allow for extensive root development and better access to water and nutrients. In the Beko watershed study, poor soil depth was identified as a constraint for crop production (Sarkar et al., 2014). Cashew trees, with their deep root systems, require soils with adequate depth to thrive and withstand drought conditions.
Slope and topography also influence soil suitability for cashew. Steep slopes can lead to increased erosion and reduced water retention, making them less suitable for cashew cultivation. The study in the Minch Yekest watershed used slope as a parameter for irrigation land suitability analysis (Hagos et al., 2022). For cashews, gently sloping or flat lands are more suitable as they reduce the risk of erosion and allow for better water management.

Soil bulk density (BD) and total porosity (TP) are important indicators of soil physical condition. Lower bulk density and higher total porosity are favourable for root growth and water movement. The study in the Ayiba watershed found that land use type and altitudinal gradient significantly affected BD and TP (Seifu et al., 2020). Barren land and higher altitude landscapes had the highest BD and lowest TP, while grassland and lower altitude landscapes had the lowest BD and highest TP (Seifu et al., 2020). For cashew cultivation, soils with lower BD and higher TP would be more suitable as they allow for better root penetration and water infiltration.

Soil organic matter (SOM) content is crucial for maintaining soil structure, water holding capacity, and nutrient availability. The study in the Ayiba watershed showed a strong positive relationship between SOM and total porosity, total nitrogen, moisture content, and clay content (Seifu et al., 2020). Higher SOM content would be beneficial for cashew cultivation as it improves soil physical properties and nutrient availability. Water availability is a critical factor for cashew production, especially in semi-arid regions of Africa (Tantuoyir et al., 2025). The study in the Ansai watershed highlighted the importance of deep soil moisture (DSM) for vegetation growth (Fang et al., 2016). For cashew cultivation, areas with adequate DSM in the 80-500 cm soil layers would be more suitable, as it provides a stable water resource for the crop's long-term growth (Fang et al., 2016). While specific pH requirements for cashew were not mentioned in the provided papers, most crops prefer slightly acidic to neutral soils. The study in Duplin County considered soil chemistry as one of the criteria for land suitability evaluation (Karimi et al., 2018).

4.2 The climatic conditions

Cashew, a perennial tropical crop, is significantly influenced by climatic conditions, which play a crucial role in its growth, productivity, and overall cultivation success (Vinca et al., 2021). The impact of climate on cashew production is multifaceted, affecting various aspects of the crop's lifecycle and economic importance (Wekesa et al., 2018). Climate change has emerged as a major factor influencing cashew cultivation, with both positive and negative impacts observed across different regions (Sheehan et al., 2023). According to a global assessment of climate change impacts on cashew suitability, shifts in suit-

able growing regions are expected due to changing climatic conditions (Grüter et al., 2022). While some areas may experience expansion in cashew cultivation, others may face contraction. This variability in climate impact highlights the need for region-specific adaptation strategies. The primary climatic factors affecting cashew cultivation include temperature, precipitation, and dry seasons (Kourgialas et al., 2022). Long dry seasons, extreme temperatures (both high and low), and annual precipitation levels (both excessive and insufficient) are identified as the most restrictive climatic factors for cashew cultivation globally (Grüter et al., 2022). These factors outweigh land and soil parameters in determining the suitability of growing regions for cashew.

In West Africa, which has become a significant cashew-producing region accounting for 45% of worldwide production in 2015, the diverse agro-climatic conditions have contributed to the crop's success (Guterres et al., 2023). The region's climate variability has allowed cashews to thrive, replacing traditional food crops in many areas. However, this shift towards cashew as a dominant cash crop raises concerns about local livelihoods and food security, emphasizing the need for sustainable production practices in the face of climate-related risks (Guterres et al., 2023). Climate change projections indicate that while global suitable areas for cashew cultivation may expand, the regions of highest suitability in most major producing countries are expected to decrease (Grüter et al., 2022). This trend suggests that climate change adaptation will be necessary in most major cashew-producing regions. The varying impacts across different geographical areas underscore the importance of location-specific climate change assessments and adaptation strategies. Intriguingly, cashew cultivation may benefit from increasing minimum temperatures at higher latitudes and altitudes (Grüter et al., 2022). This potential expansion into new areas previously unsuitable for cashew production highlights the complex nature of climate change impacts on perennial crops and the need for comprehensive, long-term planning in the agricultural sector.

The influence of climate on cashew extends beyond just cultivation suitability. Climatic factors also affect the crop's susceptibility to diseases, which is a critical consideration for tropical and plantation crops like cashew (Ghini et al., 2011). As projected climate conditions are expected to vary across continents and between developed and developing countries, it is crucial to conduct studies specific to tropical regions, considering their unique environmental conditions. To accurately assess the impact of climate change on cashews and other perennial crops, advanced research methodologies are required. Multifactor studies under realistic field situations, such as free air CO2 enrichment experiments incorporating spectral reflectance measures, are recommended for a more comprehensive understanding of climate change effects (Ghini et al., 2011). These studies should consider the combined impacts of increasing CO2 and O3 concentrations, as well as other environmental factors.

The long lifespan of cashew as a plantation crop necessitates long-term planning in cultivation strategies (Grüter et al., 2022). This characteristic makes the evaluation of climate change impacts on cashew's biophysical suitability essential for developing effective adaptation measures and selecting appropriate varieties or alternative crops when necessary.

4.2.1 The topography, and water availability (proximity to water source)

Cashew cultivation is significantly influenced by topography, water availability, and elevation, which collectively determine the crop's suitability in various regions (Tantuoyir et al., 2025). These factors play a crucial role in the growth, development, and productivity of cashew trees (Tian et al., 2023). Topography is a key determinant of cashew cultivation suitability. According to (Grüter et al., 2022), steep slopes are among the primary land and soil parameters that restrict the global extent of suitable growing regions for cashew. This suggests that cashew trees prefer flat or gently sloping terrain. The importance of slope is further emphasized in (de França e Silva et al., 2024) which, although focused on sugarcane, demonstrates that slope is one of the top contributing factors in crop suitability assessment. In the context of cashew cultivation, areas with moderate slopes may be suitable, but steep slopes should be avoided to prevent soil erosion and facilitate easier management practices (Seifu et al., 2020).
Water availability is another critical factor for cashew cultivation (SALİFU et al., 2022). (Grüter et al., 2022) indicates that long dry seasons and annual precipitation (both high and low) are among the most restrictive climatic factors for cashew growing regions. This implies that cashew trees require a balanced water supply throughout the year. While they can tolerate some drought, prolonged dry periods can negatively impact their growth and yield.

Conversely, excessive rainfall or waterlogged conditions can also be detrimental. The study in (Song et al., 2023), although not specific to cashew, highlights the importance of water yield in agricultural regions. It shows that water yield tends to decrease and then increase along an altitudinal gradient, with precipitation and actual evapotranspiration directly affecting water availability. This information can be valuable when assessing potential cashew cultivation areas across different elevations.

Elevation plays a significant role in determining the suitability of land for cashew cultivation (Tian et al., 2023). (Grüter et al., 2022) mentions that at high altitudes, cashews may benefit from increasing minimum temperatures due to climate change. This suggests that cashew trees prefer lower to medium elevations but may adapt to higher altitudes as global temperatures rise. The study in (Vahdati et al., 2019) on walnut cultivation emphasizes the importance of altitude in land suitability assessment, which can be applied to cashews as well. Both crops share similar climatic requirements, preferring warm temperatures and moderate rainfall. The interaction between these factors creates complex patterns of land suitability for cashew cultivation. For instance, (Vahdati et al., 2019), which focuses on Iran's agricultural land suitability, demonstrates how the combination of low precipitation, steep slopes, and other factors can limit crop production. While this study is not specific to cashew, it illustrates the importance of considering multiple factors when assessing land suitability.

The research presents some contradictions and noteworthy facts. (Grüter et al., 2022) suggests that climate change may lead to both expansion and contraction of suitable growing regions for cashew globally. While some areas may become more suitable due to increasing temperatures, others may face challenges due to changes in precipitation patterns or increased frequency of extreme weather events (Shifteh Some'e et al., 2012). This highlights the need for adaptive strategies in cashew cultivation to cope with future

climate scenarios. Another interesting aspect is the potential for cashew cultivation to coexist with wildlife, as demonstrated in (Rege et al., 2020). The study in Guinea-Bissau shows that cashew can be a low-conflict crop in areas where humans and wildlife, specifically chimpanzees, share the landscape (Rege et al., 2020). This suggests that cashew cultivation, when effectively managed, can contribute to both agricultural production and biodiversity conservation.

4.3 Overall Land Suitability Map

Land suitability analysis for cashew cultivation in a selected watershed requires a comprehensive evaluation of various climatic, topographic, and soil parameters. This process is crucial for sustainable land-use planning and for optimizing agricultural productivity, as noted by Sarkar (2014). To create an overall land suitability map for cashew cultivation, multiple factors that influence the crop's growth and yield must be considered. Based on the available literature, the key parameters for cashew suitability analysis include climatic factors (temperature, precipitation, and dry season length), soil characteristics (pH, texture, depth), topography (slope, aspect), and land use (Gruter et al., 2022; Mercan et al., 2023).

Climate plays a significant role in determining cashew suitability. Cashew trees require a warm tropical climate with a distinct dry season for flowering and fruit set. The average annual temperature and precipitation are crucial factors to consider (Gruter et al., 2022). Additionally, the length of the dry season is important, as prolonged dry periods can affect cashew productivity.

Soil characteristics are equally important for cashew cultivation. Soil pH, texture, and depth are critical factors that influence the crop's growth and yield. Cashew trees prefer well-drained soils with a slightly acidic to neutral pH (Fekadu et al., 2020; Taghizadeh et al., 2020). The available water capacity (AWC) of the soil is also a crucial factor to consider, as it affects the plant's ability to access water during dry periods (Fekadu et al., 2020).

Topographic factors such as slope and aspect also play a role in determining land suitability for cashew cultivation. Gentle to moderate slopes are preferred, as steep slopes can lead to erosion and make management practices difficult (Sarkar, 2014; Taghizadeh et al., 2020). The aspect or direction of the slope can influence the amount of solar radiation received by the plants, which is important for photosynthesis and overall plant growth (Mercan et al., 2023).

To create an overall land suitability map for cashew cultivation, a combination of Geographic Information System (GIS) techniques and multi-criteria decision-making methods can be employed. The Analytical Hierarchy Process (AHP) is a widely used approach for assigning weights to different parameters based on their relative importance (Fekadu et al., 2020; Taghizadeh et al., 2020). This method allows for the integration of expert knowledge and local conditions into the suitability analysis (Saaty, 2005).

Once the relevant parameters are identified and weighted, GIS software can be used to create individual suitability maps for each factor. These maps can then be combined

using a weighted overlay technique to produce the final overall land suitability map for cashew cultivation (Mercan et al., 2023; Sarkar, 2014). It is important to note that land suitability analysis should also consider potential climate change impacts. As demonstrated in the study on coffee, cashew, and avocado by Gruter et al. (2022), climate change can significantly affect the suitability of growing regions for perennial crops. For cashew, areas suitable for cultivation are expected to expand globally, but the areas of highest suitability may decrease in some major producing countries. This highlights the need for long-term planning and potential adaptation strategies in cashew cultivation.

The use of advanced machine learning techniques, such as Random Forest (RF) algorithms, can enhance the accuracy of land suitability mapping (Mercan et al., 2023). These methods can effectively handle complex relationships between multiple environmental variables and crop suitability, potentially providing more accurate results than traditional approaches.

To validate the created land suitability map, techniques such as the Receiver Operating Characteristic (ROC) curve and the Area Under the ROC Curve (AUC) can be applied (Akinci et al., 2013). These methods help assess the model's performance and reliability in predicting suitable areas for cashew cultivation.

5 Conclusions

The reviewed studies demonstrate a consistent methodology for land suitability evaluation using Geographic Information Systems (GIS) and Multi-Criteria Evaluation (MCE) techniques across various crops and regions in Ethiopia. The integration of these methods provides a framework for assessing land suitability, incorporating multiple environmental and socio-economic factors. Climate change is expected to cause shifts in suitable growing regions, with both expansion and contraction observed in different areas. The primary climatic factors affecting tree growth include temperature extremes and precipitation patterns.
Moreover, the suitability of land for cashew cultivation is determined by a complex interplay of topography, water availability, and elevation. Ideal conditions include flat or gently sloping terrain, consistent water availability without prolonged dry periods or waterlogging, and lower to medium elevations.

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