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Spatial Assessment of Agroforestry Land Suitability in the Wanggu Watershed, Indonesia

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Abstract

This study aimed to evaluate land suitability for spatial-based agroforestry development by explicitly identifying the key biophysical characteristics of the Wanggu Watershed, an urban–peri-urban watershed experiencing rapid land-use change due to urban expansion and agricultural activities. The assessment focused on critical terrain and hydrological attributes, including slope class, elevation percentage, and distance from rivers, which strongly influence land productivity, erosion risk, and agroforestry feasibility.
A Geographic Information System (GIS)-based spatial analysis was applied using a Multi-Criteria Evaluation (MCE) approach. Spatial datasets derived from Digital Elevation Models (DEM), river networks, and land characteristics were classified into weighted parameters: slope (0–15%, 15–35%, >35%) and river buffer distance (0–500 m, 500–1000 m, >1000 m). Each parameter was scored and overlaid to generate the land suitability maps. Field verification was conducted at 40 sampling points across six sub-districts to ensure consistency between spatial modeling and actual biophysical conditions.
The results revealed distinct spatial patterns of land suitability driven by topographic variations. Lowland areas with gentle slopes (0–15%) are predominantly classified as suitable for productive agroforestry systems, whereas moderately sloping areas (15–35%) require conservation-oriented agroforestry practices. Steep terrains (>35%), mainly located in upstream regions, are more appropriate for protection and for ecological rehabilitation. In terms of hydrological proximity, areas located 500–1000 m from rivers showed the highest suitability, whereas riparian zones require careful ecological management. Overall, approximately 65–70% of the watershed is categorized as "Suitable," and 30–35% as "Moderate."
These findings demonstrate that integrating biophysical characteristics through GIS-based MCE provides a robust basis for agroforestry zoning, thereby supporting sustainable land management and watershed conservation strategies.

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1. Introduction

The Wanggu Watershed in Southeast Sulawesi has experienced increasing ecological pressure due to land cover change, forest conversion, and unsustainable agricultural practices. These pressures have accelerated soil erosion, seasonal flooding, and soil quality degradation, thereby threatening the ecological stability of the watershed. In this context, agroforestry, an integrated land-use system combining trees and crops, has been widely recognized as a viable strategy for restoring watershed ecological functions while enhancing land productivity. Previous studies have demonstrated that agroforestry supports sustainable landscape management and improves the livelihoods of communities living in watershed areas (Ahmad & Goparaju, 2017; Chaturvedi et al., 2018).

Despite its potential, agroforestry implementation in the Wanggu Watershed remains limited and has not yet been guided by a systematic spatial approach. Spatial land suitability assessments have been extensively applied in agriculture, forestry, and land rehabilitation, particularly through the use of Geographic Information Systems (GIS) and remote sensing. These geospatial techniques enable the integration of critical biophysical parameters, such as topography, soil characteristics, and climatic patterns, to identify suitable areas for agroforestry development (Ahmad & Goparaju, 2017; Haile, 2024).

Recent studies have highlighted the effectiveness of Multi-Criteria Evaluation (MCE), often combined with the Analytical Hierarchy Process (AHP), in integrating multiple environmental variables and assigning relative weights based on their importance (Saaty, 1980; Ahmad et al., 2018; Rahman et al., 2020; Susanto et al., 2022). Commonly applied criteria include slope, soil fertility, distance from rivers, rainfall, and accessibility, all of which influence agroforestry productivity and risks (Dubovyk et al., 2014; Chaturvedi et al., 2018).

The novelty of this study lies in the application of an integrated GIS–MCE framework to evaluate agroforestry land suitability, specifically within the Wanggu Watershed. The analysis incorporates key spatial parameters, including slope class, elevation percentage, and distance from the river to provide spatially explicit guidance for adaptive watershed management (Gurara, 2020). This study aimed to assess land suitability for agroforestry using a spatial approach by identifying key biophysical characteristics, such as slope class, elevation percentage, and distance from rivers, to support the development of a scientifically grounded and sustainable management model for the Wanggu Watershed.

2. Material and Methods

2.1 Time and Location of the Study

This study will be conducted from August to September 2025 in the Wanggu Watershed area, which covers the City of Kendari and parts of South Konawe Regency, Southeast Sulawesi Province. The Wanggu Watershed is a crucial urban–peri-urban watershed that has undergone significant land-use changes owing to urban expansion and agricultural activities, impacting land productivity and environmental sustainability. Therefore, a spatial assessment of agroforestry land suitability is essential to support sustainable land-use planning and watershed management. A location map of the study area is shown in Figure 1.

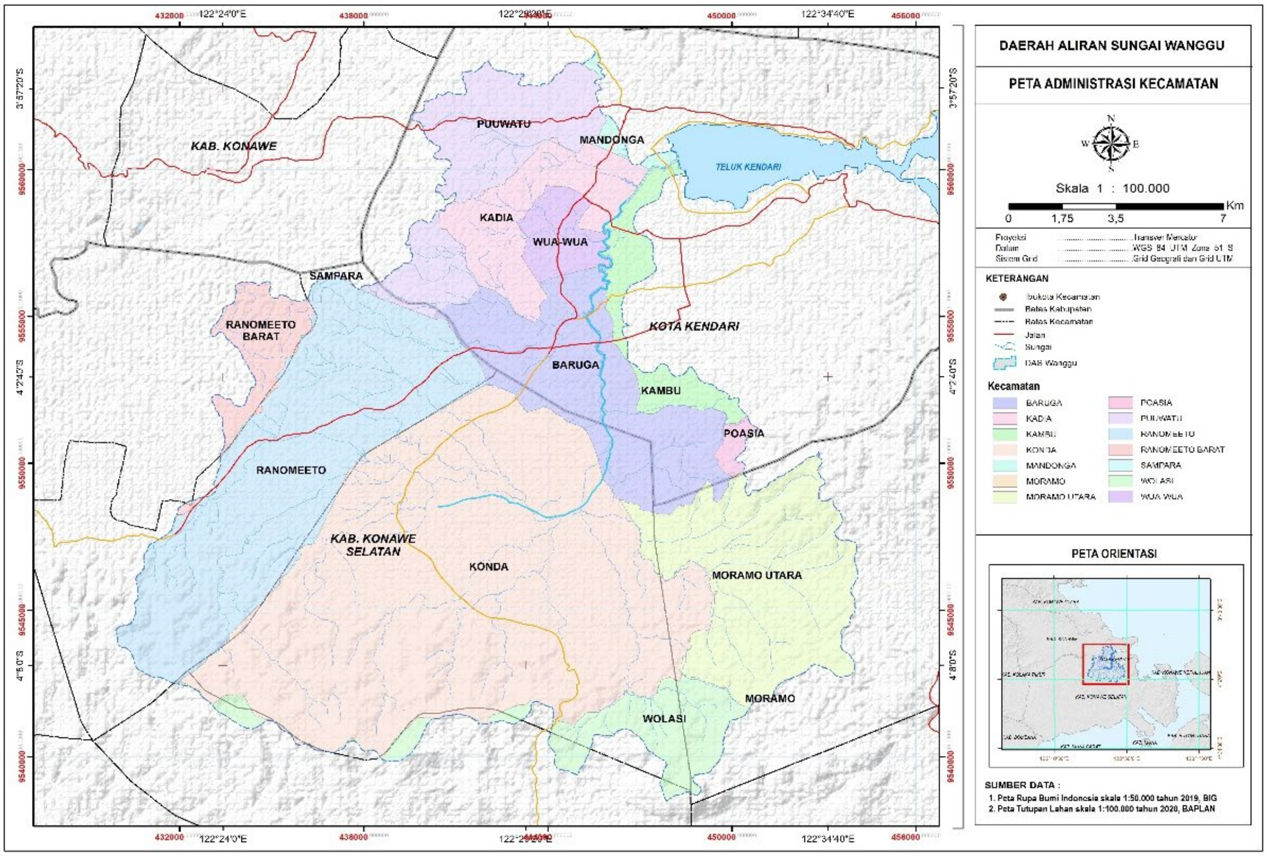

Figure 1. Wanggu watershed, Southeast Sulawesi Province tools and materials.

The tools used in this study are listed in Table 1.

Table 1. Tools and materials used.

No.	Equipment	Function
1	GPS (Global Positioning System)	Navigation and collection of coordinate data in the field
2	Computer	Processing geospatial data and preparing research outputs
3	Digital camera	Documenting field conditions and research locations
4	ArcGIS 10.8	Spatial data processing and geospatial analysis
5	Microsoft Excel 2010	Data processing and tabulation
6	Microsoft Word 2010	Preparation and compilation of research reports

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2.2 Types and Sources of Data

2.2.1 Types of data

This study employed a GIS-based spatial analysis approach using three quantitative parameters: slope class, elevation percentage, and distance from the river. The slope classes in the study area were categorized into five classes: <5% (very gentle), 5–15% (gentle), 16–25% (moderately steep), 26–35% (steep), and >35% (very steep). For analytical purposes, these classes were further aggregated into three groups: 0–15% (very gentle to gentle), 16–35% (moderately steep to steep), and >35% (very steep), representing increasing levels of terrain inclination (Rahaman & Aruchamy, 2022). For elevation percentage, areas with >80% were classified as high (score 5), 60–80% as moderately high (score 4), 40–60% as moderate (score 3), 20–40% as moderately low (score 2), and <20% as low (score 1) (Widiyanto & Suhartono, 2017). The distance-from-river parameter was classified into buffer zones of 0–500 m, 500–1000 m, and >1000 m, which represent approximately 25%, 40%, and 35% of the watershed area, respectively (Hussien et al., 2019; Balew et al., 2021). Each parameter was assigned scores and weights and subsequently analyzed using the Multi-Criteria Evaluation (MCE) overlay technique to produce two main land suitability classes: "Suitable" (±65–70%) and "Moderate" (±30–35%) (Gurara, 2020).

2.2.2 Data sources

a. Primary Data were obtained directly from the study area through field observations, including ground verification, coordinate point collection, and photographic documentation of the research locations. A total of 40 samples were used for field verification across six sub-districts within the Wanggu Watershed (Haile, 2024; Duran, 2024).
b. Secondary Data were obtained through a literature review and institutional data sources, including rainfall data from BMKG, slope and elevation maps derived from satellite imagery, river distance maps, Digital Elevation Model (DEM) data, and administrative boundary data.

2.2.3 Research design

This study was designed to evaluate land suitability for the development of spatially based agroforestry systems in the Wanggu Watershed. A geospatial approach was applied using GIS data and satellite imagery to analyze key biophysical parameters such as slope, elevation, and distance from rivers. Overlay and scoring methods were used to generate land suitability maps based on ecologically and socially relevant agroforestry criteria. Secondary data and field surveys were incorporated to validate the mapping results. The findings are expected to provide land zoning recommendations to support sustainable agroforestry implementation, watershed conservation, and improvement of local community livelihoods.

2.2.4 Data collection techniques

Data collection was conducted using two main approaches: secondary data acquisition and field observation (ground checking). Secondary data were obtained from relevant institutions, such as the Geospatial Information Agency (BIG), BMKG, and the Forestry Agency, including topographic maps, soil types, rainfall data, land use, and land-use planning information. Primary data were collected through field surveys to verify actual land conditions, including vegetation and slope characteristics, using GPS devices and observation sheets. Both data types were processed using GIS to produce accurate and context-specific agroforestry land suitability maps for the Wanggu Watershed.

2.2.5 Data analysis techniques

Data analysis was conducted spatially using a Geographic Information System (GIS) to evaluate agroforestry land suitability in the Wanggu Watershed based on three main biophysical parameters: slope class, elevation percentage, and distance from rivers. Each parameter was classified into suitability levels and assigned a score ranging from 1 (low suitability) to 5 (high). For slope, areas with >35% were scored as 5 (high), 26–35% as 4 (moderately high), 16–25% as 3 (moderate), 5–15% as 2 (moderately low), and <5% as 1 (low). For elevation percentage, areas with >80% were scored as 5 (high), 60–80% as 4 (moderately high), 40–60% as 3 (moderate), 20–40% as 2 (moderately low), and <20% as 1 (low).

For agroforestry suitability, river distance was classified into buffer zones where 0–500 m was considered low suitability (score 1) because of the high flood risk, 500–1000 m was categorized as moderately low suitability (score 2), and 1000–1500 m was classified as moderate suitability (score 3) because of more stable conditions with a relatively lower flood risk while still maintaining adequate water availability.

Each parameter was assigned an equal weight (1) to avoid bias and ensure a proportional contribution to determining agroforestry suitability. The parameters included the slope, river distance, and elevation percentage. The suitability score was calculated using a simple additive model within the Multi-Criteria Evaluation (MCE) framework: Suitability Index (SI) = {slope, elevation percentage, river distance} (Widiyanto & Suhartono, 2017).

The resulting suitability index values were then classified into three categories based on threshold ranges: areas with SI > 3 were categorized as "Suitable," indicating favorable biophysical conditions for agroforestry development; areas with SI between 2.1 and 3 were classified as "Moderate," indicating conditional suitability; and areas with SI < 2 were classified as "Not suitable," indicating limitations for agroforestry development.

The final land suitability map was generated through an overlay analysis of all parameters, and field validation was conducted at 40 sampling points to ensure consistency between the spatial model outputs and actual biophysical conditions in the watershed.

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3. Results and Discussion

Spatial analysis indicated that the Wanggu Watershed is characterized by pronounced heterogeneity in key biophysical properties, particularly slope, elevation, and distance from the river network. Slope conditions range from gentle (0–15%) in lowland areas to steep (>35%) in upland zones, and elevation gradually increases from downstream plains to upstream hilly and mountainous regions. In addition, the watershed exhibits varying proximity to river systems, with distinct riparian zones (0–500 m), transitional areas (500–1000 m), and more distant upland areas (>1000 m).

These combined biophysical characteristics form a clear north–south gradient, with relatively flat and low-elevation areas dominating the northern part of the watershed, supporting more intensive land use. In contrast, the central and southern regions are characterized by higher elevations and steeper slopes, reflecting more complex terrain conditions that influence land-use suitability and conservation needs.

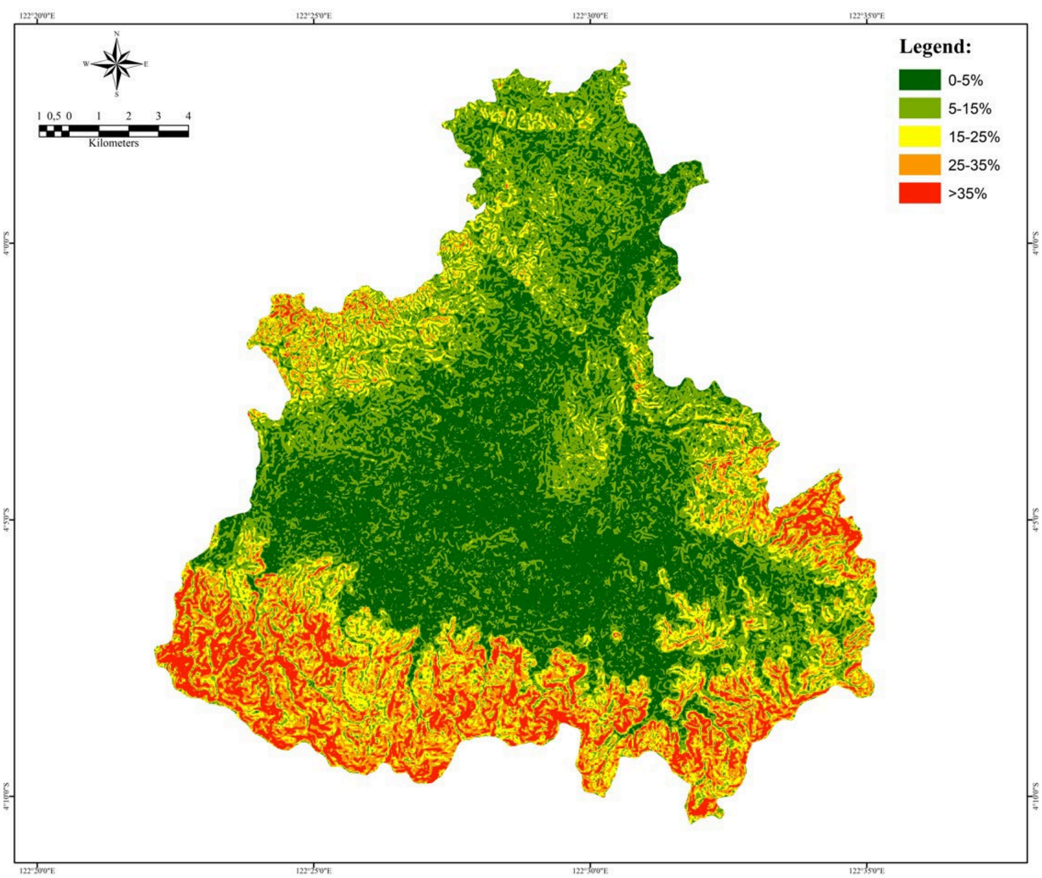

Figure 2. Slope gradient classification map of the Wanggu Watershed.

Slope analysis showed that areas with gentle slopes (0–15%) occupy approximately 45–50% of the watershed and are predominantly located in the northern and downstream regions, including the urban and peri-urban areas of Kendari City. These areas present low erosion risk, higher soil stability,

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and easier land accessibility, making them highly favorable for productive agroforestry systems, such as mixed cropping, agrosilviculture, and community-based agroforestry gardens. In contrast, slopes of 15–35%, covering approximately 30–35% of the watershed, are distributed mainly in the midstream areas. These zones exhibit moderate erosion risk and require conservation measures, such as contour planting, terracing, and the integration of perennial tree species, to maintain land productivity.

Very steep slopes (>35%), accounting for approximately 15–20% of the watershed, are concentrated in the upstream and southernmost areas, particularly in the Wolasi and North Moramo Districts. These areas play a crucial role as water catchment zones and are highly sensitive to changes in land use. Agroforestry development in these zones should prioritize conservation-oriented systems or ecological restoration rather than intensive production to prevent accelerated erosion, landslides, and hydrological imbalances.

Elevation analysis further strengthens the spatial differentiation observed in the slope patterns. Low-elevation areas (0–100 m above sea level) dominate the downstream sections and are generally associated with flatter terrain and deeper alluvial soils. These characteristics enhance the suitability of these species for intensive agroforestry practices. However, several low-lying areas located near river confluences, such as the Lepo-Lepo and Alolama sub-watersheds, are prone to seasonal flooding, which may constrain crop selection and require flood-resilient agroforestry designs.

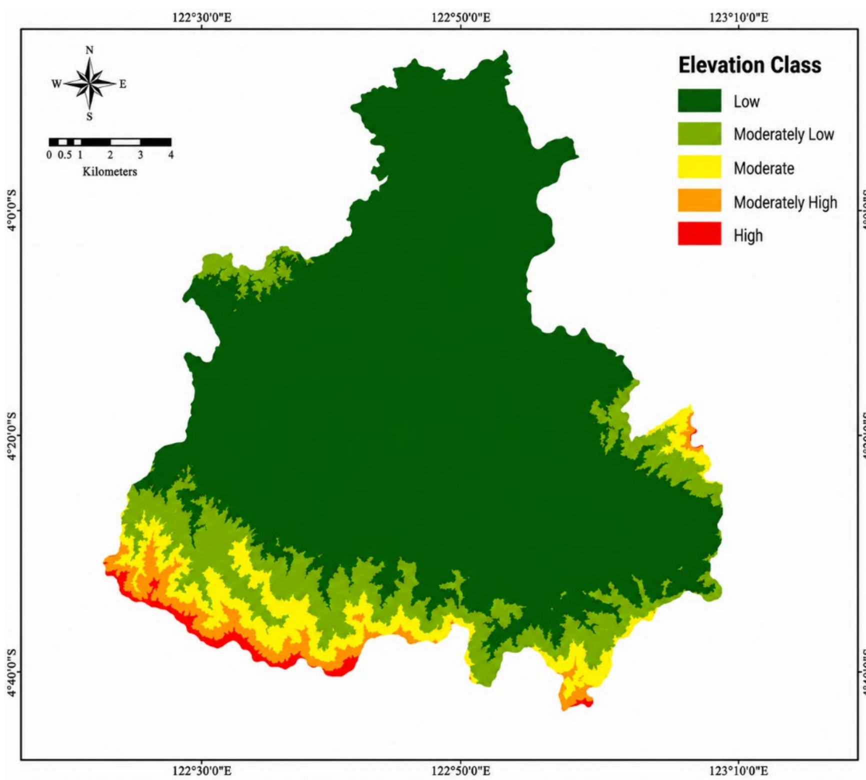

Figure 3. Percentage Elevation (DEM) map of the Wanggu Watershed.

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In contrast, upland areas (>200 m) are characterized by steeper slopes, thinner soil, and limited accessibility. Although less suitable for intensive agroforestry, these areas remain important for ecological functions, such as biodiversity conservation and water regulation. Agroforestry systems in upland zones should emphasize soil protection through the integration of native tree species and long-rotation crops, as this approach strengthens the soil structure, reduces erosion, and enhances nutrient cycling (Fahad et al., 2022; Kaur et al., 2023). In addition, the use of native species supports biodiversity and ecosystem resilience, whereas long-rotation crops contribute to sustainable production and land stability over time (Ottoboni & Andreani, 2025).

Distance from the river network is another critical factor influencing agroforestry suitability because of its relationship with soil moisture availability, groundwater recharge, and flood risk. Riparian zones within 0–500 m of the river channels cover approximately 25% of the watershed. These areas offer high water availability and fertile soils but are ecologically sensitive to erosion and to flooding. Consequently, agroforestry activities in these zones should be limited to low-impact systems and accompanied by riparian buffer protection measures.

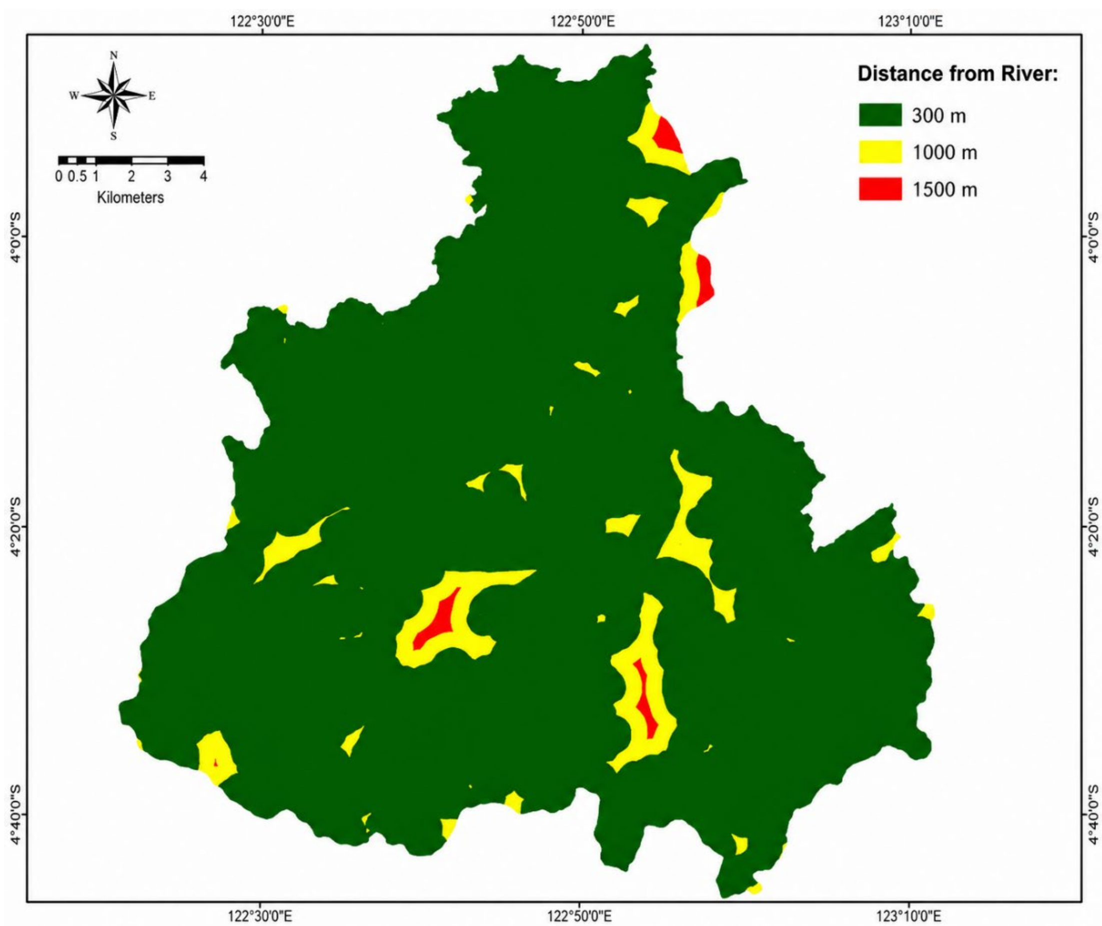

Figure 4. River buffer distance map of the Wanggu Watershed.

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The 500–1000 m buffer zone, which covers approximately 40% of the watershed, represents the most optimal balance between water availability and land stability. This zone exhibits the highest potential for productive agroforestry development, with relatively low environmental risk. Areas located more than 1000 m from the river, accounting for approximately 35% of the watershed, tend to have lower soil moisture and a higher dependence on rainfall, requiring drought-tolerant species and adaptive management strategies.

The overlay analysis integrating slope, Percentage elevation, and river distance using Multi-Criteria Evaluation (MCE) produced two main agroforestry land suitability classes: "Suitable" and "Moderate." The suitability assessment was quantified using a weighted Suitability Index (SI), calculated as follows: SI = {slope, elevation percentage, river distance}(Widiyanto & Suhartono, 2017). The weighting scheme prioritizes slope as the most influential factor because of its strong control on erosion risk and land stability, followed by proximity to rivers as a proxy for water availability, and elevation percentage as a complementary terrain characteristic influencing land management feasibility. Based on this analysis, approximately 65–70% of the Wanggu Watershed was classified as "Suitable," characterized by gentle slopes, low to moderate elevations, and close proximity to water sources. These areas exhibit high SI values, indicating optimal biophysical conditions for sustainable agroforestry development with minimal environmental constraints.

Meanwhile, 30–35% of the watershed fell under the "Moderate" category, which is generally associated with intermediate SI values and located in hilly transitional zones. These areas remain potentially suitable for agroforestry but require additional soil and water conservation measures, such as contour planting, terracing, and vegetative barriers, to mitigate erosion risks and maintain productivity.

Overall, the results highlight the importance of biophysical zonation in guiding agroforestry planning in the Wanggu Watershed. Aligning agroforestry systems with land capability can improve productivity while simultaneously supporting key watershed functions, such as erosion control, hydrological regulation, and ecosystem resilience. To verify the reliability of the spatial model, field validation was conducted at 40 sampling points, showing an overall accuracy of 87% between the model outputs and actual biophysical conditions in the field. This relatively high level of agreement indicates that the model provides a robust representation of the on-site conditions. These findings are consistent with established land evaluation frameworks that emphasize land-use decisions based on ecological suitability and risk minimization (FAO, 1976; FAO, 2017; Nair, 2019; Hairiah et al., 2020).

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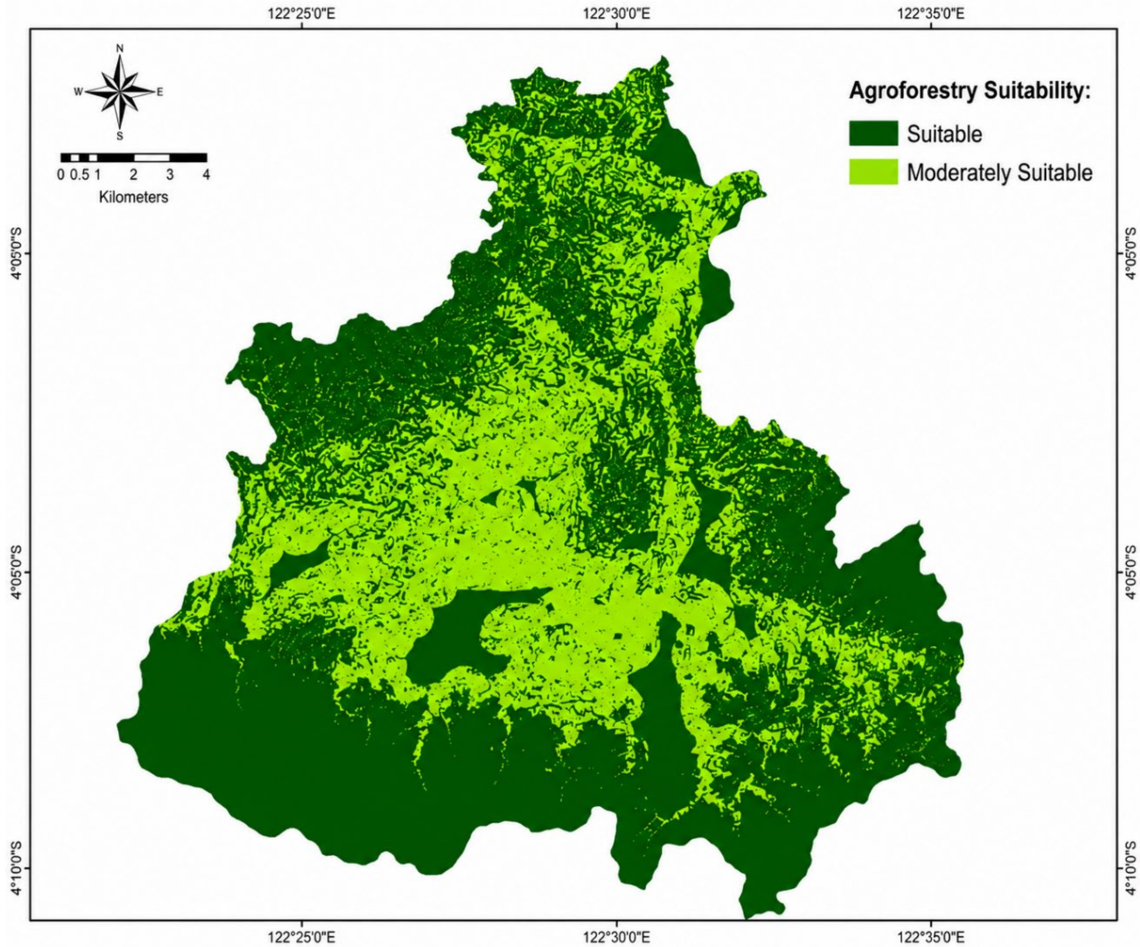

Figure 5. Agroforestry land suitability map of the Wanggu Watershed.

4. Conclusion

This study demonstrates that the Wanggu Watershed is characterized by diverse biophysical properties, particularly in terms of slope, percentage elevation, and distance from the river, which collectively determine agroforestry land suitability. A clear spatial gradient was observed, where lowland areas in the northern part are dominated by gentle slopes (0–15%) and favorable conditions for intensive agroforestry, whereas the central and southern upland areas are characterized by steeper slopes (>15–35% and >35%) that require conservation-oriented or protective land use. Hydrologically, riparian zones (0–500 m) function as ecologically sensitive buffer areas, the 500–1000 m zone represents the most optimal area for agroforestry development, and areas beyond 1000 m require adaptive management because of lower water availability.

The integration of these biophysical characteristics through GIS-based Multi-Criteria Evaluation confirmed that approximately 65–70% of the watershed was classified as “Suitable,” while 30–35% falls into the “Moderate” category. These findings highlight that agroforestry development in the

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Wanggu Watershed must be aligned with land capability to ensure sustainability. By matching agroforestry systems with site-specific biophysical conditions, this study provides a scientifically grounded basis for sustainable land management that supports erosion control, hydrological regulation, and long-term watershed resilience.

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6. AI Writing Statement

The authors used Grammarly solely to assist with English language editing, grammar correction, spelling, punctuation, and improving the clarity and readability of the manuscript. Grammarly was not used to generate scientific content, research data, analyses, interpretations, discussions, figures, tables, references, or conclusions. All scientific content, study design, methodology, data analysis, interpretation of results, and conclusions were developed, verified, and approved entirely by the authors. The authors take full responsibility for the accuracy, originality, and integrity of this manuscript.

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