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Innovative Strategies for Sustainable Agroforestry in Landslide-Affected Sukajaya, Bogor, Indonesia

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ABSTRACT

Landslides in Sukajaya, Bogor, have caused damage to secondary forests, agriculture, plantations, and also to settlements. Sustainable strategies, including vegetation-based restoration technology, can mitigate landslides, preserve ecosystems, and enhance farmers' livelihoods. This study presents a post-landslide sustainability analysis of agroforestry using a multidimensional scaling (MDS) technique. Monte Carlo analysis and the alternating least-squares algorithm were used to assess sustainability status and identify key characteristics of innovative mitigation strategies. The sustainability index for agroforestry in Sukajaya, spanning economic, environmental, social, technological, and institutional dimensions, ranged from 52.53% to 62.51%, indicating that it is overall fairly sustainable. Rap-Pforest leverage analysis identified 12 attributes out of 42 with an influential impact on the sustainability index. Monte Carlo analyses confirmed a stable sustainability status, as variations were insignificant within the 95% confidence interval. Strategies to enhance the sustainability of agroforestry for landslide mitigation in Sukajaya should focus on adopting advanced agricultural technologies, such as precision farming and agroecological approaches. Additionally, efforts should be directed toward empowering farmer groups, implementing soil conservation measures, enhancing government involvement, and improving market accessibility. Therefore, the sustainability of agroforestry should prioritize technological aspects, with a focus on key technological attributes to inform government policies and programs for landslide mitigation.

1. INTRODUCTION

Indonesian islands, including Java, are dominated by forests, agriculture, plantations, open land, shrubs, and settlements. Forests serve as ecosystem protectors and germplasm reserves, supporting social, ecological, economic, and cultural sustainability. They are interconnected ecosystems with biological resources, inhabited by interconnected trees. In addition, forests serve conservation, protection, and production purposes, aiming to achieve balanced and sustainable environmental, social, cultural, and economic benefits. However, due to continuing pressure on land utilization, particularly in Java Island, Indonesia (Figure 1), landslides and flash flood disasters have become more frequent. This is evident from the landslides and flash flood disasters in the Bogor area, West Java, particularly in the Sukajaya area. In this area, the massive landslides occurred on January 1, 2020, affecting almost the entire region. The landslide soil typology mostly consists of debris slides, which evolve into debris flows along the valley, eventually reaching the streams. In some areas, landslides also occur in the form of soil slides. Several factors contribute to these landslides, including steep slopes, conditions of the soil and geology, land use, rainfall, drainage patterns, and human activity. The most influential factors contributing to landslide disasters include steep to very steep slope gradients, highly weathered volcanic rocks underlain by slightly weathered rocks, extreme daily rainfall before and during the landslide occurrence, and human activities.

Mitigating post-landslide areas is essential in planning for safe and sustainable development. Various studies in Indonesia and worldwide underscore the urgency of ensuring land sustainability for landslide mitigation. In Indonesia, for example, the widespread utilization of agricultural land and urbanized areas reduces the land's carrying capacity, rendering the area more susceptible to natural disasters [1]. They propose that intensifying land use and spatial planning can serve as alternative strategies to mitigate potential landslides. Land management significantly impacts ecosystems, necessitating ecosystem-based strategies for landslide mitigation [2]. Agroforestry is a highly effective technique for the mitigation of landslides. By implementing agroforestry systems, which involve the diversification of tree crops and food crops, farmers are able to decrease the risk and vulnerability associated with landslides, while simultaneously enhancing the conditions of household food security [3]. Furthermore, an important factor in preventing erosion is agroforestry and the reactivation of landslides by strategically arranging trees and crops based on morphological units that have been formed as a result of previous landslides [4]. The multistory agroforestry system, characterized by its meticulously stratified canopy trees and significant soil coverage, acts as a preventive measure against landslides by promoting soil organic matter formation and enhancing soil stability [5]. Moreover, agroforestry systems can be utilized to produce a wide array of resources, including food crops, fodder, building materials, and medicinal substances, thus establishing it as a sustainable and advantageous approach to the mitigation of landslides [6].

Agroforestry with multiple strata can help restore and stabilize landslide-affected areas. Species combination constraints are used in agroforestry systems on sloping land in the Central Amazon. Agroforestry also contributes to sustainable land use and reduces the adverse effects of landslides [7]. Traditional agroforestry systems are classic examples of sustainability due to their significant role in preserving biodiversity, enhancing food security, and maintaining environmental health. In the Eastern Himalayas of India, agroforestry is highly diverse. Over 1.2 billion people practice agroforestry on around 1 billion hectares of land, and in India, agroforestry is practiced on approximately 25.32 million hectares [8]. Agroforestry also reduces carbon emissions. Agroforestry with *Ananas comosus* in the Eastern Himalayas, India, and other Asian countries maintains stable carbon stock ecosystems and provides additional community benefits [9].

In Uganda, the significant impact on livelihoods, infrastructure, and the environment over the past 40 years emphasizes the urgent need for reliable and sustainable measures to prevent landslide hazards [10]. Similarly, in Nepal, sustainable land management approaches from an interdisciplinary perspective demonstrate environmental benefits, increase livelihood security, and contribute to disaster risk reduction in mountain agriculture [11]. Economic estimates show that landslides and erosion processes in Armenia harm the Voghjaberd community's ecology, agroecosystem productivity, and socioeconomic conditions. Producing crops in favorable conditions increases yields and profitability [12].

Sustainability is characterized as the capacity of agricultural endeavors to remain productive and meet the growing demands of people while preserving environmental quality and conserving natural resources. Sustainable development oriented towards three interrelated sustainability dimensions: economic, social, and ecological [13]. The equitable use of resources, investment strategy, technology advancement, and institutional modifications to satisfy human needs are all included in sustainable development and aspirations across these three principal dimensions: ecological, social, and economic [14].

Assessing sustainability is crucial for helping policymakers and stakeholders make informed decisions on actions required to ensure the sustainability of agroforestry. One tool for evaluating sustainability is multidimensional scaling (MDS), known as Rapid Appraisal for Fishery (Rapfish), which is a Multi-Criteria Analysis (MCA) method operated using ordination approaches that involve ranking quantitative attributes using multidimensional scaling (MDS) [15]. Initially, this method was used to assess the multidisciplinary sustainability of fisheries. Originally, the method was also used to recommend fisheries policies, but it has since evolved into other sectors, including agriculture (RapLandUse), forestry (RapPforest), community forestry (RapCF), and others. In addition, MDS studies have been conducted on the sustainability of biorefinery production from Palm Oil Mill Effluent (POME) [16].

Although research on sustainability has been conducted separately in forestry, agriculture, and fisheries, its application to assess the sustainability of agroforestry systems for landslide mitigation has not been explored. Despite numerous landslides occurring in Indonesia's secondary forest environments, extensive plantations, and partially inhabited areas, there is a lack of literature on this subject. The status of agroforestry sustainability is crucial for assessing sustainability compromises, determining the dimension of the management restrictions in agroforestry, promoting expanded stakeholder attendees, and facilitating improvements such as planning and strategies to achieve agroforestry goals for landslide mitigation in rural areas.

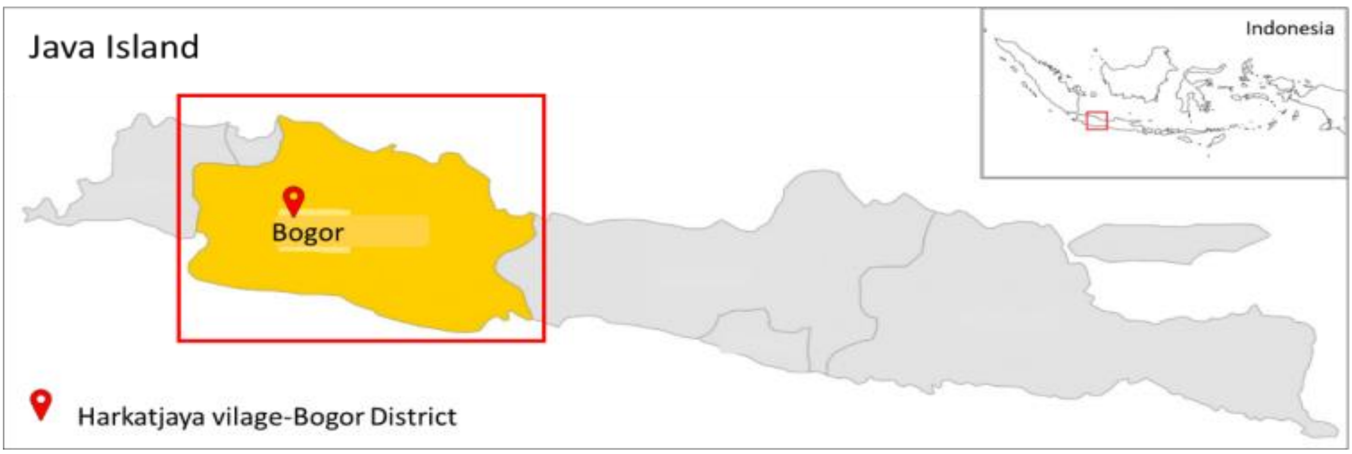

Figure 1. Map of Sukajaya, Bogor, Java, Indonesia

This study aims to assess the sustainability status and key factors influencing agroforestry sustainability in Sukajaya, Bogor, highlighting the importance of adopting sustainable land management practices for innovative landslide risk mitigation. This evaluation will facilitate the identification and implementation of more effective mitigation measures. The research findings provide valuable insights for policymakers in crafting policies for the advancement of agroforestry farming and sustainable landslide mitigation innovations in Sukajaya, Bogor Regency, West Java. Furthermore, the analytical approach and its outcomes offer a viable model for landslide mitigation in regions characterized by secondary forests, agriculture, and plantations elsewhere.

2. METHODS

2.1 Data collection and analysis

The method of obtaining secondary data involves collecting data from agroforestry and forestry guidelines, research journals, and other literature related to income and the sustainability of agroforestry. The research was conducted in Sukajaya, Bogor, Java, Indonesia (Figure 1), and data were collected from relevant institutions supporting this research, such as the Forestry and Plantation Agency of Sukajaya. In addition, original information was acquired by observations, and direct interviews were conducted utilizing questionnaires.

Respondents in this study were purposively selected as individuals who are actively involved, proficient, and knowledgeable about mixed garden farming in agroforestry in Sukajaya. Based on the specified respondent criteria, a total of 20 respondents were determined, including individuals from village government, the Forestry Agency, members of farming groups, and members of the landslide disaster response team.

The sustainability analysis of community forest management was conducted using the multidimensional scaling (MDS) approach employing the Rapid Appraisal for Private-Forestry analysis tool (Rap-Pforest). The selected attributes reflect the level of sustainability in each discipline, adjusted based on the availability of information about the characteristics of the studied resources [17].

Twenty respondents participated in the study, including agroforestry managers, extension workers, researchers, agricultural economic organizations, and corporate actors. The focus group discussion was held to determine the current conditions of business players and support for the management of agroforestry resources at the research site, which will be used to develop dimensions and sustainability attributes. There are five dimensions: environment/ecology, economics, social, technology, and institutional. This study used 42 attributes (Table 1). The dimensions and features are then described using a questionnaire with response options based on a Likert scale. The expert respondents scored the questionnaire's questions as 0, 1, and 2 for bad, average, and good responses.

The ordination technique used the alternating least squares technique, which is based on the Euclidean distance (squared distance) root and is known as the ASCAL algorithm method. This method optimizes the ordination or the squared distance d_{ij} to squared data (origin $=o_{ijk}$) in three dimensions (i, j, k), called S-Stress. Determination techniques of ordination were based on Euclidian distance in n-space, and written as follows [18]:

Table 1. Dimensions and attributes of the Rap-Pforest

Dimension	Attributes
Environment	1. Knowledge and practice of soil conservation
	2. Vegetation diversity
	3. Arrangement of vegetation planting
	4. Use of organic resources for fertilizers in crops
	5. High land productivity
	6. Soil as a water conservation measure
	7. Condition of water sources
	8. Suitability of land for agroforestry farming
	9. Use of pesticides
	10. Soil erosion intensity
	11. Illegal felling of trees
Social	1. Farmer education level
	2. Community perception of agroforestry activities
	3. Perception of the benefits of soil conservation
	4. Farmers' knowledge of soil and water conservation
	5. Availability of agroforestry technology packages
	6. Farmer group performance
	7. Participation in farmer groups
	8. How often education on agroforestry is given
	9. Farmer's proficiency in disease and pest management
	10. Governmental organizations' involvement in agroforestry
	11. The private sector's impact on agroforestry cultivation
	12. Ownership of the land
Economy	1. Products produced from agroforestry systems
	2. Product marketing patterns
	3. Percentage contribution of income from agroforestry to total farmer income
	4. The poverty level of individual farmers is compared with the poverty level at the district-wide
	5. Family number per head of household
	6. Sources of capital for agroforestry farming
	7. Simple access to the marketplace
	8. Sales method for harvest
	9. Consistency in crop harvesting pricing
	10. Agriculture's economic viability
Technology	1. How to prepare the land
	2. Selection of vegetation type
	3. How to care for plants
	4. How to harvest
	5. Post-harvest process
Institutional	1. Farmer group activities
	2. Knowledge and implementation of conventions
	3. Making decisions in farmer group
	4. Heading up farmer associations

$$d = \sqrt{\left(|x_1 - x_2|^2 + |y_1 - y_2|^2 + |z_1 - z_2|^2 + \cdots\right)} \quad (1)$$

Configurations of objects or points in MDS were then approximated by regressing Euclidian distance (d_{ij}) from point i to point j with point of origin (o_{ij}), as the following equation shows:

$$d_{ij} = \alpha + \beta\delta\beta_{ij} + \varepsilon \quad (2)$$

The regression technique used for the equation above was the ALSCAL algorithm. The ALSCAL method optimizes squared distance (squared distance $=d_{ijk}$) against squared data (point of origin $=o_{ijk}$), which in three dimensions (i, j, k) is written in a formula called S-Stress as follows [18]:

$$s = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i \sum_j \left(d_{ijk}^2 - o_{ijk}^2\right)^2}{\sum_i \sum_j o_{ijk}^4}\right]} \quad (3)$$

where, the squared distance is Euclidian distance assigned a value:

$$d_{ijk} = \sum_{a=1}^{r} w_{ka}\left(x_{ia} - x_{ja}\right)^2 \quad (4)$$

2.2 Agroforestry sustainability analysis

The levels of sustainability performance are divided into 4 levels, resulting in intervals of 0%, 25%, 50%, 75%, and 100%. The assessment categories are as follows: 0.00-25, poor category and unsustainable; 25.01-50, less category, less sustainable; 50.01-75, adequate category, fairly sustainable; 75.01-100.00, good category, sustainable [19], as presented in Table 2. The levels of sustainability performance are divided into 4 levels, resulting in intervals of 0%, 25%, 50%, 75%, and 100%. The assessment categories are as follows: 0.00-25, poor category and unsustainable; 25.01-50, less category, less sustainable; 50.01-75, quiet category, fairly sustainable; 75.01-100.00, good category, sustainable [19], as presented in Table 2.

Table 2. Index category and sustainability status for every dimension

No.	Index Value	Category	Status
1.	0-25	Poor	Unsustainable
2.	25.01-50	Less	Less sustainable
3.	50.01-75	Quite	Fairly sustainable
4.	75.01-100	Good	Very sustainable

2.3 Leverage factor analysis

The values of the leverage factors fall within the range of 2%-8%, indicating a moderate to good impact. If<2%, the factor is considered not influential, while if>8%, the factor is considered dominant (sustainable) according to study [17]. Table 3 presents the factors that have an impact and are dominant.

Table 3. Parameter values of the leverage factor

No.	Factor Value	Category	Description
1	<2.0%	Neutral	Not Influential
2	2-8%	Influential	Moderate to Good Impact
3	>8.0%	Significant	Dominant

2.4 Validity analysis using Monte Carlo test

Monte Carlo analysis aims to assess the possibility of errors in determining indicator score values, and the impact of variations in level scores due to differences in questionnaire completion by respondents. The MDS calculation process is repeated at least 25 times for a stable calculation. If the difference between the MDS value and the Monte Carlo value is small (<5%), the MDS analysis for determining sustainability is sufficiently accurate with a 95% confidence level.

3. RESULT AND DISCUSSION

3.1 Sustainability analysis

The results of the MDS analysis for the performance of agroforestry are 55.37% on a sustainability scale of 0-100, with R^2(SQR)>0.80, indicating that it is quite a category and fairly sustainable (Table 4). This value results from evaluating 42 attributes covered over four dimensions: environmental, social, economic, technological, and institutional. The environmental dimension has an index value of 53.77%, the social dimension has 53.49%, the economic dimension has 52.53%, the technical dimension has 62.51%, and the institutional dimension has 54.57%. The five dimensions have an average index value of 55.37% and R^2(SQR)>0.80. The results of the sustainability analysis can be seen in Figure 2 and Table 4. The index values representation is depicted in a flyover diagram as in Figure 2.

Table 4. The sustainability index results for all dimensions

Dimension	Index (%)	Stress	R^2(SQR)	Status
Environmental	53.77	0.146	0.947	Fairly sustainable
Social	53.49	0.141	0.951	Fairly sustainable
Economical	52.53	0.151	0.945	Fairly sustainable
Technological	62.51	0.159	0.956	Fairly sustainable
Institutional	54.57	0.177	0.923	Fairly sustainable
Average	**55.37**			**Fairly sustainable**

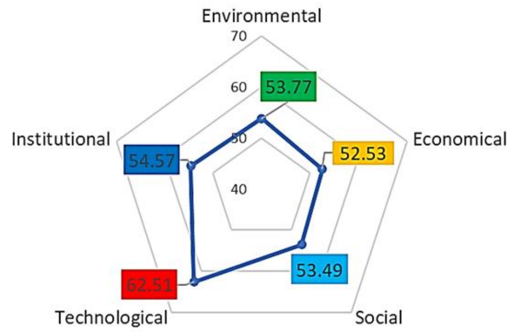

Figure 2. The sustainability index of environmental, economic, social, technological, and institutional dimensions

3.2 Leverage analysis

3.2.1 Environmental dimension

The environmental dimension's sustainability index value is 53.77%, indicating fairly sustainable agroforestry activities in Sukajaya. The leverage analysis results demonstrate that it is necessary to improve the leverage attribute of soil a water conservation measure with value with a value of 2.93 (Figure 3). Soil as a water conservation measure is the facet of sustainability's environmental aspect that is most influential in agroforestry in the post-landslide area of Sukajaya. The agroforestry system in the post-landslide environments is advantageous from an economic standpoint as well as being appropriate for conserving water and improving soil quality. Therefore, the soil as a water conservation measure is crucial to be managed and maintained for its function.

The other leverage attribute that needs to be considered and improved is the knowledge and practice of soil conservation which is related to the soil and water measure. If the knowledge and practice of soil conservation attributes are high, the community will engage more in soil conservation, thus increasing the value of soil as water conservation [19]. High knowledge and practice of soil conservation also affect the community's awareness of carrying out vegetation restoration in post-landslide areas. Mitigating landslides requires restoring the vegetation, particularly in regions where agroforestry systems have been implemented. Soil characteristics are greatly impacted by the restoration of vegetation. Saturated hydraulic conductivity rises noticeably while some soil densities drastically drop. Two important physical properties of soil are cohesiveness and moisture content, which both influence saturated hydraulic conductivity [20]. Apart from impacting the characteristics of soil, vegetation cover resulting from restoration, including forests with grass, diminishes the capacity of runoff on hillslopes via canopy interception and lengthens the time it takes for infiltration [21]. The influence of soil properties and slope runoff capacity from this vegetation restoration will positively impact slope stability.

3.2.2 Social dimension

Values for the social dimension of the sustainability index is 53.49% (Table 4) showing that this dimension is fairly sustainable in the activities of agroforestry. The social dimension's leverage analysis results show that the government's involvement in agroforestry cultivation has a value of 2.07 (Figure 4), is the most important attribute in the improvement of agroforestry activities to support the landslide mitigation strategies. All others attributes with the value range from 0.01 to 0.91 (Figure 4) do not show the significant effects for the improvement of agroforestry for the mitigation effort. However, landownership status is an essential attribute in improving the sustainability status. The government should include the settlement of the landownership status as an important program. The agroforestry ownership scheme is the government-granted village-level community's right to forest management but does not include ownership rights, limiting further transfer of rights to other parties, such as companies [22].

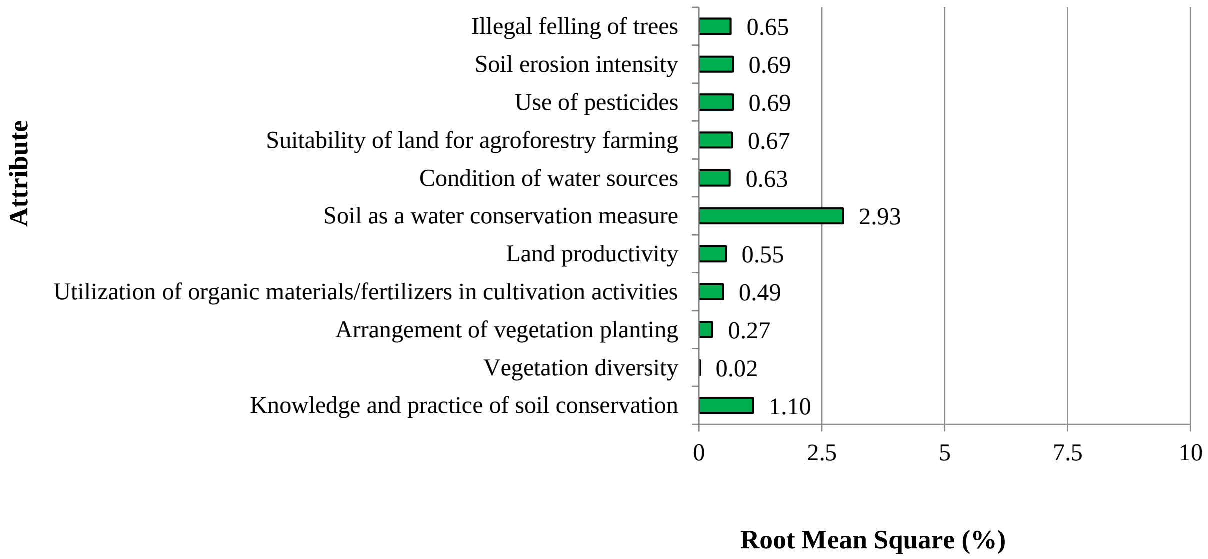

Figure 3. Leverage of environmental attributes

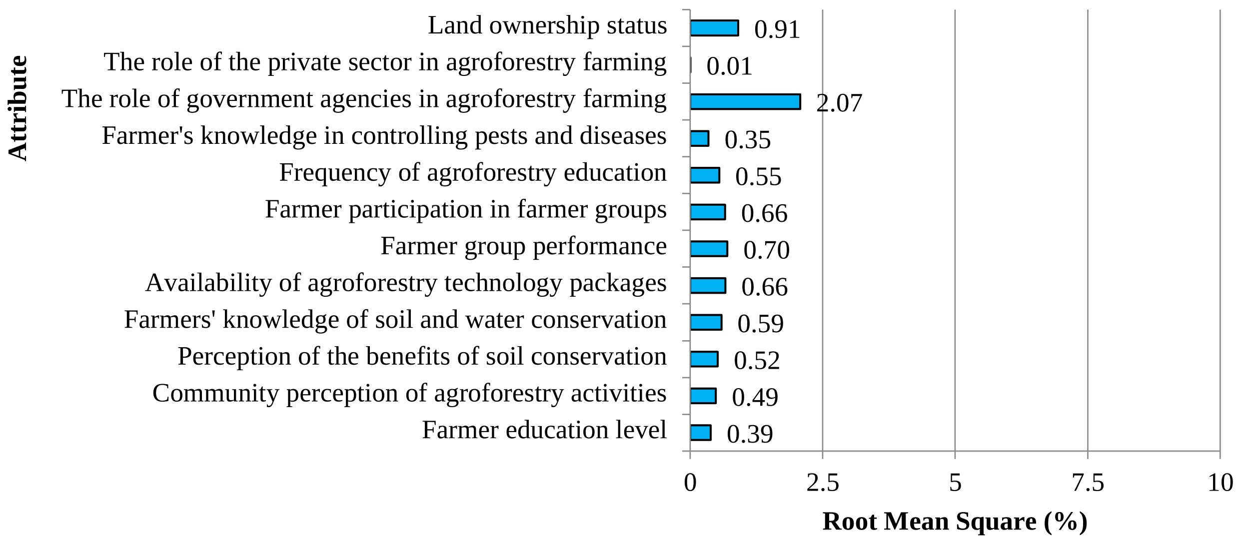

Figure 4. Leverage of social attributes

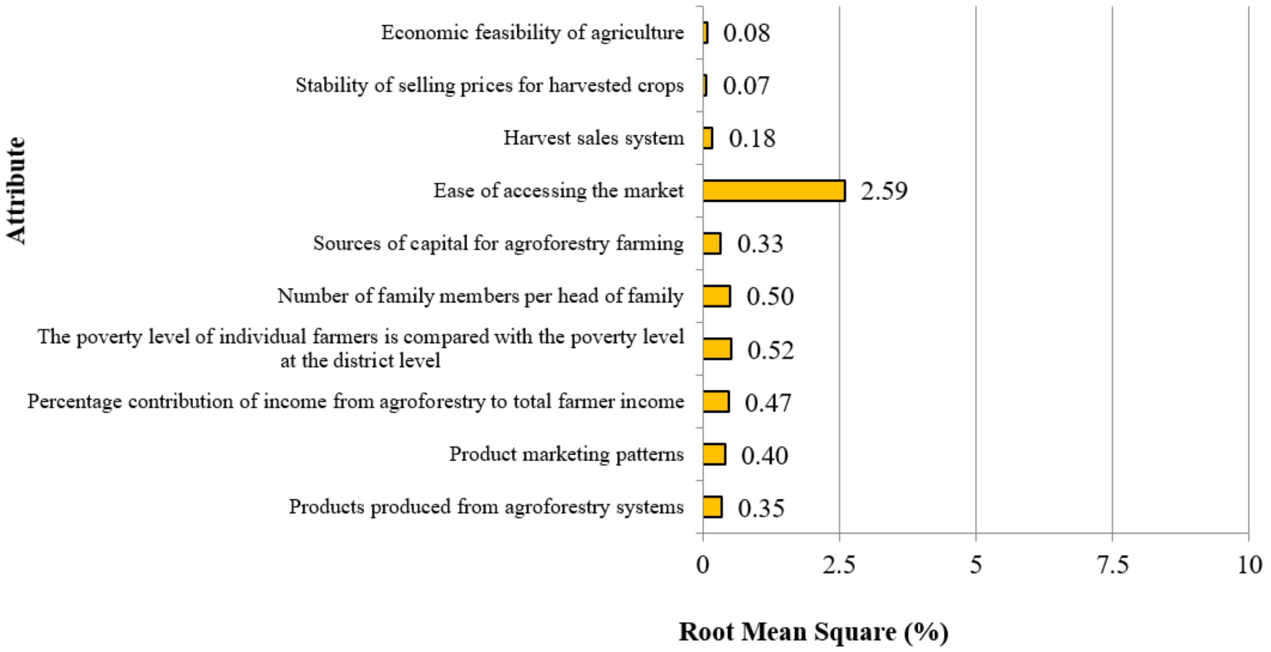

Figure 5. Leverage of economic attributes

The role of community institutions for the sustainability of agroforestry is also crucial. Interview results revealed that the control of plant pests and diseases is already done using modern methods, with only a small portion still using conventional methods. This is due to socialization by the local forestry and environmental agency [23]. Agroforestry is managed by community institutions under the supervision of the village government [24].

3.2.3 Economical dimension

The economics dimension's sustainability index value is 52.53% showing the fairly sustainable agroforestry practices in Sukajaya, Bogor (Table 4). The leverage analysis results demonstrate that the ease of accessing the market with a value of 2.59 is the characteristic most influential in affecting agroforestry's sustainability in Sukajaya. (Figure 5). This evidence shows that careful management and preservation are required for Sukajaya.

In addition to helping agricultural families enter high-value markets, cooperatives and government regulations play a critical role in assisting and directing them as they create other market tactics like processing, quality seals, price differential, and others [25]. Another attribute that influences the sustainability of agroforestry in Sukajaya is the number of family members per head family attribute. The poorest households obtained higher incomes if they collected unsustainable fuelwood [26]. The poorer the farmers, the greater the income, unsustainable agroforestry, long-term income disruption, and vice versa for higher-income households. Poor communities tend to increase environmental degradation to generate more revenue, resulting in long-term income loss. Based on these findings in Sukajaya, it is important for stakeholders to implement more comprehensive policies concerning tree felling, particularly in landslide-prone areas. This is crucial to ensure the sustainability of agroforestry practices and to mitigate environmental degradation. The attributes that leverage the economic feasibility of agriculture and the stability of selling prices for harvested crops both show minor sensitivity in the improvement of the sustainability of agroforestry in Sukajaya. The stability of sales and prices of harvested crops can influence profitability. Weaknesses in profitability can lead to the abandonment of sustainable agroforestry management. In this regard, concentrated agricultural extension research and public policy efforts are needed to support and reward small and medium-scale farmers [27].

3.2.4 Technological dimension

The technological dimension's sustainability index value is 62.51% (Table 4), showing that this dimension is fairly sustainable in agroforestry activities. The leverage analysis findings for the technical dimension show that all attributes, ranging from 4.30 to 7.94 (Figure 6), significantly affect the improvement of agroforestry activities to support the landslide mitigation strategies.

In the technology dimension, the five attributes, namely how to care for plants, how to harvest, how to prepare the land, the post-harvest process, and the selection of vegetation type, are influential to the sustainability of agroforestry in Sukajaya. How to care for plants becomes a priority for the community in Sukajaya. Caring for plants involves nurturing and maintaining plant health through practices like irrigation, fertilization, pruning, pest and disease management, and overall plant maintenance. Land preparation methods form the basis for successful agroforestry establishment and productivity, including soil cultivation, vegetation clearance, leveling, and soil amendment. The selection of appropriate vegetation types is critical for designing effective agroforestry systems, considering ecological compatibility, market demand, soil conditions, climate resilience, and desired ecosystem services. The harvesting process entails careful and timely extraction of crops or products to maximize yields, preserve quality, and minimize damage to plants and ecosystems. Post-harvest activities, including handling, processing, storage, and transportation, ensure product quality, reduce losses, and add value to agricultural commodities, enhancing the overall sustainability of agroforestry.

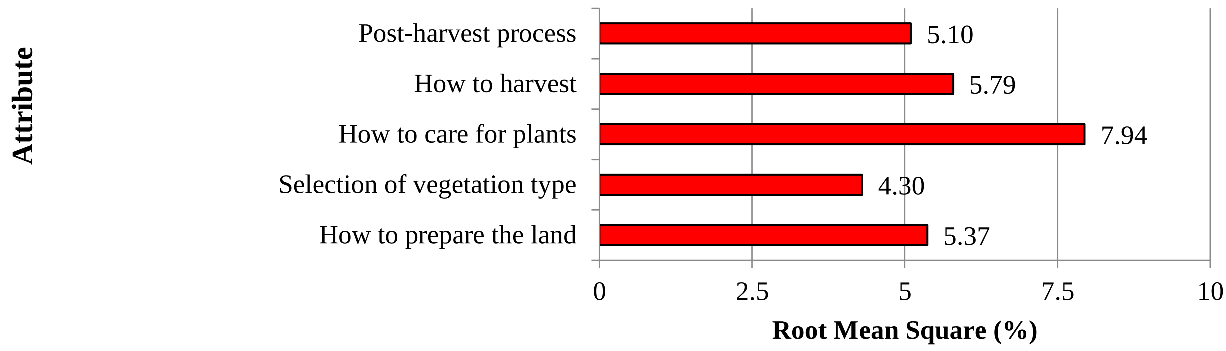

Figure 6. Leverage of technological attributes

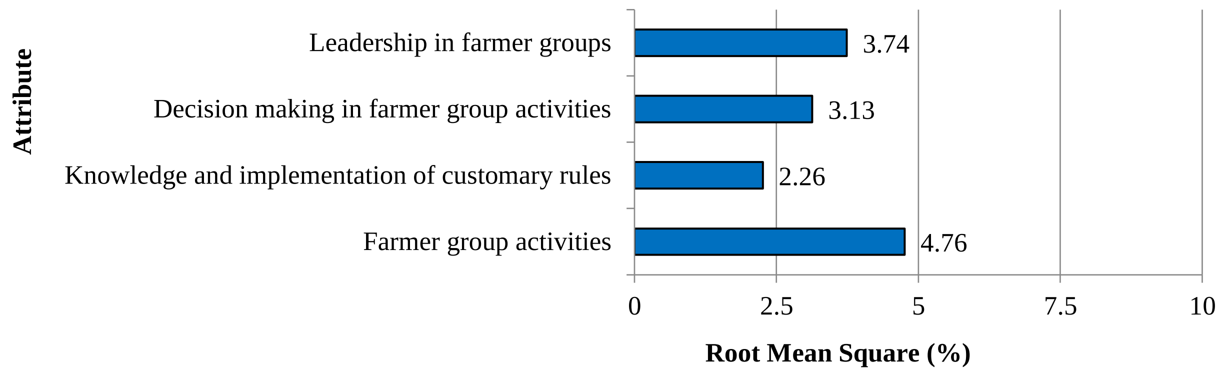

Figure 7. Leverage of institutional attributes

The application of advanced agricultural technologies like precision farming and agroecological approaches can improve landslide mitigation in Sukajaya. Precision farming leverages cutting-edge technologies such as GPS (Global Positioning System), sensors, drones, and analytics to revolutionize traditional farming practices. Farmers, with the support of the government, can apply advanced technologies like GPS, sensors and drones. The GPS and application on the Android cellphone allow farmers to accurately map their fields and monitor soil conditions and erosion patterns. Sensors embedded in the soil or attached to farming equipment gather real-time data on environmental factors like soil moisture, temperature, nutrient levels, and crop health. Drones with high-resolution cameras and sensors provide aerial surveillance, detailed imagery, and data on crop health, pest infestations, and soil conditions. These aerial surveys provide valuable insights into spatial variability, enabling targeted interventions and optimized resource management.

Precision farming is beneficial for landslide mitigation because it allows farmers to implement soil conservation measures and apply water more efficiently, reducing soil erosion and runoff. Agroecological methods focus on enhancing ecological resilience by mimicking natural ecosystems. They include planting diverse vegetation, such as trees, shrubs, and groundcover plants, to reduce erosion and improve soil structure. Combining these technologies can effectively address landslide risks and promote sustainable agroforestry practices in Sukajaya.

Sukajaya community cultivates various types and focuses on maintenance, obtaining harvest results that can be a source of livelihood. The main plant grown is the Sengon tree because it proliferates, making it considered capable of preventing landslides. However, many Sengon trees could not withstand landslides during the landslide in early 2020. Sengon is an economically valuable tree, and its wood has market value, making the logging of Sengon trees potentially significant and impacting landslide vulnerability [28]. Based on these facts, the sustainability of Sengon trees in Sukajaya should be maintained because of their function in landslide mitigation. However, considering the economic value for the people in Sukajaya, intercropping with other beneficial plants that can provide added value for the farmers is suggested. The study results indicate the need to study plants suitable for the land conditions in Sukajaya further. It can be suggested to plant rubber-based agroforestry, as rubber plantations have proven profitable in agroforestry biodiversity without reducing land productivity [29]. In agroforestry management, Landscape-Life Scape Integration needs to be studied [30]. Intercropping in non-food plant-based agroforestry must be done with food crops that help the community's economy [31].

3.2.5 Institutional dimension

The institutional dimension's sustainability index result of 54.7% indicated that the agroforestry operations in Sukajaya were fairly sustainable (Table 4). The leverage analysis showed that all attributes influence the sustainability of agroforestry in Sukajaya, with values ranging from 2.26 to 4.76 (Table 4). Those attributes ranging from more to less influence are farmer group activities, leadership in farmers groups, decision-making in farmer group activities, and knowledge and implementation of customary rules (Figure 7). To bolster the sustainability of agroforestry, empowering farmer groups is essential. This entails fostering stronger collaboration, leadership development, and knowledgesharing platforms among farmers. Additionally, enhancing understanding and adherence to customary rules pertinent to agroforestry can lead to improved farming practices and community cohesion.

Every attribute in the institutional dimension has the potential to affect sustainability because the communities or farmers work together within established formal institutions. The development of agroforestry in a region results from innovation and adaptation to the environment, involving the intentional arrangement of elements of the natural system to facilitate the utilization of its components [32]. The use of diverse resources strengthens the survival of the population and forms agroecosystems as landscape units based on integrated land management. In this case study, agroforestry adaptation results from the historical interaction of the population with its environment and the utilization of resources. However, this occurs in conjunction with the development of changes in social production relations related to the production system. The community significantly influences capacity building in forest management [33].

3.3 Monte Carlo analysis

Monte Carlo analysis was used to estimate the influence of random errors using the method of scatter plotting, with 25 repeats at a 95% confidence level in each dimension. The analysis of Monte Carlo demonstrated that the sustainability index's value differed little from the MDS study results, showing that the analytical and data analysis methods have extremely few faults.

The values remained relatively consistent across Monte Carlo simulations for the environmental dimension, with an average result of 52.78%, compared to the ordination index for the environmental dimension at 53.49%. The Monte Carlo study findings indicate that the agroforestry sustainability index value in the Sukajaya district showed minimal variance within a 95% confidence interval. Table 5 provides a comparison between the ordination index and Monte Carlo values, highlighting the slight disparity between the two analyses. This minor inconsistency between the ordination and Monte Carlo analyses suggests a minor procedural error in the analysis technique and a slight discrepancy in attribute score assignment. Minor fluctuations in MDS and Monte Carlo sustainability index values could prevent data entry mistakes and loss, maintain stability in the repeated MDS analysis process, and result in relatively small errors in attribute scoring, which aligns with the findings of slight variations [34]. The researchers can therefore conclude that there is great trust in the research analysis. The RAP-Pforest method showed that a number of traits produced test findings that were sufficient to be used as a quick and quantitative way to evaluate the sustainability of Sukajaya's basic agroforestry system.

Table 5. Differences in ordination values and Monte Carlo values

Dimension	Ordination Index (%)	Monte Carlo Index (%)	Difference (%)
Environment	53.77	52.78	0.71
Social	53.49	55.09	2.56
Economic	52.53	52.83	0.94
Technology	62.51	61.56	0.95
Institutional	54.57	53.65	0.92

It is expected that attributes with values more than 2% will have an impact on agroforestry sustainability. The expected result of this research is an attribution of less than 1%, implying that there is no impact on agricultural sustainability. As a result, it is hoped that the attributes mentioned above will have a significant impact on sustainability. The only sensitive attribute that meets sustainability requirements is plant care, which is found in the technological dimension. Sensitive attributes must be improved or modified. Based on the results of the survey, the high dimension must be maintained for sustainability, while the low dimension must be improved to support the sustainability of the agroforestry system. A study on the Sustainability Status Index of Agroforestry in Magersaren, East Java, Indonesia has revealed that sensitive attributes are closely related to the sustainability of management and technology dimensions, wherein the management of a simple agroforestry system requires good planning using adequate technology. Therefore, it is necessary to improve the quality of human resources, namely, the awareness of the importance of using technology and good planning to ensure the sustainability of the simple Magersaren agroforestry system, especially in supporting its function as an educational forest area and the livelihoods of Magersaren people in UB Forest [34].

3.4 Improving the sustainability status of agroforestry in Sukajaya

The Sukajaya, Bogor community uses agroforestry technologies to manage a large percentage of their land. Agroforestry systems are essentially mixed garden systems that include timber, plantations, fruit, and agricultural crops. Community forest agroforestry combines forestry, agriculture, and livestock cultivation on the same land for economic, ecological, and social benefits [35]. Agroforestry near communities can reduce deforestation and address food crises [36]. It takes a comprehensive approach to land use sustainability, providing ecosystem services and benefits for small-scale farmers [37, 38]. Agroforestry integrates woody vegetation with crops and animals, capitalizing on ecological and economic interactions [39]. It harmonizes agriculture, forestry, landscapes, and livelihoods, contributing to sustainable development goals [40]. Agroforestry mitigates climate change, protects biodiversity, enhances soil health, and improves air and water quality [41]. It provides benefits like fuelwood, timber, and additional income for farmers, while reducing soil erosion and stabilizing crop yields [42]. Agroforestry supports forest biodiversity connectivity, but native forest tree species incorporation is crucial for its effectiveness [43].

Apart from having a positive impact on landslide disaster mitigation, agroforestry also has significant environmental impacts. Agroforestry contributes to soil health, preventing erosion and breaking down harmful chemicals. Agroforestry systems promote biodiversity, carbon sequestration, and climate change mitigation, with tree cover storing more than 75% of global carbon sources [44]. Additionally, agroforestry improves ecosystem services by improving soil structure, increasing carbon sequestration, and increasing water retention, thereby supporting soil and ecosystem health [45]. Incorporating native tree species will diversify agricultural income, increase land use efficiency, and improve soil health through nutrient pumping and decomposition processes. Overall, agroforestry is emerging as a sustainable solution that increases agricultural productivity and significantly contributes to environmental conservation and sustainability.

Despite its numerous advantages, agroforestry may have adverse effects on the environment. One particular concern is the possible rise in pressure on natural forests or degradation of forests due to traditional practices that do not align with agroforestry principles, reducing natural resource security [46]. Furthermore, integrating agroforestry systems could lead to the loss of habitats and environmental harm, ultimately decreasing biodiversity. These negative consequences underscore the importance of carefully implementing agroforestry practices and considering local conditions and species characteristics to minimize unfavorable environmental outcomes.

The leverage analysis of agroforestry systems in Sukajaya shows that just 12 of the 42 attributes are considered to be influential, with leverage factors ranging from 2-8% (Table 3). The results of this research showed that influential attributes are 1 (one) attribute in the environmental dimension, 1 (one) attribute in the social dimension, 1 (one) attribute in the economic dimension, 5 (five) attributes in the technological dimension, and 4 (four) attributes in the institutional dimension (Figures 3-7). Prioritizing these influential attributes will advance the sustainability level of agroforestry systems.

Concerning the primary findings, specifically the significant factors contributing to the sustainability of agroforestry, recommended approaches include preserving natural conditions, especially by maintaining tree coverage; raising education standards to promote higher levels of technological literacy; enhancing market accessibility and alleviating poverty are important goals; enhance management and technology by employing better seeds, caring for plants, and harvesting; preparing the land better and enhancing the value of agroforestry goods; enhancement of farmer group activities, leadership, and decision-making, as well as knowledge and implementation of conventions.

Local mycorrhiza can accelerate planting techniques for woody plants [47] and the selection of woody plant species is crucial for biotechnological slope stabilization in landslide-prone areas [48]. Based on field observations, agroforestry management is generally limited by several factors, including market access, financial resource constraints, technological inputs, and product variety. Previous research on this study shows that seasonal patterns, land conditions, product diversification, and customary institutions are essential in agroforestry development [49]. With strong collaboration between the government, private sector, and the agricultural sector, the findings, obstacles, and challenges mentioned above in agroforestry development can be overcome. The government can assist in ensuring market availability and providing the best technical guidance to farmers. Capital-intensive agroforestry efforts can involve the private sector as investors or partners. As the main actors, farming communities need to stay motivated and enthusiastic in their work.

Adaptation in agroforestry management depends on technical capacity or traditional knowledge and social, economic, political, and cultural factors that hinder such adaptation. The results of this study show that technology and institutional dimensions are the most influential factors in agroforestry sustainability. Meanwhile, not all environmental, social, and economic attributes are influential. However, to comprehensively understand agroforestry dynamics, this study emphasizes the importance of analyzing agroecosystem adaptation considering environmental, economic, and social aspects while maintaining or enhancing technological and institutional factors.

Technical capacity is a farmer's ability to perceive, comprehend, understand, and apply diverse technical principles, knowledge, and plant cultivation abilities. Farmers' managerial capacity refers to their ability to plan, manage, implement, and evaluate agroforestry farming practices. Farmers must have managerial abilities to make decisions at each level of agroforestry farming, from providing business finance to technical crop production, packaging, and product marketing to manage their resources. Farmers' social capacity is defined as their ability to interact with parties other than themselves, such as fellow farmers, the government, private parties, traders, and others. Farmers' social talents serve to encourage cooperation with other parties in overcoming various challenges encountered throughout the agroforestry agricultural process.

Strategies for strengthening farmers' capacity for agroforestry development can be implemented by optimizing farmer education, training, and counseling programs in a systematic, planned, targeted, and long-term manner. The education and training program can be optimized in a variety of methods, including (1) increasing the performance of extension by expanding the capacity of extension workers and the availability of innovation in training methods and materials, (2) optimizing coordination and intensive communication among various stakeholders related to the program training, such as between extension agents and government and private research and development agencies in updating agroforestry technology innovations, (3) providing policy assistance in the form of a legal framework, programs, and finances for the implementation of an effective, efficient, and sustainable education and training program.

4. CONCLUSIONS

The Sukajaya region has experienced landslide disasters that damage secondary forests, plantations, and residential structures, demanding the deployment of effective and long-term mitigation techniques. Our post-landslide sustainability analysis, which included Rap-Pforest analysis and Monte Carlo validity testing, highlighted critical components of agroforestry sustainability on the economic, environmental, social, technological, and institutional dimensions. The sustainability index research revealed that Sukajaya's agroforestry is fairly sustainable in all dimensions, with Monte Carlo results providing high confidence in our conclusions. Twelve of the 42 attributes significantly impacting agroforestry sustainability must be targeted to improve the system's sustainability. Improving influential attributes in all five categories is critical. The action involves combining soil conservation measures, including governmental entities in agroforestry, enabling market access, integrating farming technology, and strengthening farmer group activities and decision-making.

Our findings highlight the significance of conducting a thorough analysis of agroecosystem sustainability, focusing on environmental, economic, social, technological, and institutional issues. The use of MDS as a method for assessing agroforestry sustainability and identifying essential attributes required for landslide hazard mitigation is highlighted. Farmers and stakeholders need access to knowledge and statistics to support long-term landslide mitigation methods in agroforestry management. Furthermore, government support and technological considerations are critical for advancing agroforestry systems in Sukajaya and Indonesia, particularly in implementing innovative mitigation measures to improve ecosystem resilience. Future research should focus on refining and implementing these solutions and investigating new paths for improving agroforestry sustainability and disaster resilience in rural areas.

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