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Assessment of Soil and Water Conservation Potential Using Vetiver Crops (*Chrysopogon zizanioides*) as a Nature-Based Solution for Watershed Restoration

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ABSTRACT

Watersheds play an important role in the hydrological cycle to ensure water availability and support food security. Currently, many watersheds are experiencing degradation due to excessive agricultural practices without the implementation of soil and water conservation measures. This study aims to assess the potential of Vetiver crops (Chrysopogon zizanioides L.) for soil and water conservation as a nature-based solution for watershed protection.n. This research use Geographic Information System (ArcGIS) tools to analyze land suitability for Vetiver cultivation. A multi-criteria evaluation approach was applied using a scoring system based on key environmental indicators including rainfall, temperature, slope gradient, land use type, soil type, and organic matter content. The results indicate that most of the study area was classified as moderately suitable (61.98%) and marginally suitable (38.00%) for vetiver plants, with only 0.01% falling into the highly suitable and not suitable categories, respectively. The integration of spatial analysis and environmental indicators allowed for the identification of priority areas where Vetiver could be effectively implemented to enhance watershed resilience, mitigate erosion, and support sustainable land management. The finding of this study provides a reference for vegetation method development using crops with economic value which is suitable for tropical areas.

1. INTRODUCTION

Water is essential for life including agriculture for food production. Its availability must be sustained by preserving the authenticity of the hydrological cycle through soil and water conservation activities. Watersheds play a vital role in the hydrological cycle by ensuring water availability, supporting food security, and maintaining ecosystem balance (Abdissa & Chuko, 2024). However, many watersheds in Indonesia are currently experiencing significant degradation due to unsustainable human activities such as land conversion, deforestation, and intensive agricultural practices without the application of soil and water conservation measures. This degradation is characterized by increased soil erosion rates, river sedimentation, and a decline in both the quality and quantity of water resources (Rampu *et al*., 2023; Setyowati, 2021). Therefore, mitigation strategies are urgently needed to restore the ecological functions of watersheds in a sustainable manner.

As a tropical country, Indonesia has significant water resource potential, as indicated by its high annual rainfall. However, water resources need to be managed properly, as their availability varies across space and time, while water demand tends to remain consistent throughout the year. In Indonesia, water resource management encounters various challenges, including the limited availability of water for agriculture due to disruptions in the hydrological cycle caused by an imbalance between water utilization and conservation effort. Excessive water uses for various purposes, including in the agricultural sector, has caused an imbalance in water availability-resulting in severe shortages during the dry season and excessive supply during the rainy season, often leading to flooding and related losses.

At the watershed scale, agricultural activities without implementing conservation principles have been reported to trigger land and watershed degradation in the form of soil erosion and surface runoff. This condition also triggers other problems, such as landslides, reduced soil fertility, downstream sedimentation, flooding, and decreased river water quality. Soil and water conservation is essential to mitigate the negative impacts of various human activities, particularly agriculture, and to ensure the sustainability of the watershed's ecological functions. Soil and water conservation is a form of watershed management aimed at maintaining the sustainability of its functions. The main principle of soil conservation is basically to minimize surface runoff, which triggers soil erosion, nutrient leaching, sedimentation, and downstream flooding. Soil and water conservation at the watershed scale has been proven effective in addressing these various problems.

In watersheds that have experienced severe degradation, immediate short-term actions as well as medium- and long-term measures are required. Short-term watershed damage control can be carried out using mechanical methods, specifically through the construction of conservation structures. Although this method can effectively reduce the impact of watershed damage in a relatively short period, it involves high implementation costs. Mechanical methods using conservation structures have been reported to be insufficient in fully addressing critical watershed problems. Therefore, a combination with medium- and long-term watershed management through vegetative methods is needed. The existence of vegetation or cover crops has been proven to significantly control surface runoff and soil erosion, enhance water infiltration, and recharge aquifers, thereby reducing flooding and increasing surface water availability during the dry season. The use of vegetative methods is essentially aimed at restoring the natural function of vegetation in the hydrological cycle. This approach aligns with the principles of nature-based solutions.

A promising strategy involves implementing nature-based solutions (NbS), such as planting vetiver grass (*Chrysopogon zizanioides* L.), which is well known for its strong ability to control erosion and improve soil stability (Truong & Loch, 2004). Vetiver possesses a deep, dense root system that stabilizes soil on steep slopes and naturally enhances soil structure. Conducting a land suitability analysis is essential to determine the most appropriate sites for effective vetiver planting. Geographic Information Systems (GIS) tools such as ArcGIS or ArcMap offer a possibility to integrate various environmental parameters such as rainfall, temperature, land slope, soil type, and organic matter content to generate accurate land suitability maps that inform data-driven conservation planning (Malczewski, 2004; Pramono *et al*., 2021). This study highlights the potential of vetiver for restoring vegetation cover in tropical basin areas where communities are highly dependent on land for agriculture.

2. MATERIALS AND METHODS

2.1. Study Site

The study was carried out in a sub-basin of the Serayu River, which is administratively situated in Wonosobo Regency (covers the areas of Kejajar, Garung, Mojotengah, Watumalang, Leksono, Wonosobo, and Kertek Districts), Central Java Province, Indonesia (Figure 1). Geographically, it is located between 7°11'–7°25' S and 109°53'–109°59' E, at an elevation ranging from 733 to 2,200 meters above sea level and covers an area of 136.65 km² including water body.

The study site was chosen due to the importance of this sub-basin as a water catchment area for agriculture. The basin has a reservoir downstream that serves as water storage for irrigation, a hydroelectric power plant, and a source of water supply around the area. Currently, the Serayu watershed including the study site is reported to be experiencing several land degradation issues, such as increased soil erosion and runoff. These problems are primarily caused by agricultural activities that do not apply conservation principles. Implementing soil and water conservation is crucial for controlling land degradation, which can lead to damage within the basin. Figure 2 illustrates agricultural activities at the study site.

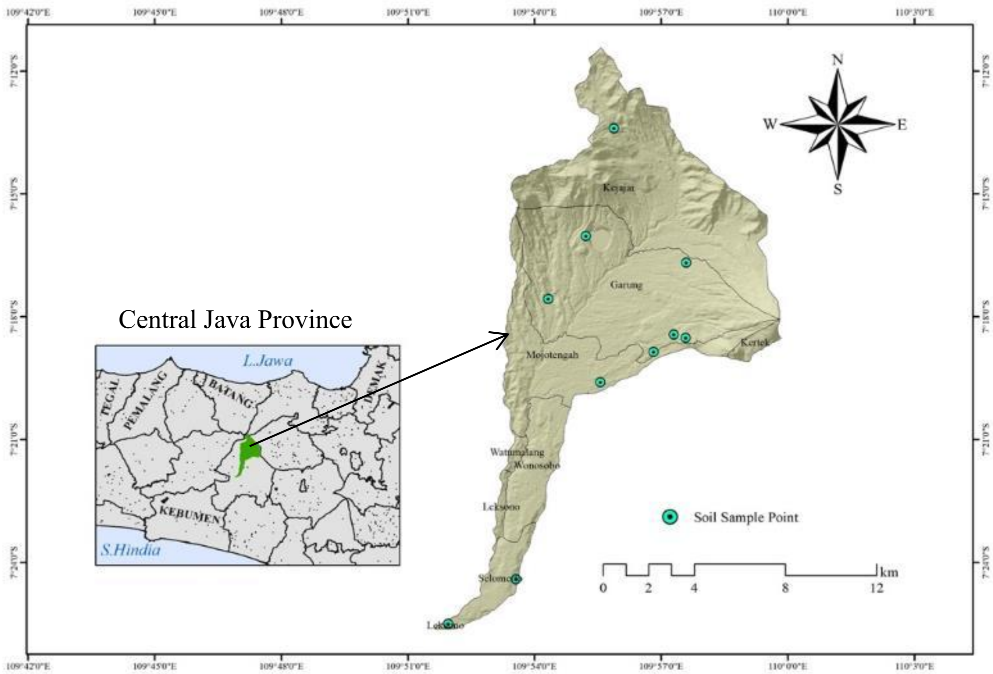

Figure 1. Location of the study site

Figure 2. Farmland in the study site

2.2. Data Analysis

Referring to the Research and Development Agency of the Ministry of Agriculture (currently integrated into the National Research and Innovation Agency) Indonesia and some related research, six indicator such as rainfall, temperature, slope gradient, land use type, soil type, and organic matter content were used for land suitability analysis of vetiver grass in the study site (Ramadhani *et al*., 2020). The selection of indicators also considered data availability to facilitate a rapid assessment of land suitability. Each indicator was then assessed for its average value, which corresponds to one or more class categories and scores, namely S1 or highly suitable (score: 3), S2 or moderately suitable (score: 2), S3 or marginally suitable (score: 1), and N or not suitable (score: 0). Table 1 showed the categories for each indicator (Djaenudin *et al*., 2011; Khoirotunnisa *et al*., 2025). The indicators were analyzed spatially in Arc GIS 10.3 using an overlay method which will produce land units. All data and indicator values were presented as maps in vector data format. The value of each indicator was obtained by multiplying the score (based on the land suitability class category) by the weighting factor (Eq. 1):

$$\textit{Indicator Value} = \textit{Score of Indicator} \times \textit{Weighting factor (WF)} \quad (1)$$

Table 1. Indicator for Land Suitability Analysis of Vetiver (Djaenudin *et al*., 2011; Khoirotunnisa *et al*., 2025)

No	Indicator	Weighting Factor	Land Suitability Class Category			
			S1	S2	S3	N
1	Annual rainfall (mm)	0.20	>1500 mm	501-1500	300-500	<300
3	Land Slope (%)	0.30	0-15	15-45	>45	-
2	Land Use Land Cover (LULC)	0.20	Farmland	Forest and Vegetation	Settlement	Water Body
3	Temperature (°C)	0.10	18-20	21-27 10-12	28-30 8-9	>30 <8
4	Soil Type	0.10	Andosol, Aluvial	Latosol, Grumusol	Regosol	Mediteran
5	Soil Organic Matter (%)	0.10	>1.2	0.8-1.2	<0.8	

Land suitability class categories are spatially determined based on total scores of all indicator values which are automatically summed through overlay analysis in the Arc GIS (Table 2). Weighting factors are determined using the eigenvector method of the Analytic Hierarchy Process (AHP), which is commonly used to derive priority weights from pairwise comparison matrices. A proposed land suitability class category based on total score of indicator values as described in Table 2 was determined based on reference of some previous studies with some modification (Khidzir *et al*., 2023; Khoirotunnisa *et al*., 2025).

Table 2. Category for Spatial Land Suitability Class for Vetiver (Khidzir *et al*., 2023; Khoirotunnisa *et al*., 2025).

No	Total Score Range	Category	Remark
1	0.0-1.0	Not Suitable (N)	The land has no significant limitations for vetiver crops cultivation
2	1.1-2.0	Marginally suitable (S3)	The land has limitations that influence vetiver crops growth, and its control is relatively more difficult
3	2.1-2.5	Moderately suitable (S2)	The land has limitations that influence vetiver crops growth. However, these are relatively easy to manage or mitigate.
4	> 2.5	Highly suitable (S1)	The land has no significant limitations for vetiver crops cultivation

3. RESULTS AND DISCUSSION

GIS facilitates spatial land suitability analysis by generating detailed and specific results for each land unit through overlay analysis. The use of vector data results in land units with varying areas. Information from each indicator map can still be identified within the overlay land units. This section discusses the values of the indicators individually.

3.1. Rainfall

Vetiver has a high tolerance to a wide range of rainfall conditions, from approximately 200 mm to 4,000 mm per year. However, for optimal growth, an annual rainfall of around 1,000–2,000 mm is ideal. Both excessive and insufficient rainfall can affect the growth and effectiveness of vetiver in soil and water conservation (Hamdhan *et al*., 2020). This study uses annual rainfall data over a period of 10 years (2015-2024) from seven rainfall stations located in the districts of Kejajar, Garung, Mojotengah, Kertek, Watumalang, Leksono, and Selomerto.

Rainfall data was obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics or BMKG (Badan Meteorologi, Klimatologi, dan Geofisika). This rainfall data was then used to calculate regional rainfall at the study site using the Inverse Distance Weighting (IDW) interpolation method. Rainfall map of the study site is shown in Figure 3. The highest annual rainfall, exceeding 3,000 mm, occurs in the Mojotengah and Kertek areas. Rainfall ranging from 2,500 to 3,000 mm per year is found in the Kejajar and Garung areas, while areas with less than 2,500 mm of annual rainfall include Leksono and Selomerto. Rainfall variability in tropical regions including Indonesia is very high, making it necessary to have more rainfall stations to accurately identify the spatial distribution of rainfall intensity. One of the challenges in collecting rainfall data is the limited number of recording devices or stations. The amount of rainfall data in this study was considered sufficient, with rainfall stations evenly distributed across the study site. The rainfall map (Figure 3) shows that the average rainfall in the study area exceeds 1,500 mm, placing it in the 'highly suitable' category (score: 3). The rainfall at the study site is very suitable or appropriate for vetiver crops.

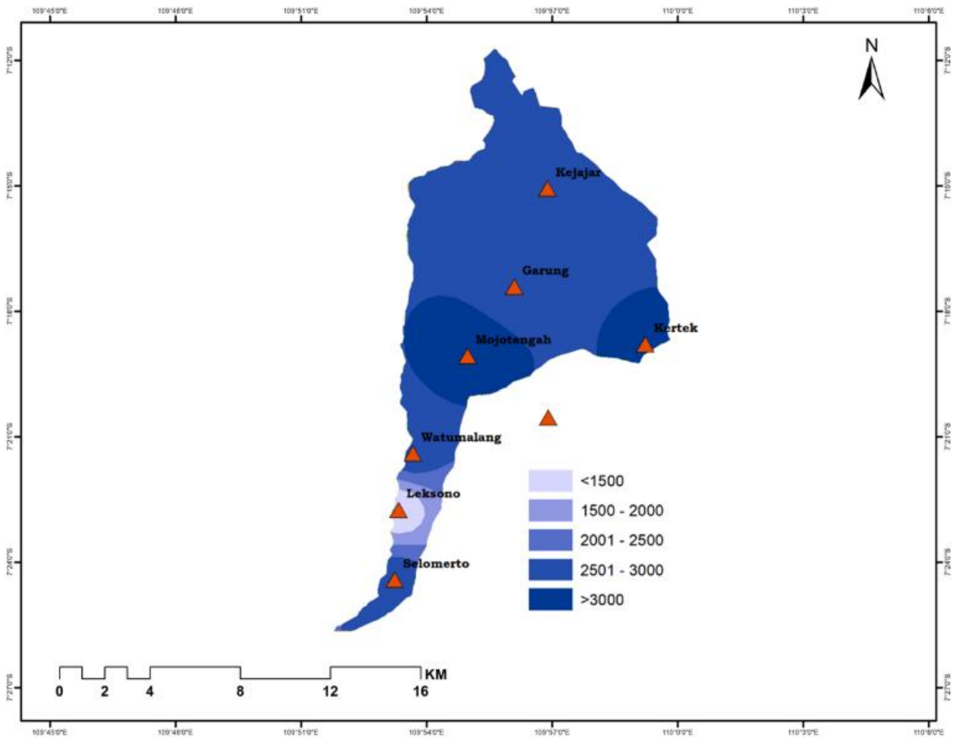

Figure 3. Rainfall map of the study site

3.2. Land Slope

Vetiver plants are widely recognized for their effectiveness in enhancing slope stability due to their deep and strong root systems. At 5-6 months of age, vetiver roots can increase soil cohesion by up to 142% at a depth of 20 cm on slopes with a gradient of 35.54°, significantly improving slope safety (Siagian *et al*., 2024). A study by Hamdhan *et al*. (2020) using the 3D finite element method, demonstrated that vetiver-based slope reinforcement on a 30° slope can raise the safety factor by 10.94%.

Land slope data in this study was obtained from the geospatial information agency of Indonesia or Badan Informasi Geospasial in 2024. Land slope data is presented in map form, showing that the study site is predominantly composed of areas with slopes ranging from 0–15% (66.16% of the total area), which fall into the 'very suitable' category (score: 3) for vetiver cultivation (Figure 4). Other areas have slopes ranging from 15-30% (27.97 % of the total area), 30-45% (5.62 % of the total area), and with only a few areas having slopes greater than 45% (0.25 % of the total area).

Vetiver plants have strong root systems; however, in areas with relatively steep slopes greater than 30%, woody plants are more effective due to their superior ability to stabilize soil masses. Vetiver plants are most effective when used as ground cover to enhance infiltration, reduce surface runoff, and prevent soil erosion.

3.3. Land Use

Land use significantly influences the suitability of land for planting vetiver crops. This crop is ideally planted in open areas such as drylands, agricultural fields, or degraded land for conservation purposes (Hamdhan *et al*., 2020). Thus, agricultural land falls into the 'highly suitable' category. Vetiver can be planted to replace non-food crops for commercial purposes. On food crop farms, vetiver can be planted in areas not covered by cover crops. In this study, land use was classified into four categories namely water bodies (16.61%), forests or vegetation (20.22%), settlements (16.70%), and

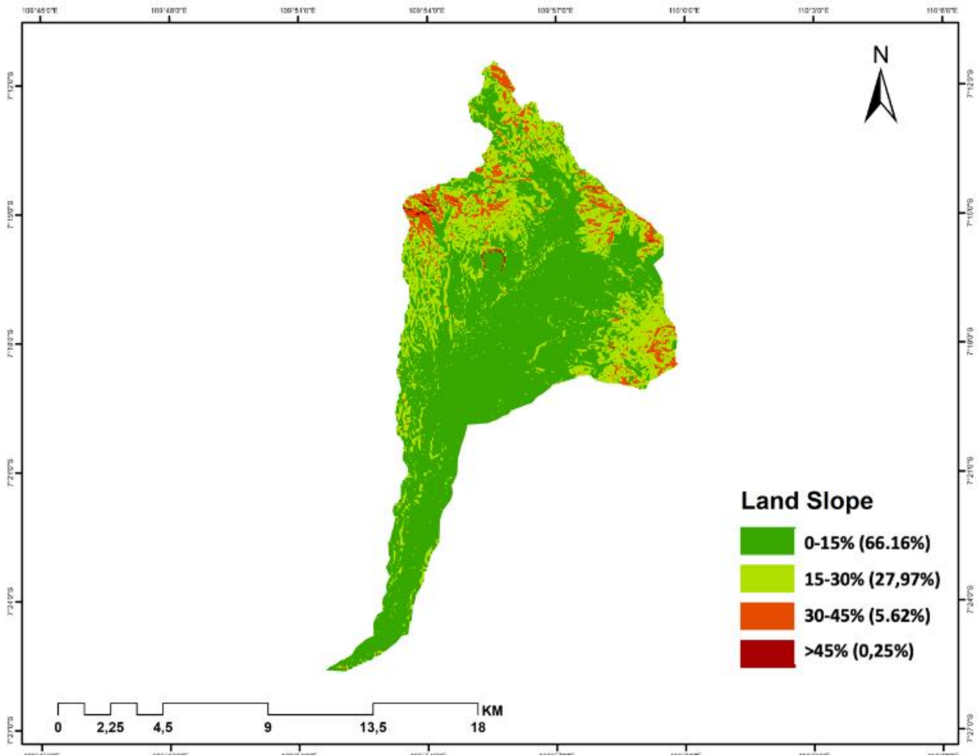

Figure 4. Land Slope of the Study Site

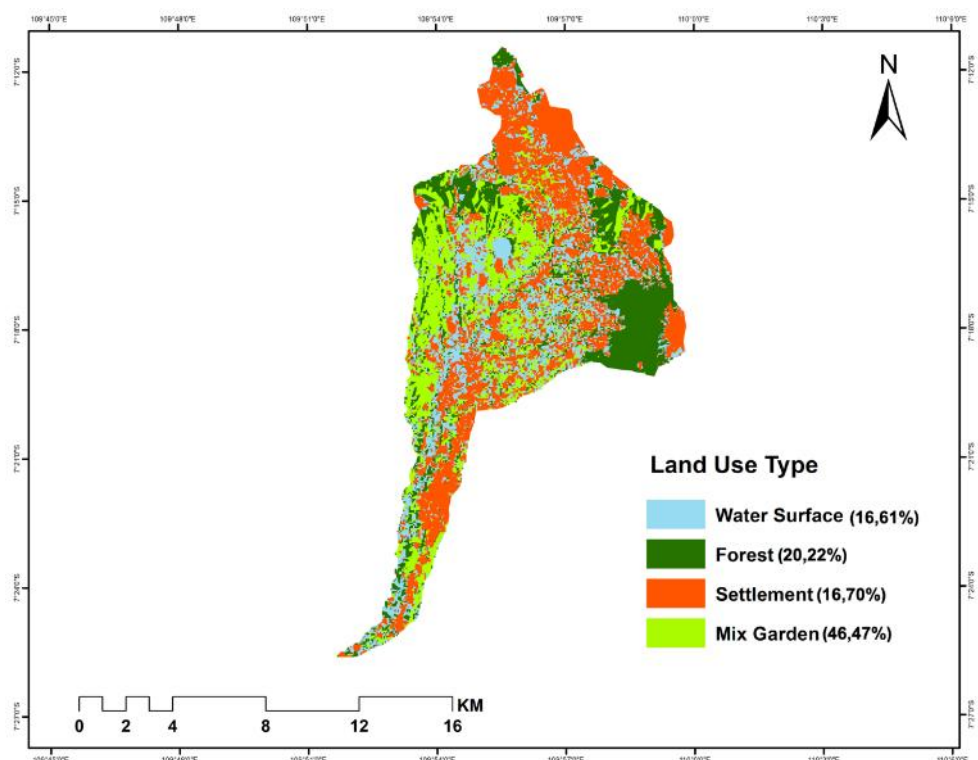

Figure 5. Land Use Type in the Study Site

agricultural land or mixed gardens (46.47%) as shown in Figure 5. Land use map was obtained from geospatial information agency of Indonesia (https://tanahair.indonesia.go.id/) in 2024.

Forests or vegetation include shrubs and grasses, while settlements comprise office buildings and shops. Most of the agricultural land is classified as non-rice dryland agriculture. The forest is categorized as moderately suitable because the leaf canopy blocks sunlight, which can inhibit the growth of vetiver plants. Meanwhile, settlements are categorized as marginally suitable because planting vetiver requires high costs to compensate for converting residential land into vegetated areas.

3.4. Soil Type

The suitability of soil types for vetiver planting is determined based on the soil's physical properties, particularly its structure and texture. Vetiver can grow in various soil types (Garate-Quispe *et al*., 2021), including sandy soils, clay, and soils with pH levels ranging from 3.3 to 12.5. However, well-drained soils with moderate acidity are more conducive to optimal growth. Studies have shown that vetiver performs poorly in heavy clay soils, as such conditions can restrict root development (Ramadhani *et al*., 2020). In this study, soil type map was obtained from the Main Office of Serayu Opak River, the Ministry of Public Work and Housing in 2024. Three types of soil were identified at the study location, as shown in Figure 6. The study site is dominated by latosol soil, covering 94.72% of the total area (moderately suitable). The remaining areas are covered by grumusol (0.15%, classified as a moderately suitable) and regosol (5.58%, classified as a marginally suitable) soil types.

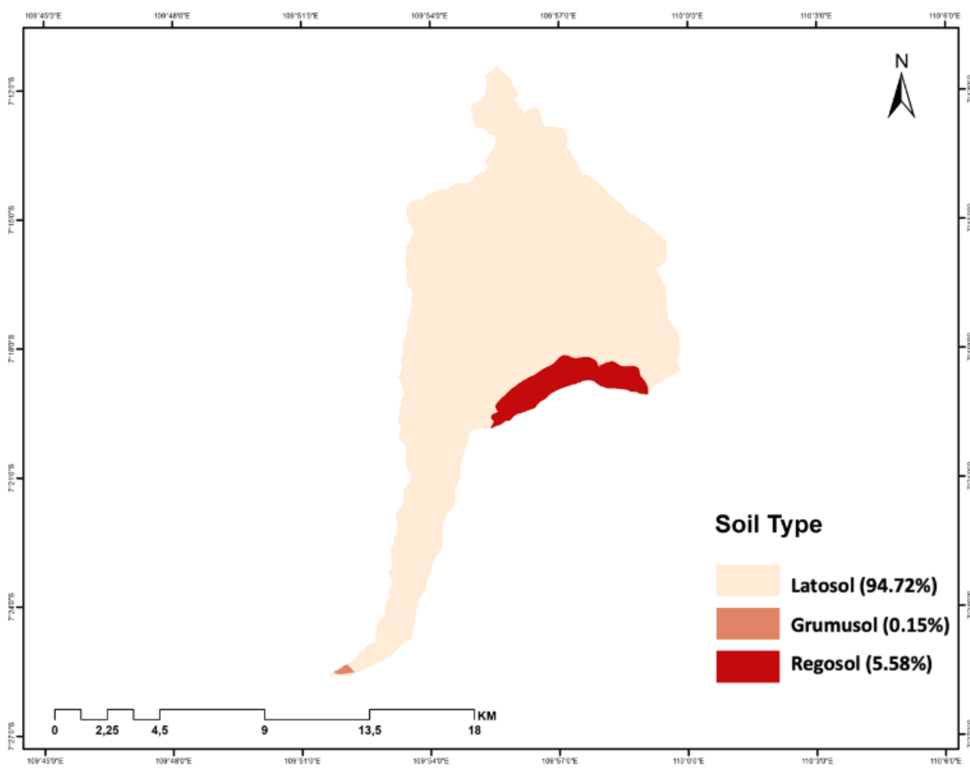

Figure 6. Soil Type in the Study Site

3.5. Soil Organic Content

Organic matter plays a key role in enhancing the soil's water retention capacity and improving its structure. Vetiver is known for its tolerance of soils with low organic matter content (Garate-Quispe *et al*., 2021). The long, deep fibrous roots of vetiver enable it to access water and nutrients from the subsoil. Vetiver also shows strong resistance to pH and salinity, which is influenced by the soil's organic matter content (Liu *et al*., 2016). The soil's organic matter content was determined from the analysis of ten soil samples collected at the study site in 2024 (see Figure 1). The sampling points were selected based on the types of land use present at the site. The distribution map of organic matter content at the study site was generated using the IDW interpolation method as shown in the Figure 7.

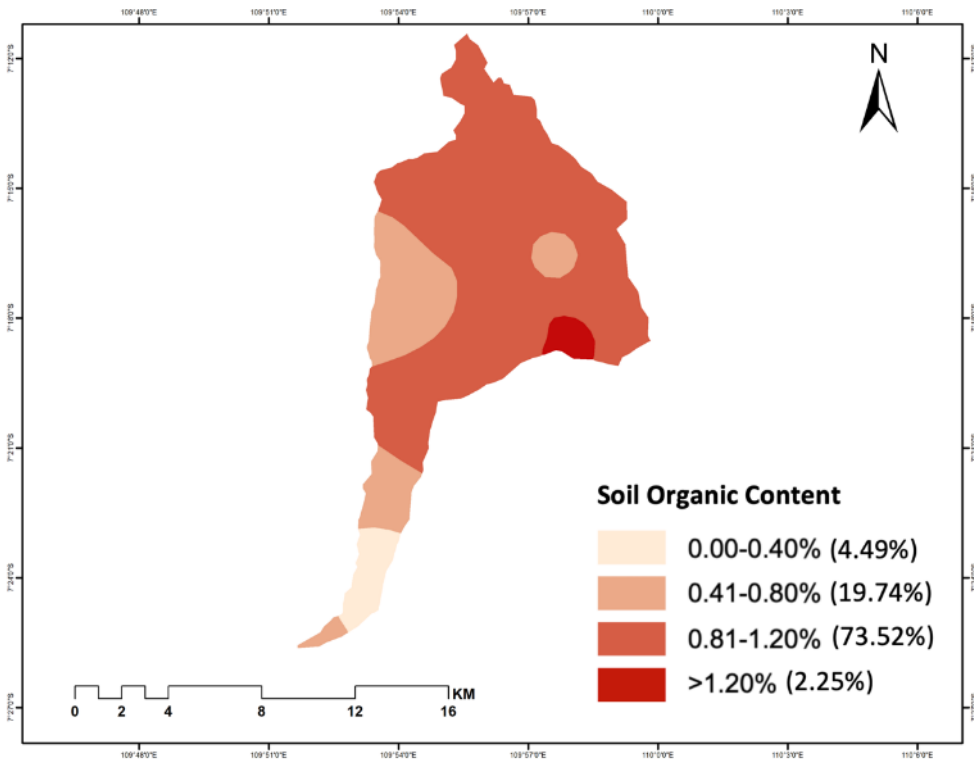

Figure 7. Organic Level Content in the Study Site

Most of the study site has an organic matter content ranging from 0.81% to 1.20% (moderately suitable) covered about 73.52% of the study site. Areas with soil organic matter content of less than 0.8% (marginally suitable) cover approximately 19.74% of the total site. The remaining area areas classified as not suitable (soil organic content less than 0.40 %) and highly suitable (soil organic content more than 1.20 %) covers approximately 4.49% and 2.25% of the total site respectively. The organic matter content in the northern area tends to be higher than in other parts of the site. Although some areas have low organic matter content, vetiver generally exhibit good tolerance to this condition. As a result, the weighting factor for this indicator is lower compared to several other indicators. Agricultural activities greatly influence the distribution of organic matter content in the soil at the study site.

3.6. Temperature

Land use significantly vetiver grows optimally at temperatures ranging from 20 °C to 35 °C but can tolerate a wider range, from 15 °C to 55 °C. However, low temperatures may slow shoot development, even though root activity continues (Rahman *et al*., 2024). In this study, average temperature data of land surface were obtained from Landsat 8 imagery and analyzed using ArcGIS (Figure 8). The calculated data were validated using temperature data from the PB Soedirman Reservoir Climatology Station, located downstream outside the study site. Landsat 8 data were used due to the limited availability of temperature data within the study site. In general, four temperature ranges were identified across the study area: 18-20 °C (highly suitable, cover 9.43% of the total area), 21-27 °C (moderately suitable, cover 34.64% of the total area), 28-30 °C (marginally suitable, cover 32.85% of the total area), and above 30 °C (not suitable, cover 23.08% of the total area).

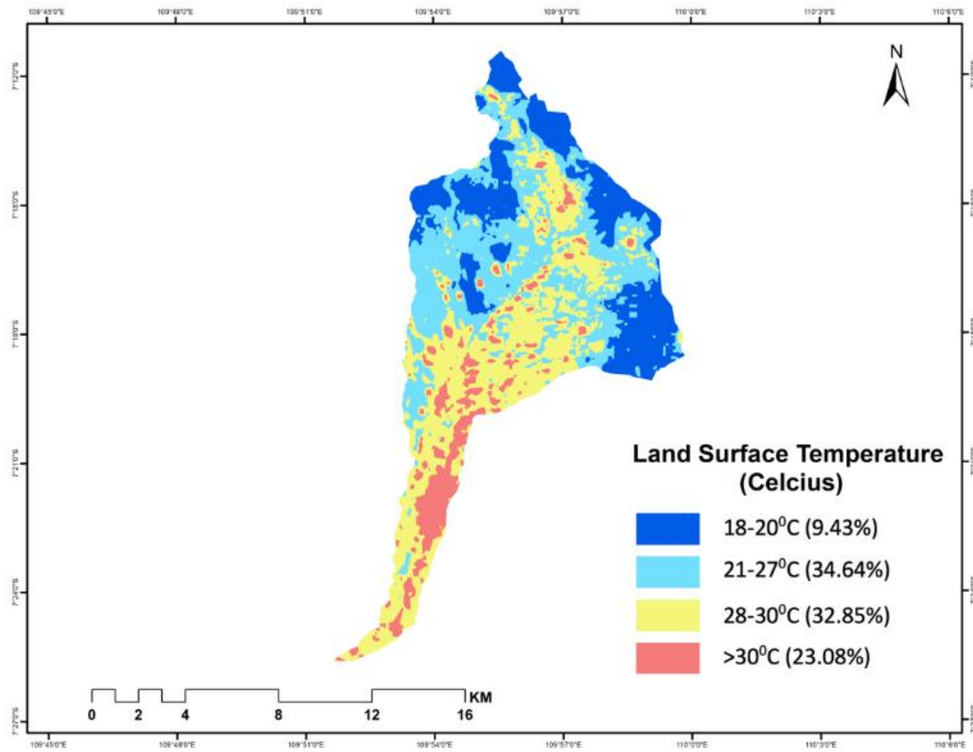

Figure 8. Land Surface Temperature in the Study Site

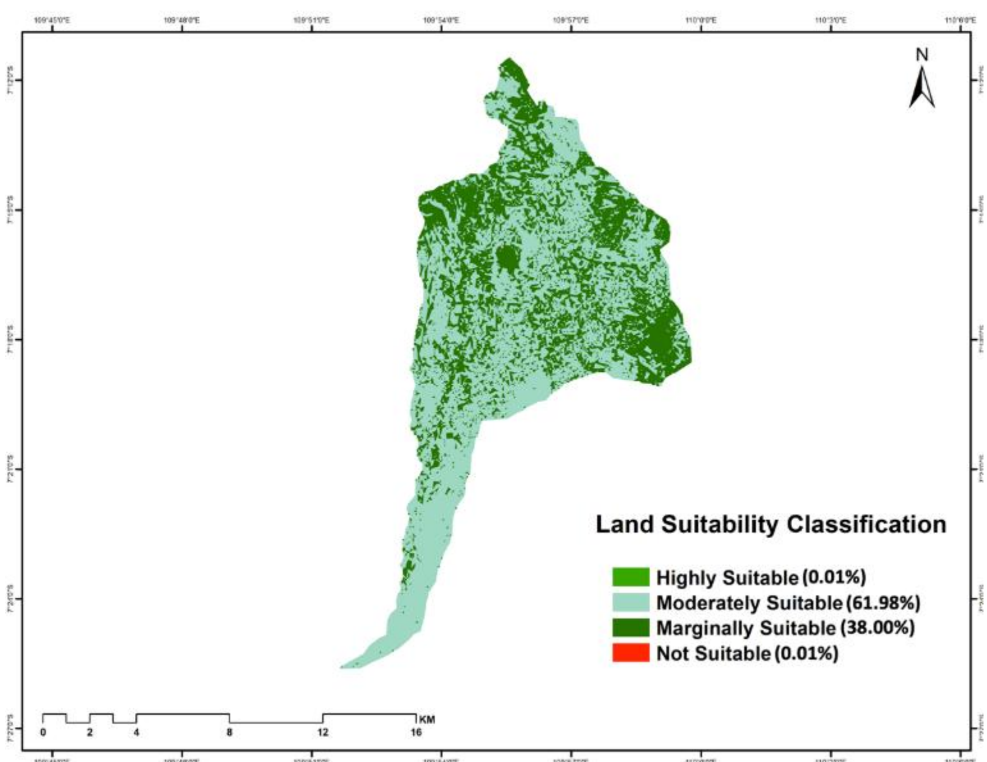

Figure 9. Land Suitability Area for Vetiver Crops in the Study Site

3.7. Distribution of Land Suitability Areas

This research was conducted in response to the degradation of the basin caused by land conversion, particularly for agriculture, without the application of adequate conservation principles (Susanti *et al*., 2020). The six indicators used are key factors that have a significant influence on the growth of vetiver crops. The overlay analysis of the six indicators i.e. rainfall, temperature, slope gradient, land use type, soil type, soil depth, and organic matter content, resulted in a distribution map of land suitability classes at the study site, as shown in Figure 9.

Water bodies were not considered in this land suitability analysis. The results of the overlay analysis show that 61.98% of the area falls into the moderately suitable category for vetiver, followed by 38.00% classified as marginally suitable. The remaining areas fall into the highly suitable and not suitable categories, each covering 0.01% of the total area. Areas classified as not suitable (0.01%) are due to indicators with 'not suitable' values, namely temperature.

3.8. Vetiver for Conservation and NbS Implementation

In principle, Nature-based Solutions (NbS) aim to address environmental challenges by restoring and utilizing natural ecosystems (Dunlop *et al*., 2024). In degraded basins, the NbS concept is applied to restore the functions of disrupted basin components resulting from changes in the natural landscape caused by various human activities, including agriculture. The implementation of the NbS concept can encompass various aspects, including the application of green industry principles, the protection of biodiversity, integrated ecosystem management, and other components such as adaptive and sustainable management (Li *et al*., 2023). In this study, the focus of the NbS concept is on handling problems in the basin through conservation practices.

Mechanical and vegetative soil and water conservation practices have been implemented in the Serayu Basin area (including the study site) and the Opak Basin by the Ministry of Public Works, the Ministry of Forestry, and several other relevant parties. However, these efforts have not been sufficient to control significant basin degradation. Socio-economic factors remain the main challenge in ensuring sustainable conservation through active local community involvement (Setyawan *et al*., 2019). Several issues that indicate the basin's critical condition such as surface runoff, soil erosion, sedimentation, and metal pollution resulting from agricultural activities are still being observed (Astuti & Suryatmojo, 2021; Cantik *et al*., 2023; Sukarjo *et al*., 2023).

Mechanical conservation requires relatively high costs. In contrast, vegetative conservation which is more affordable offers a realistic option for restoring vegetation landscapes, although its benefits may only be realized over a longer period. Vegetation is one of the effective methods for implementing the Nature-based Solutions concept. Vegetation is used to protect and restore the ecological function of the basin (Greksa *et al*., 2024).

The most feasible strategy is to integrate conservation plants with agricultural crops. Converting agricultural land used for food production into permanent vegetation or forests is less realistic, as it would require substantial compensation. The use of economically valuable conservation plants or crops can enhance community participation in soil and water conservation, and support the long-term sustainability of conservation efforts at the basin scale (Leknoi & Likitlersuang, 2020). To avoid disturbing the main (agricultural) crop, conservation crops can be planted on embankments or in empty areas around it. Continuous support from upstream cultivation to downstream product processing by universities, the government, and other relevant stakeholders plays a crucial role in ensuring that the harvest of conservation crops is effectively absorbed by the market especially in the form of processed products. This approach may also gradually lessen the local people's reliance on land, especially concerning intensive agricultural land use.

Vetiver has been reported to be effective in controlling surface runoff and soil erosion. It can also improve the physical properties of the soil, particularly soil structure, thereby enhancing the soil's ability to withstand the impact of raindrop kinetic energy (Aziz & Islam, 2023). Vetiver is widely recognized globally, including in Asia, for its high economic value. The global demand for vetiver continues to grow annually (Jain & Verma, 2023). In the medical and industrial sectors, the demand for vetiver as an ingredient in medicines and perfumes both domestically and internationally is also quite promising. In addition to its high economic value, vetiver is relatively easy to cultivate due to its strong resistance to various environmental conditions. It can even thrive in acidic soils (Sharma, 2024; Taufikurahman & Fatimah, 2023).

From a social perspective, the community at the study site has demonstrated familiarity with vegetative conservation practices. Consequently, vetiver cultivation holds considerable potential for further development in the area. It is important to note that most areas within the study site are classified as moderately suitable for vetiver cultivation, primarily due to soil type and organic matter content falling within that category. Therefore, the successful development of vetiver for conservation purposes will require improvements in soil properties and chemical composition. The use of vetiver plants facilitates the implementation of Nature-based Solutions in tackling watershed degradation. Figure 10 showed the application of vetiver for conservation purposes.

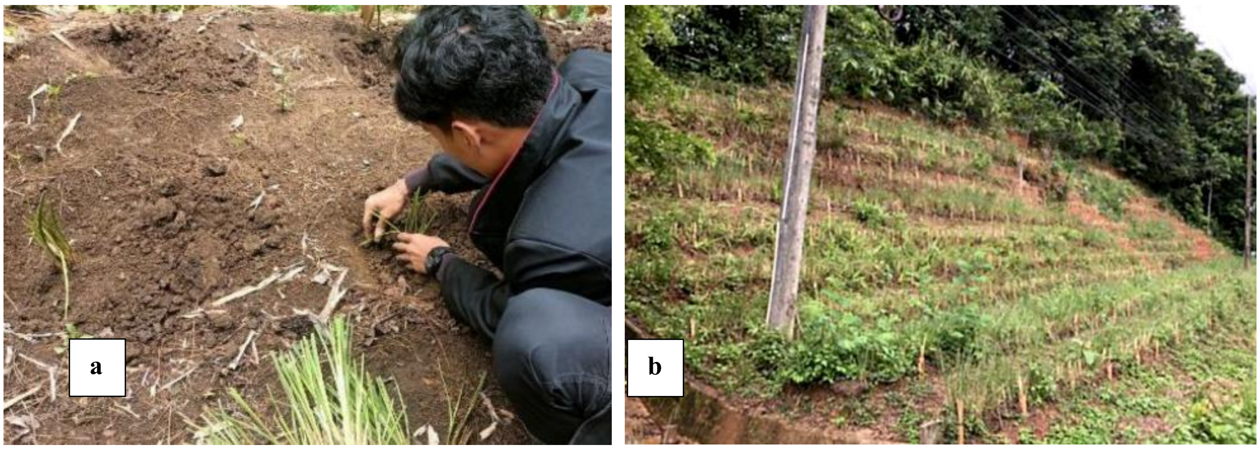

Figure 10. a) Application of Vetiver in Malang, East Java Indonesia (Rahayu & Hidayat, 2025) and b) Huai Khayeng Area, Thailand (Leknoi & Likitlersuang, 2020).

4. CONCLUSION

Most of the research site area (61.98%) falls into the moderately suitable category for vetiver plant development. This suggests that, from an environmental perspective, the use of vetiver for conservation holds significant potential. However, a key limiting factor is the soil condition, which requires improvement, particularly in terms of nutrient content. In socio-economic terms, the use of vetiver for conservation shows strong potential. The local communities are also well acquainted with the use of vegetative methods for conservation. Vetiver crops offer a potential solution for addressing critical land issues through the application of Nature-based Solutions. Based on several related case studies, practical recommendations for vetiver application include conducting land suitability analyses, carrying out cultivation trials to measure its effectiveness in reducing surface runoff and soil erosion, producing processed products from vetiver (downstream), and developing markets for these products. Further research should include establishing a demonstration plot for planting vetiver to validate the results of the land suitability analysis and to test its effectiveness for soil and water conservation.

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