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Karst of Gunung Sewu Land Use and Land Covers Dynamics: Spatio-Temporal Analysis

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Abstract

A study of karst land use and land cover dynamics is critical for managing karst areas, which provide many pivotal services for people. This study aims to study such dynamics, especially in relation to the karst of Gunung Sewu, due to its development as a new emerging sector. Using a mixed methods approach, the study combines spatial data analysis with qualitative analysis. Spatial analysis was performed to examine the dynamic of the land cover derived from 2013 and 2021 Landsat 8 imagery, analyzed with the Google Earth Engine tool, together with analysis of spatial patterns using Global Moran's I and LISA. The spatial analysis results were complemented by a qualitative analysis of the environmental history and development trends, as an explanatory method. The land cover analysis reveals a conversion from vegetation to agriculture, while the spatial pattern analysis shows that such conversion has mostly taken place in the northern part of the study area of Wonosari Basin. The environmental history of teak forest exploitation and agriculture is key to understanding current land use related to the emerging tourism sector, which is fundamental to the region. To manage the negative impacts, sustainable land use with a firm policy framework urgently needs to be implemented.

Keywords: Land Use, Land Cover, Google Earth Engine, Sustainable Land Use, Karst.

1. Introduction

Karst areas are likely to suffer from water and groundwater pollution, soil erosion, rocky desertification, and landform changes due to their intrinsic characteristics and human activities (Lan *et al.*, 2021). Compounded by impermeable limestone, the hydrological features in karst areas mostly comprise cracks and fissures, making surface water scarce and irrigation hardly to be made. Hilly landforms and land slopes also result in soil erosion, leading thin soil and making it difficult to cultivate crops. This may lead to disasters and disturbances which could affect the people's livelihood, such as drought and flooding (Amin *et al.*, 2017; Marfai *et al.*, 2013; Wijayanti & Noviani, 2020).

Apart from the intrinsic characteristics, the ecological fragility and vulnerability of karst areas are also driven by their land use and land cover (LULC) (Li & Geng, 2022; Xiao & Weng, 2007). LULC is a result of human activity in adapting and altering their surroundings to satisfy their needs, making it one of the fundamental aspects of resource utilization and environmental management, ultimately involving regional development activities (Abebe *et al*., 2022; Liu *et al.*, 2020). LULC also influences many key elements of the ecosystem, including vegetation, soil, and water, which affect one another and can result in different geo-ecological dynamic outcomes. Aspects that are impacted by resource utilization and LULC include carrying capacity and ecosystem services, and economic and sociocultural elements (Chen *et al*., 2022; Makwinja *et al*., 2021; Wang *et al.*, 2019). LULC itself is influenced by the characteristics of a landform or landscape, so it is very important to understand the dynamics of land use to determine the capacity of a landscape and the strategy for developing it (Liu *et al*., 2018).

Indonesia, as an archipelagic country, has numerous vast karst area landscapes, scattered in most of its islands and taking various forms, from archipelagic types such as Raja Ampat and Derawan-Maratua karst areas (Haryono *et al.*, 2018), to the land conical karst type of Karangbolong, Maros, Sangkulirang-Mangkalihat, and Gunung Sewu Karst Area (Hartawan *et al*., 2020; Haryono *et al.*, 2017). The karst ecosystem in Indonesia and its LULC support millions of people's livelihoods, including in agriculture, settlement, and tourism sectors, while also generating considerable environmental pressure, such as groundwater pollution (Budiyanto *et al.*, 2020). The denser the population, the greater the pressure exerted, as can be clearly seen at the Karst of Gunung Sewu. As the ecosystem dynamics and people's livelihoods in Karst of Gunung Sewu are closely interrelated to the LULC, it is vital to understand the LULC dynamics (Madrigal-Martínez &

Miralles i García, 2019; Wang *et al*., 2022). However, studies on LULC karst changes in Indonesia are relatively limited, even though the environmental deterioration that is taking place in the karst area is a pressing issue (Setya *et al*., 2019; Shiska *et al.*, 2017).

Karst of Gunung Sewu area is fast-growing. The development of the region began to accelerate in the early decade of '2010s, in line with the growth of the tourism sector. Beforehand, Karst of Gunung Sewu was known for its harsh landscape, whose teak forests experienced massive exploitation. Since then, the area has become famous for its various tourist attractions typical of a karst area, such as caves and beaches. This development momentum has also been accelerated by marketing strategies, such as the application for Global Geopark status (Vitrianto *et al*., 2021). This growth inevitably affects the dynamics of LULC because it is related to the types of resources needed in the income-generating sector. The tourism sector, for example, requires land for the construction of access roads and various supporting facilities in the form of buildings, such as hotels, parking lots, and places to eat (Boori *et al.*, 2015; Saha & Paul, 2021). Another example is the agricultural and forestry sectors, in which people in Karst of Gunung Sewu have modified their environment in line with economic and cultural considerations (Nibbering, 1999), strictly selecting the vegetation that produces the highest profit.

Understanding the dynamics of LULC, especially on a karstic landscape scale, is one of the approaches of this research. The study aims to capture LULC in the spatiotemporal dimension and historical setting, together with the current trends that influence the shape and dynamics of land use (Ritohardoyo, 2016). It also presents LULC change in a spatial, environmental, and regional context in order to be able to build a new synthesis method, especially in karst areas, to understand the issues from a wider perspective. The study of LULC dynamics in this karst area is expected to reveal the environmental issues which are pivotal for both regional development and spatial planning. It will help decision makers to formulate a science-based policy, especially when facing the ecological fragility of Karst of Gunung Sewu.

To achieve these goals, the study aims to answer research problems related to the LULC dynamics at the Karst of Gunung Sewu, specifically the problem of the nature of the dynamics of land use change in the Gunung Sewu karst area. From the results and the analysis, it is hoped that this research will contribute to understanding of the dynamics of LULC and will be taken into consideration in the formulation of spatial policies, such as the designation of protected areas, special strategic areas, and regional spatial plans. It will also provide essential material for further analysis, such as ecosystem services analysis and land use planning.

2. Research Method

To achieve the research objectives, we initially deployed the Google Earth Engine (GEE) as the primary instrument. GEE contains the raw dataset and analytical tools that provide most of the data used in the research (Feng *et al.*, 2022). From the explanatory stage using the quantitative data, the discussion is broadened to a qualitative descriptive elaboration. Quantitative data were mostly employed, but discussed qualitatively, meaning a convergent mixed-method approach was taken (Creswell, 2014).

2.1. Research Location

The research was conducted at the Karst of Gunung Sewu. This karst area is located in the southeastern part of the Yogyakarta Special Region and is the largest regency in the area, occupying more than 40% of the total. Administratively, the Karst of Gunung Sewu covers three regencies and three provinces, but this research is limited to the Karst of Gunung Sewu within the Gunungkidul Regency, due to data availability and the focus on development policy. The boundaries of the karst landscape are set inside the Karst Landscape Area (*Kawasan Bentang Alam Karst*), based on Energy and Mineral Resource Decree Number 3045 of Year 2014. The research location can be seen in Figure 1.

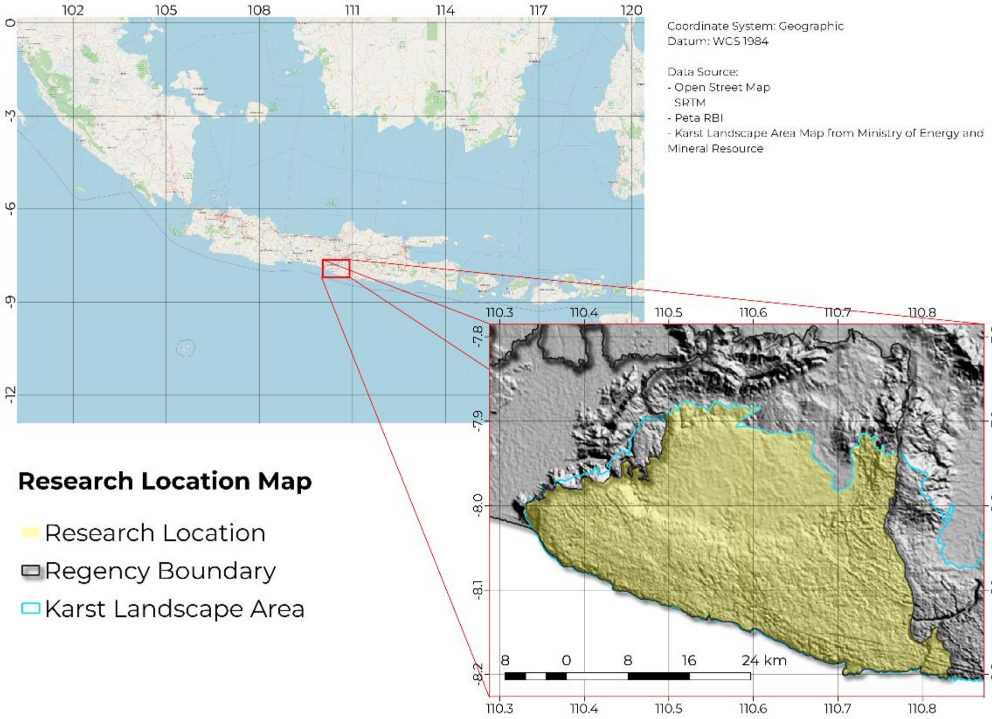

Figure 1. Research Location Map.

2.2. Data acquisition

We used two types of data and combined them in order to make a comprehensive analysis. The LULC data were derived from Landsat 8 satellite imagery, which is commonly employed for LULC modelling (Afrin *et al.*, 2019; Putra *et al.*, 2017; Raziq *et al.*, 2016; Setyowati, 2021; Wijaya, 2015), accessed through a GEE dataset. To capture the dynamics, we used the 2013 and 2021 data acquisitions. The data processing was all performed in GEE, including the training, and accuracy and error calculation, within its algorithm. The LULC was divided into four types in line with the associated characteristic of the karst area and the significance of each LULC in relation to the environmental impact and ecosystem dynamics. The classifications can be seen in Table 1 and the data used in Table 2.

Table 1. LULC Classification.

No	LULC	Association
1	Built-up area	Settlements, economic facilities, tourism areas
2	Agriculture	Non-irrigated rice fields, shrubs, bushes
3	Vegetation	Homogenous forests, hard-wood plantations
4	Bare land	Mining, unused land, water bodies

Table 2. Data Types Used.

No	Data Used	Type	Source	Description
1	Landsat 8 Imagery	Raster	Google Earth Engine	Time-series years 2013 and 2021
2	Karst Landscape Area Boundaries	Vector	Regulation	
3	Topography	Vector	Digital Elevation Model (DEM) *Nasional*	

In creating the LULC maps, the Landsat images were processed and trained, and the classification process was performed using supervised classification. Validity of the classification was ensured using 66 and 57 polygons for 2021 and 2013 image respectively from field verification, resulting in total 91% overall accuracy and 0.81 Kappa value.

2.3. Data analysis

For the analysis, the LULC data from GEE were transferred into the QGIS software. In QGIS, we examined the LULC changes from the reference year of 2013 to the target year of 2021, using the Semi-Automatic Classification Plugin (SCP) in QGIS developed by Luca Congedo (Congedo, 2021). This allowed us to create a LULC change map for each type. The LULC change results from SCP were expressed using pixels, with each pixel having a certain value. From our four classifications, SCP generated 4 x 4 = 16 values; each LULC from 2013 was paired with the other four LULC types in 2021 to observe the changes that had occurred.

To obtain the LULC change per unit analysis, the number of pixels within a village boundary were totalled, with the calculation of the LULC change area made using equation (1) (Putra *et al*., 2017).

$$LULC = \frac{N\ x\ sr}{A} \tag{1}$$

where N is the number of pixels; sr is the spatial resolution of the Landsat 8 OLI image (30 x 30 m); and A is the village area.

LULC dynamics in the karst area take place not only from the temporal aspect, but also spatially. To understand the spatial characteristics of the LULC, the aggregate and spatial patterns of the LULC changes were analyzed using Moran's I on a global and local scale (Fan & Wang, 2020; Hu *et al*., 2019). Global Moran's I gives us an indication of spatial autocorrelation; a phenomenon that occurs where the position of a feature influences others and can interfere with further analysis (Shaikh *et al*., 2021) and then continued with LISA. For the temporal discussion, we examined the current LULC characteristic using environmental history narrative and associated this with the current issues and challenges. The research flowchart is shown in Figure 2.

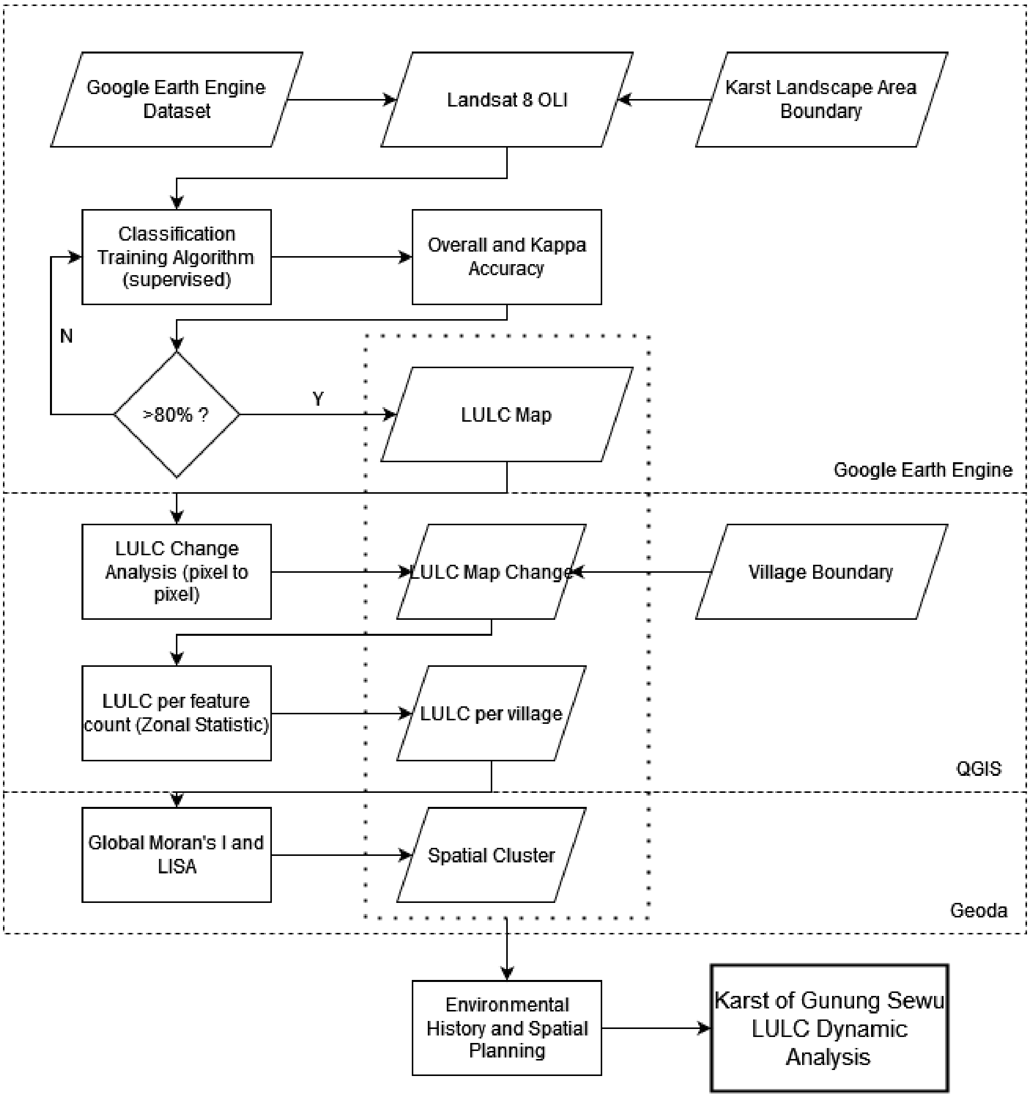

Figure 2. Research flowchart.

3. Results and Discussion

3.1. LULC Dynamics of Karst of Gunung Sewu

LULC dynamics in the Karst of Gunung Sewu can be seen from the land conversion and the LULC change in the spatio-temporal dimension. In the 8 years from 2013 to 2021, the karst area underwent a LULC change, as demonstrated in four LULC types: built-up areas, agriculture, vegetation, and bare land. Derived from the Landsat 8 satellite imagery and the associated classification, the LULC changes during the 2013-2021 period in the four types of LULC can be seen in Figure 3 and Table 3, and are summarised in Figure 4.

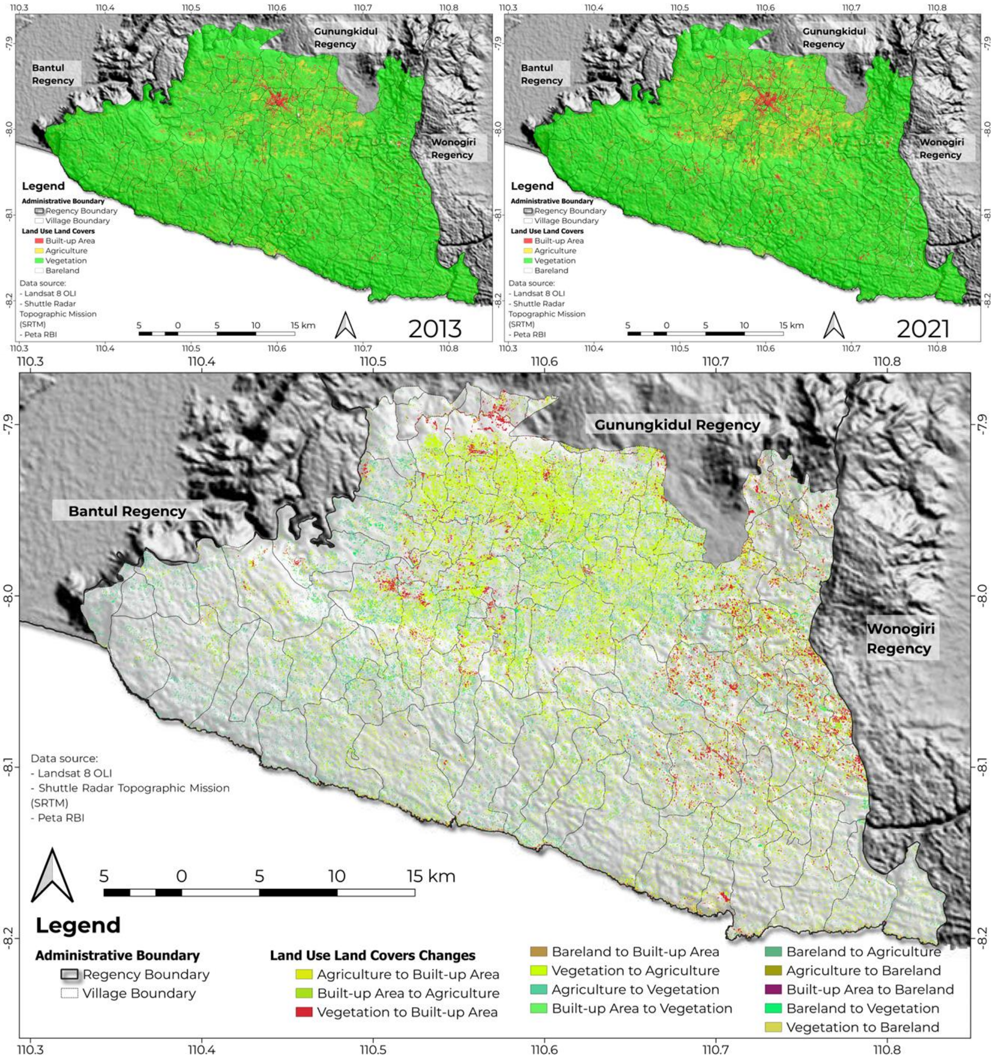

Figure 3. LULC Change Maps.

Table 3. Area Changes for Each Type of LULC.

LULC	Number of Pixels (count)		Area (Ha)		Change (Ha)
	2013	2021	2013	2021	
Built-up area	31534	39621	2838.06	3565.89	727.83
Agriculture	119044	154169	10713.96	13875.21	3161.25
Vegetation	1071566	1029416	96440.94	92647.44	-3793.5
Bare land	6779	5717	610.11	514.53	-95.58

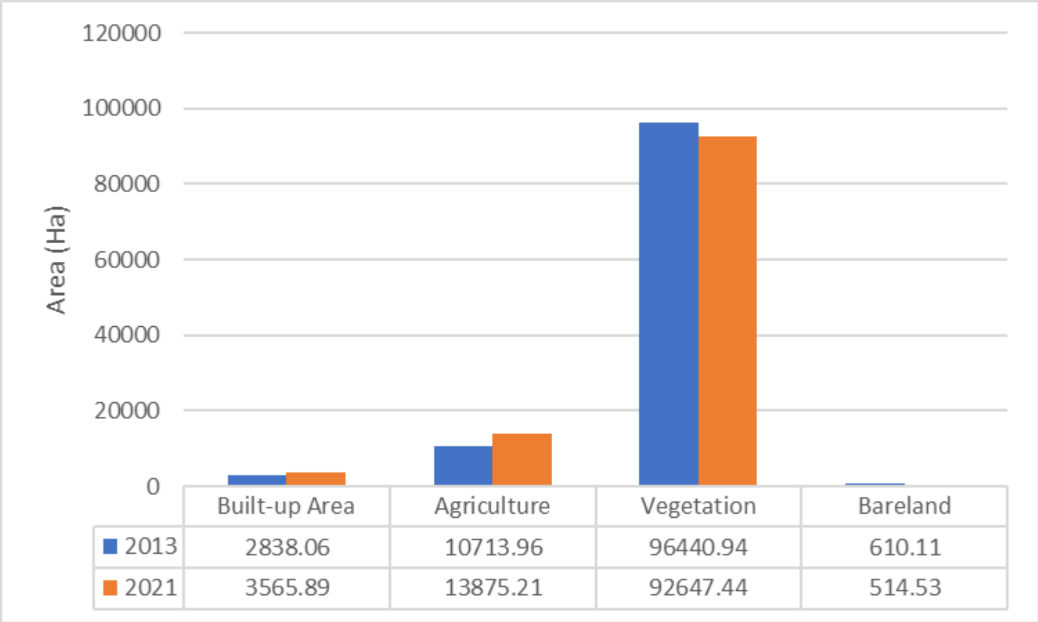

Figure 4. Bar Graph of LULC Dynamics.

The LULC map and LULC table in Figure 3 and Table 3 show the spatial distribution of the LULC change and the affected area in the temporal dimension. Table 3 indicates that the built-up area and agriculture rose to 727.83 ha and 3161.25 respectively, while the vegetation and bare land areas fell to 3793.5 and 95.58 ha. The land conversion from one cover to another can be seen in the LULC change matrix shown in Table 4.

Table 4. LULC Dynamics Matrix (areas in Ha).

	To				
	LULC	**Built-up Area**	**Agriculture**	**Vegetation**	**Bare land**
From	Built-up area	-	689.13	7.74	19.44
	Agriculture	566.1	-	5607.09	1.35
	Vegetation	2716.47	12676.41	-	306.36
	Bare land	96.39	32.4	12.06	-

From the matrix in Table 4, it can be seen that most land conversion was in the form of vegetation to agriculture. The vegetation area replaced the agricultural for about 12,676 ha from 2013 to 2021. Following this change from agriculture to vegetation, the dynamic of these two types of LULC was the most predominant LULC change, because, in the same way, around 5,607 ha of agriculture changed into vegetation. Following this reciprocal interaction, the built-up area replaced 2,714 ha of the previously vegetated area, whereas 566 ha of the agricultural area was changed into a built-up area. Some of the bare land was also taken over and turned into a new LULC.

3.2. Spatial Pattern of LULC Change

LULC change in Karst of Gunung Sewu appears in a spatial pattern. This may occur due to it being a local phenomenon, only existing in a certain location. Examining the spatial pattern of LULC change gives us a glimpse of the factors that influence it. First, the type of spatial pattern must be determined beforehand. Using the Global Moran's I from Geoda software, the LULC change within a village administration boundary is clustered with an I value of 0.662 and a p-value of 0.001. This means the LULC change is concentrated in a specific location and aggregated at that exact point. The results of Moran's I calculation can be seen in Figure 5.

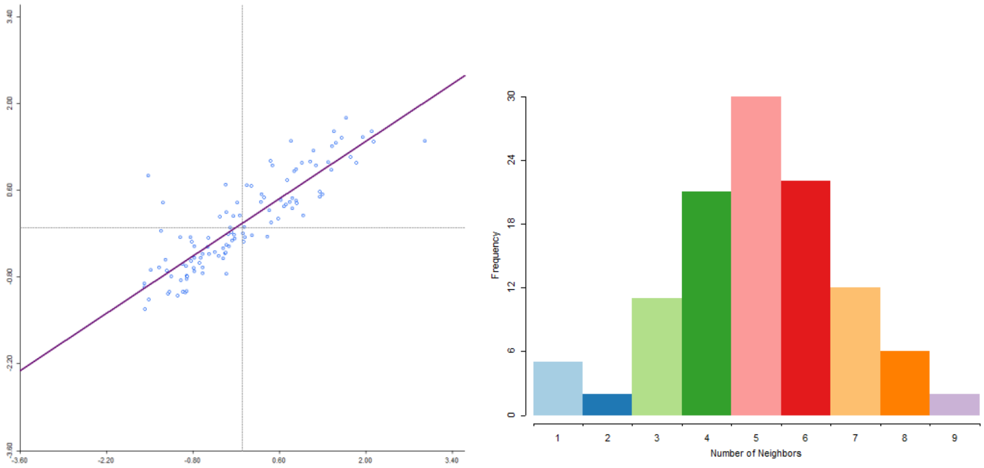

Figure 5. Moran's I Scatterplot and Neighborhood Histogram.

To reveal the location of the cluster, a LISA calculation, also from Geoda software, indicates that the location of the cluster of LULC change is situated in the northern part of the study area. The LISA map and can be seen in Figure 6 below.

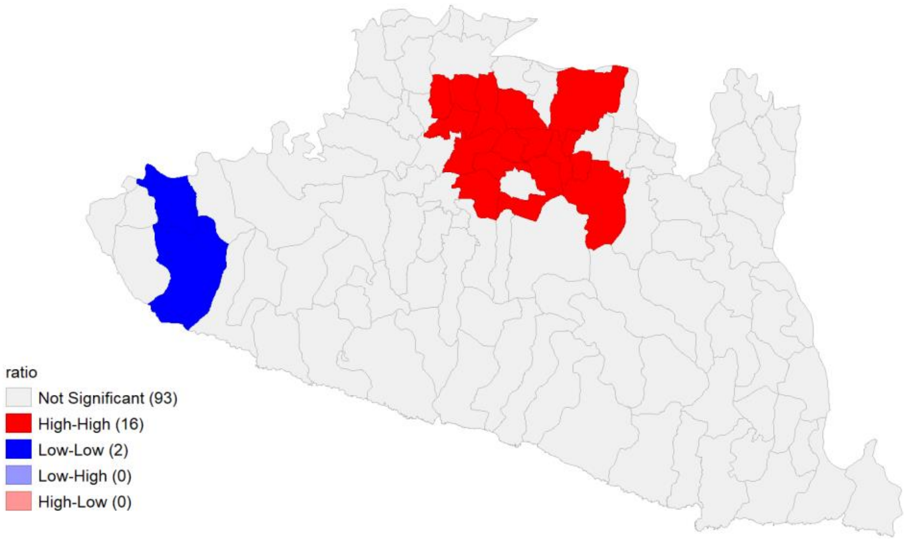

Figure 6. Spatial Pattern and Cluster from the LISA Analysis.

The LISA cluster illustrates the spatial aggregation that occurs in the northern part of the area. According to the physiographical conditions, this area is called Wonosari Basin and, as its name implies, it is characterized by basin conditions: abundance of the surface river, a flat surface, and thick soil from sedimentation (Diah *et al*., 2021; Harriyadi, 2020; Kabo & Giyarsih, 2018). All these characteristics indicate suitable condition for agriculture and settlement centers, which will later lead to crowded, dense activities. This directly impacts the LULC, as agriculture and built-up land demand considerably large areas, causing land conversion and change from vegetation and bare land to agriculture, and from agriculture to built-up areas and settlemenst. The LISA map shows a High-High cluster, where a feature or a village with a high number of LULC changes is surrounded by villages which also have a high value of LULC change.

The spatial cluster or aggregation also indicates the degree of development. The northern part, nearer to the Regency Capital of Wonosari sub-urban area, has a higher degree of development, mainly driven by the sufficiency of natural resources: water (both surface river water and groundwater); soil (suitable for agriculture); and land (supported by flat surfaces). In comparison, the southern part of Sewu Mountain physiography is marked by a hilly topography, thin soil, and an underground river. The lack of infrastructure and physical development, which eventually leads to the high conversion of a certain LULC to built-up areas, appears to be concentrated in the southeastern part of the research area. Both Giripurwo and Giritirto villages were grouped into a

Low-Low cluster, in which a low-value of LULC change feature is encircled by another low-value feature. The Low-Low cluster is located at a cornered location. This area is relatively far from every regional growth pole and activity.

3.3. Development of the Karst of Gunung Sewu and Its Implications for Land Use and Land Cover

Historically speaking, Karst of Gunung Sewu has seen many radical changes to its ecosystem and environment. In modern times around 19th century, Junghuhn, a naturalist from Germany, wrote about the dense vegetation, with various animals such as rhinos, monkeys and buffalos (Rahmadi *et al*., 2018). Junghuhn observed similar characteristics in several places. During his brief visit, he went to Rongkop and Siung Beach, where the vegetation was also similar. Karst of Gunung Sewu entered the age of exploitation and extraction during the colonialist era. Karst soil (terra rosa) is rich in calcium due to rock weathering. This type of soil is ideal for the growth of the teak tree (Faida, 2014), which was massively cultivated under the colonial government directive to satisfy the demand for wood. Environmental historians noticed that teak exploitation took place in many limestone regions on Java Island as a form of resource control exploitation (Peluso, 2006). This became the trigger for further exploitation and the development process in Karst of Gunung Sewu (Fujiwara *et al*., 2018).

Another factor that also consistently played a critical role in LULC dynamics is agriculture. The agriculture and forestry sectors resulted in the most distinctive current LULCs described in the previous sub-section vegetation and agriculture. The historical trajectory then facilitated the shaping of the vegetation and agricultural landscape, determining the type of vegetation and the agricultural commodity. This phenomenon contains not only economical motives, but also the cultural adaptation and social configuration inside the LULC. Previous studies (le Polain de Waroux *et al*., 2021; Twisa & Buchroithner, 2019) mention, LULC encapsulates various aspects and process that occur in many dimensions, including the cultural and socio-economic.

The agricultural sector in the Karst of Gunung Sewu is highly adjusted to the topographical aspect. (Nibbering, 1997) observed that the agricultural practice in the Karst of Gunung Sewu, especially at the Sewu Mountain Zone, mostly takes place on the flat surface of doline morphology. The same observation was also made by Tamimi and Rachmi and Reinhart et al. (Reinhart *et al*., 2021; Tamimi & Rahmi, 2020), whose research probed farmers' adaptation and the limit of agricultural development in the Sewu Mountain Zone. They also noted that there were special distinctions of agricultural utilization in the different types of morphology: karst hills with high slopes are mostly used for hard-wood vegetation, while the foothills are the location for the farmers to build their houses. The physiographical characteristics of the Mountain Sewu Zone act as a constraint for the expansion of the agricultural area, which explains why such expansion is relatively more intense in the Wonosari Basin, where there are no physical or topographical barriers.

As the primary sector of Gunungkidul Regency (Feriyanto, 2015; Susanawati *et al*., 2022), agriculture attracts many residents to live in and construct houses in built-up areas. Agricultural expansion in the Wonosari Basin is also accompanied by the development of the built-up area, which eventually influences land conversion. Urbanization and the demand for settlement are also drivers in this process, while another fast-growing sector, tourism, is also developing quickly and begins to catch up with the agricultural sector to be the primary industry.

Karst of Gunung Sewu is facing great pressure from tourism. The development of the tourism industry began in 2010's decade and continued to grow until it plummeted due to the COVID-19 pandemic in 2019. While the general situation is gradually returning to normal, the tourism sector is responding and starting to rebound strongly, as witnessed by the sharply increasing number of visits. During this period, the authorities, community and private investors, eagerly developed and erected numerous tourist buildings and facilities, including new attractions and amenities, such as hotels, cottages, and photo spots.

Tourism development in terms of facilities and amenities takes place at a micro-level. This type of land conversion- takes place, for example, when the tourism industry expands without appropriate land management, as shown by the study by Duong et al (Duong *et al*., 2020) in Vietnam. A contrasting case occurred in Lombok (Yudita, 2017), where slow tourism development resulted in slow land conversion. In our case, the tourism-related LULC change has not yet been significantly detected in the LULC analysis due to the extent of the land conversion the tourism sector caused and the spatial resolution of the Landsat modalities used. Nevertheless, a significant pattern could be observed in the LULC change map when the Java Trans-Southern

Road was opened and was interpreted as a built-up area. This large-scale construction project covered a large area and led to significant land conversion, which may have a critical impact on the ecosystem and habitat in the karst area.

3.4. LULC Change Impact and Sustainable Development in the Karst Area

Karst areas are notorious for their vulnerability and ecological fragility. LULC conversion could put pressure on them and deplete their ecosystem, affecting people who are dependent on them for their livelihood. Several studies of karst areas in China have demonstrated how land conversion directly affects the ecosystem facilities they provide (Jiao *et al*., 2022). As Hu et al. (Hu *et al.*, 2020) highlight, LULC changes reduce the value of ecosystems by billions of dollars. Such changes may also decrease and cut off the regulatory ecosystem service in karst areas. In the case of the Karst of Gunung Sewu, conversion from vegetation to agriculture then to built-up areas disrupts regulatory services, including hydrological and morphological aspects.

The impact of land conversion includes physical and socio-cultural elements (Faisal, 2020). The physical or abiotic impact of land conversion comprises the increasing morphological change and change in the hydrological system in the karst area. The hydrological aspect of the karst area, including in the Karst of Gunung Sewu, is closely related to the LULC on the surface *(*Bittner *et al*., 2018). The Karst of Gunung Sewu has an intricate hydrological system consisting of conduit channels with poor infiltration. Many studies have suggested that these properties relate to a high degree of groundwater contamination. Agricultural and built-up areas become an imminent threat to the quality of water because built-up areas and settlements might contaminate the groundwater with E. coli bacteria (Buckerfield *et al*., 2019; Richter *et al.*, 2021), while the agricultural sector is responsible for chemical pollutants, including phosphates and nitrogen (Yue *et al.*, 2019). LULC change in northern part of Karst of Gunung Sewualso needs more attention, since land conversion and built-up areas occur mostly upstream of Wonosari Basin, affecting the spring and water resources in the Sewu Mountain Zone. The growth of a settlement in the Wonosari Basin has become the main discussion point regarding E. coli pollution.

Conversion from agriculture or vegetation to a built-up area might also involve morphological alterations. This is a critical issue, as the Karst of Gunung Sewu is supposed to be a protected area because of its unique tropical karst landscape. The karst hills, with thousands scattered around the Karst of Gunung Sewu, are the result of millions of years of geomorphological processes and have a high scientific value; therefore, any alteration in the morphological features must be strictly monitored. Furthermore, the Karst Landscape Area and the Geopark status of the Karst of Gunung Sewu have a mandate for the protection of their morphological integrity.

The most prevalent land conversion takes place from vegetation LULC into an agricultural one. Such conversion may alter the capacity of soil generation and increase pollutants in the groundwater. It also downsizes the carbon stock in biomass (Priyadarshini *et al*., 2019) and soil organic material (Chen *et al*., 2014). Another impact that should be urgently addressed is the conflict between humans and the long-tailed monkey (*Macaca fascicularis*) due to the loss of habitat resulting from land conversion. Monkey attacks on croplands have been reported to be becoming more severe, and more frequent and widespread. This causes considerable destruction and loss of profit for farmers.

Land conversion or LULC change must to a certain degree be managed well to ensure sustainability and carrying capacity (Litasari *et al*., 2022; Pu *et al.*, 2020; Wang *et al.*, 2018). All sectors must be harmonized and support each other to optimize the advantages for the community. In the initial stage, sustainability must be implemented through sustainable land-use (SLU) practices that work on two levels: technical and policy (Fleury, 2009; Peng *et al.*, 2011). The latter includes land distribution, land protection, and zoning policy. SLU policy is urgently required to ensure the policy maintains sustainability on a macro, larger scale, especially since the Karst of Gunung Sewu is an integrated system, in which a disturbance in one certain location may unnoticeably provoke another disturbance. On the other hand, the technical aspect works on a smaller, micro level. The objective is to maintain soil health, livelihood sustainability, and food productivity at a household level. It is expected that LULC changes could be managed both in quantitative and qualitative terms under the SLU framework.

SLU implementation is also also part of the the sustainable development goal number 15: Life on Land (Zhang *et al.*, 2022). This goal ensures healthy landscape and promotes better land management. In karst areas, especially the Karst of Gunung Sewu, promoting SLU and managing the impact of LULC change and land conversion is imperative, considering that this landscape is prone to desertification. For the tourism sector, since it is a growing trend, a similar approach to sustainability may also prevail (Boavida-Portugal *et al*., 2016; Waridin & Astawa, 2021). The Indonesian Government had established a legal framework for sustainable tourism, whereby all tourism activities must be operated within the SDGs, including the land aspect.

4. Conclusion

This paper has thoroughly interpreted and calculated the LULC changes in the Karst of Gunung Sewu from 2013-2021 using GEE tools and has successfully demonstrated that the changes related to four types of LULC, with most conversion being from vegetation to agriculture (12.676 ha). Using Global Moran's I and LISA, it has also been shown that there are two main clusters with a Moran's I value of 0.662 of LULC change in the Karst of Gunung Sewu: High-High in the Wonosari Basin and Low-Low at the South-West part of the Sewu Mountain Zone. In relation to the environmental history and current trends, it can be concluded that LULC change and land conversion are influenced by the exploitation by the forestry and agricultural sectors, with the tourism sector currently emerging. Regarding the method, the paper combined spatial quantitative data with qualitative GIS to enhance understanding of the LULC dynamics within the mixed-method approach. This may open up new possibilities in the use of mixed methods, especially the review of environmental history to reach a timeline when satellite and spatial data are not available. It is suggested that the analysis and data needed to be deepened in further studies.

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