RESEARCH PAPER

THE ROLE OF LATE HOLOCENE LANDSCAPE EVOLUTION IN AFFECTING SETTLEMENT DISTRIBUTION IN BOROBUDUR BASIN, CENTRAL JAVA, INDONESIA

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ABSTRACT. Human life has never been separated from the interaction with the surrounding physical environment, especially landscape conditions. In this paper, the role of landscape evolution in influencing the distribution of settlements in the Borobudur Basin, is investigated. The data were collected through observations, remote sensing, documentations, and literature studies. The data were analysed using analytical-descriptive analysis and spatial analysis supported by geographic information system (GIS) analysis. GIS analysis employing average nearest neighbour and buffer analysis. The results of this study indicate that the landscape evolution affects the distribution of settlements as a form of community adaptation to physical environmental conditions in the Borobudur Basin. The distribution of settlements can be traced from the time of Hindu-Buddhism based on the existence of past relics in the form of temples. At present time, the settlements are scattered as hamlets which are grouped in several villages in the Borobudur Basin. Based on the existence of 20 temples located next to the ancient river valleys, the distribution of past settlements mainly follows the pattern of river valleys. The pattern of past settlements is random, correlates with the paleochannel distribution pattern which is also random. This is possibly due to the reason of obtaining resources and a factor of belief (faith or reliance). The pattern of the current settlement distribution is spreading and is more evenly distributed in the Borobudur Basin. The settlements develop to a wider area outside the paleochannel, not only limited to the paleochannel. Instead of far more numerous population, this distribution pattern is also caused by landscape changes that enable them to build settlements more widely. In summary, this study provides new insight into evidence of the influence of landscape evolution due to geomorphic processes on the distribution of settlements. Traditional intelligence encourages humans to choose the best location for settlement.

KEYWORDS: landscape evolution, settlement distribution, Borobudur Basin, human adaptation

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INTRODUCTION

The Borobudur region in Central Java has been widely known mainly due to the existence of the Borobudur Temple which was designated as a UNESCO world heritage and international tourist destination. However, as an area that has long been occupied by residents and become the centre of cultural development, there is a lot of other information that can be revealed from this region. The existence of various ancient sites provide clues about how the model of lives in the past look like. In addition, it reveals the life of people at the present time that are widely spread in various villages in the Borobudur region. The community life from time to time in this region is definitely inseparable from the condition of the physical environment of the residence, especially the characteristics of the landscape. With their ability to think, humans are able to adapt to the characteristics of the landscape where they live to afford the best life conditions. Due to this situation, geomorphological changes that occur throughout the geological period may correlate with the characteristics of life between generations in the Borobudur region. One of them is the selection of residential locations that can be viewed from the settlement distribution patterns.

Like Java island in general, the Borobudur region has complex geomorphological conditions resulted from the combination of endogenous and exogenous processes. The endogenous process are the tectonism and the influence of volcanic activity around this region. Meanwhile, exogenous processes are influenced by wet-tropical climates with high temperatures and rainfall. Physiographically, the Borobudur region is a basin surrounded by three andesitic volcanoes. The existence of volcanic activity greatly influences the landscape evolution that occur in this region. Gomez et al.

(2010) explain that a large volcano eruption that occurred in ~119,000 BP and ~31,000 BP produced clastic volcanic deposits that covered the Borobudur Basin with more than 10 meters thick. Among the volcanoes that surround the Borobudur Basin, Merapi Volcano with its activities provide the greatest effects (Newhall et al. 2000).

Murwanto and Purwoarminta (2015) say that the Borobudur Basin was formerly a lake that experienced a siltation. The siltation process takes place in stages which are divided into three periods of the lake, namely the Late Pleistocene, Early Holocene, and Late Holocene. Lake siltation is caused by volcanic activity, tectonics, mass movements, and human activities. Tectonic activity plays a role in silting the southern part of Borobudur lake (Murwanto et al. 2014). This indicates the influence of tectonic factors on the landscape evolution in the Borobudur region. Mass movements show the influence of climate, whereas human influence is a form of adaptation to changes in landscape conditions. The changes of landscape conditions require attention because they give a lot of influences on various aspects of the earth's surface, especially human life. Landscape changes and its influence on the lives of people in the Borobudur area, in particular, need to be investigated and informed as a reflection for the present and future lives considering this region has a high cultural value, becomes a world tourist destination, and is occupied by many residents.

The existence of Borobudur temple and other temples in the Borobudur region shows that this region has developed as a centre of civilization since the past time. Degroot (2009) explains that the area between Merapi and Sumbing Volcano was the centre of a strong kingdom in Central Java in between 8th and early 10th centuries. The main temples in the Borobudur area such as Borobudur, Mendut, and Pawon temples were built between 760 - 812 AD indicating the initial period of civilization in Central Java. This tells that the Borobudur area has long been inhabited by the community. In addition, over the past few centuries since the development of the civilization there have been various changes in the physical conditions of the landscape in the Borobudur Region. At this time, Borobudur basin which was geologically included in the Late Holocene Epoch (recent), the last part of Borobudur Lake that had existed since the Late Pleistocene began to disappear (Gomez et al. 2010; Murwanto 2015; Murwanto and Purwoaminta 2015). With regard to this, it is interesting to know thoroughly about how the ability to adapt of the community to deal with the changes of the physical environment therefore it produces a model of life for each generation.

This paper aims at investigating the role of landscape evolution in influencing the distribution of settlements in the Borobudur Basin and the distribution of past settlements related to the condition of the physical environment of the landscape at that time. Population settlement is indicated by the existence of the temple. It is assumed that people who used temples as a place of worship and/or work for taking care the temples might live next to the temple. Determining the location of the temple should take into account the condition of the landscape. There are several requirements to consider in building the temples namely reliefs, availability of groundwater and surface water, contours, and soil conditions such as colour, odour, appearance, taste, fertility, touch, surface flatness, and plant characteristics which grow on it (Darini 2013; Harto 2005). Moreover, the condition of the landscape and the distribution of settlements that exist today need to be revealed.

MATERIALS AND METHODS

This research employed a geographic approach, namely the spatial approach and emphasis on geographical themes in the analysis especially the themes of location, place, and human-environment interaction. The spatial approach was enhanced with the discussion on temporal aspects that were specifically used to analyse paleogeographic conditions. The author combined data collection and data analysis techniques by analysing field data and field investigations. The data consisted of primary and secondary data. Primary data were collected from field observations, namely geomorphological data while secondary data were gathered from previous research and documented data in the publication of statistical data and maps. Geomorphological data include morphology, morphogenesis, morphochronology, and morphoarrangement.

Other primary data gathered from the field are location of temple, settlement, important geomorphological units that indicate changes in landform conditions, and settlements that have toponyms related to past landscape conditions. Temple location data and settlement location are combined with secondary data obtained from previous publications and topographic maps.

Data collection techniques employed in this study are observation, remote sensing image interpretation, literature study, and documentation. Observations were carried out to obtain primary data, utilized the geomorphological survey method. Sampling for observation in the Borobudur Basin was performed purposively on geomorphological units which provided traces of landscape evolution. Remote sensing images interpretation was intended to obtain geomorphological data and distribution of settlement data. Geomorphological data were obtained from the interpretation of Landsat imagery while settlement data were gathered from Quickbird imagery. Literature studies were carried out to obtain secondary data on temple distribution, rock age, and past geomorphological conditions. Meanwhile, documentation was carried out to obtain population data, settlements, and geological conditions collected from BPS data, Geological Maps, and Topographical Map (Table 1).

An analytical descriptive analysis was supported by a geographic information systems (GIS) analysis. In addition, spatial analysis was used to answer research problems. The analysis began by identifying the condition of past landscapes and investigated the distribution of the temple affected by the culture of the people in the past. The GIS analysis which utilized the average nearest neighbour analysis technique was intended to know the type of temple distribution. The type of distribution is indicated by the nearest neighbour value obtained from the analysis. To determine the type of distribution patterns, the z-score and p-value are used as an indicator (Nirwansyah et al. 2015). The z-score and p-value indicate the nature of the relationship between points and their area boundaries as described by Clark and Evans (1954). There are three types of distribution patterns, namely clustered, dispersed, and random. After investigating the temple distribution pattern, the next step is performing spatial analysis to know the physical environmental factors which influence the distribution of the temple. The influence of the physical environment on the temple are indicated by the location of the temple against certain landscape units. After undergoing this analysis process, the influence of past landscape conditions on the distribution of the temple as an indicator of settlement can be described. The same step is repeated to analyse the influence of landscape conditions on the current distribution of settlements. The final step is comparing the past conditions and current conditions (Fig 1)

Table 1. Data Types, Data Collection Methods, Instruments, and Data Sources

No	Data	Data collection methods	Instrument/data sources
1	Landform	Field observation	GPS, observation sheet, digital camera
		Remote sensing image interpretation	Landsat Imagery, Quickbird Imagery
2	Slope	Field observation	Yallon, abney level, roll meter
		Documentation	*Peta Rupabumi Indonesia* (Indonesian Topographical Map)
3	Relief unit	Field observation	Yallon, abney level, roll meter
		Documentation	*Peta Rupabumi Indonesia*
4	Rock type	Field observation	Geological compass, GPS
		Documentation	Geological Map Sheet Magelang and Semarang
5	Paleolandscape	Literature Study	Gomez et al (2010), Newhall et al (2000), Murwanto (2015), Murwanto and Purwoarminta (2015), Murwanto et al (2004)
6	Settlement distribution	Documentation	*Peta Rupabumi Indonesia*
7	Temple distribution	Literature Study	Degroot (2009)

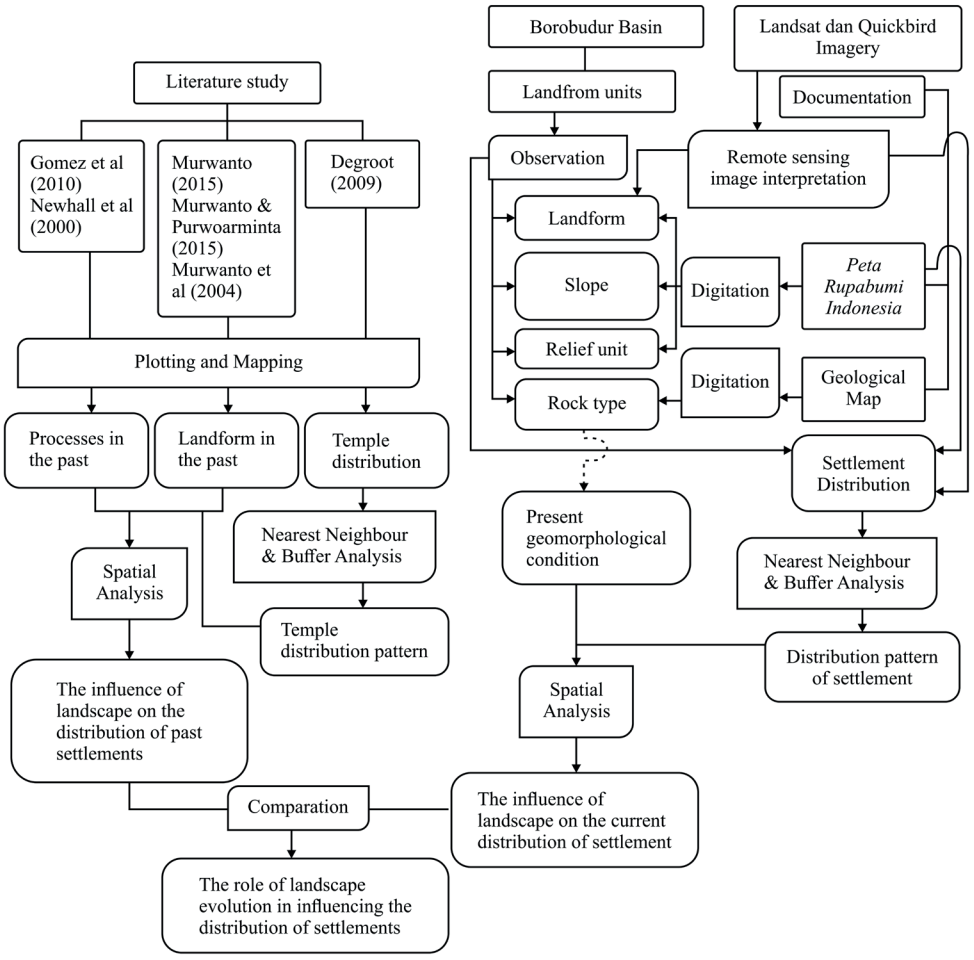

Fig. 1. Research procedure

The Study Area

This research was conducted in the Borobudur Basin area, Central Java. The total area is 65 km2. Physiographically, the study area is bordered by escarpment of the Menoreh Mountains in the south and west, the volcanic foot of the Sumbing volcano in the north, and the volcanic foot of the Merbabu and Merapi volcanoes in the east (Fig 2). The boundaries of the Borobudur Basin area in this study was determined by referring to the ancient Borobudur Lake region during the late Pleistocene published by Murwanto and Purwoarminta (2015) and Murwanto (2015). It's assumed that the Borobudur Basin in the Late Pleistocene period was a landscape of lakes which then experienced an evolution along with the commencement of the historical period of occupancy by the community. After the community occupancy period began, this region continued to be occupied by different generations till the present time. Murwanto and Purwoarminta (2015), as well as Murwanto (2015), determine the boundaries of the

Borobudur Ancient Lake region based on the presence of black clay. Murwanto (2015) explained that black clay deposits are swamp deposits which are indicated by the presence of pollen from swamp community vegetation. The black colour itself derives from high carbon content (Murwanto & Purwoaminta 2015). Furthermore, Murwanto and Purwoarminta (2019) also explained that in addition to the lacustrine sediment outcrop, evidence of ancient lakes around Borobudur can also be revealed by geomorphological features.

The study area is administratively located in Magelang Regency which consists of six subdistricts, namely Mertoyudan, Mungkid, Muntilan, Borobudur, Tempuran, and Salaman. The population in 2021 was approximately 475,502 people. Based on the Geological Map Yogyakarta Sheet Year 1995 by Raharjo et al. (1995), the research area is composed of various types of rocks, including alluvium, young Merapi volcanic deposits, Merbabu volcanic deposits, young Sumbing volcanic deposits, volcanic breccias, and andesites. Murwanto et al. (2004) explain that, Quaternary deposits of lacustrine and volcaniclastic are dominated in the Borobudur region.

RESULTS AND DISCUSSION

The Borobudur Basin's Chronicle: A Review of the Paleogeography

Borobudur Basin is well-known due to the existence of Borobudur Temple which is designated as a UNESCO World Heritage and become international tourist destination. Moreover, this region has rich historical heritages, both geological history and the history of civilization. Borobudur Temple is not the only temple in the Borobudur Basin area. There are 17 other temples in the Borobudur Basin area which are restricted as this study area. However, the structure of the temples is not always complete. Degroot (2009) states that the Borobudur region is one of the core temple-heritage regions in Central Java. Borobudur area, as part of the Progo Valley region is the zone with the highest density of temple remains. The Borobudur region in the past was a Hindu-Buddhist centre in Central Java, and even various evidences show that this region was the former capital of Central Java at that time. Among the two main temple-regions, Borobudur and Prambanan, the ancient kingdom was closer to Borobudur. Borobudur Basin has undergone changes of landscape conditions for a long time. At the Late Pleistocene, a long time before the development of civilization that produced a cultural heritage of temples, this region was a lake landscape.

The lake landscape in the Borobudur Basin has developed since the Late Pleistocene which lasted until Recent. As the time went by, the lake was narrowing and eventually became a plain (Murwanto and Purwoaminta 2015). At the Late Pleistocene, the lake was very wide which then became narrower due to the influence of volcanic, tectonic, and deposition activities (Murwanto and Purwoaminta 2019). Furthermore, volcanic and tectonic activities continued to occur in the beginning of the holocene therefore they buried and lifted the lake. The community began to inhabit this area and manage the land for agriculture, thereby it increased the process of erosion and sedimentation (Murwanto 2015; Murwanto and Purwoaminta 2015). During the drying process, two separate lakes were formed. Borobudur Hill and the other two stand as islands in between (Murwanto et al. 2004).

Gomez et al. (2010) describe that there are several generations of paleolake in the Borobudur Basin. The formation of paleolakes most likely derived from the blockage of hydrographic network by volcanic materials. The volcanic process related to the formation of paleolake possibly occured 31,000 years BP from Merapi Volcano. There are similarities and differences between this view and that of Van Bemmelen (1949) stating that the activity of Merapi Volcano contributes to the formation of paleolake, but this volcanic activity has occurred in the Pleistocene far from the time proposed by Van Bemmelen in 1006. In historical times, the last period of paleolake had

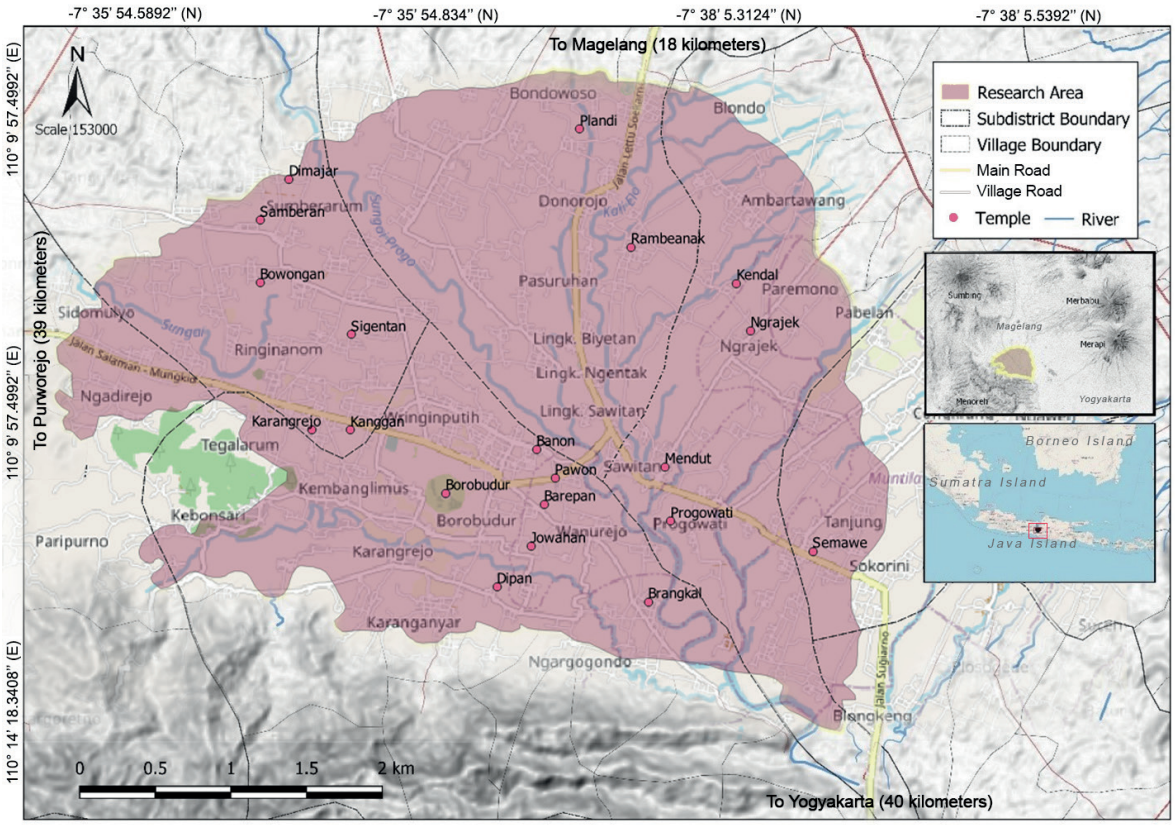

Fig. 2. The Study Area

experienced a shrinkage. This provides information that there was paleolake in the Borobudur region when the civilization began to develop. It was not the first paleolake but a paleolake which has undergone evolution since its initial formation in the Late Pleistocene. Futhermore, Gomez et al. (2010) explain that the presence of early paleolake can be identified from 27,640 years BP lacustrine deposits with a mixture of millimeters to centimeters of clastic pumice and other pyroclastic materials. Paleolake had existed permanently for 20,000 years around the Sileng River, or the entire southern part of the Borobudur Basin, until the historical period. In the Sileng area as a main area, the lake possibly did not dry up for a very long time (Murwanto et al. 2004). Paleolake is not entirely limited to paleochannel but it spreads over a large area at the intersection between the Elo River and the Progo River (Gomez et al. 2010). The development of paleolake in the Borobudur Basin since the Late Pleistocene was greatly influenced by the geographical setting in this region. Geomorphologically, Borobudur Basin is a basin surrounded by volcanoes and Menoreh Mountains. This condition determines the geomorphological process that takes place from time to time since the Late Pleistocene, thus causing the siltation and disappearance of paleolake. The quaternary volcanic which borders Borobudur Basin plays the most important role in the evolution of paleolake in the Borobudur Basin (Murwanto 2015).

The volcanism process has been very influential in the Borobudur area for long time. In relation to the paleolake, all of these volcanic activities influence the development of paleolake. Merbabu Volcano produce an important eruption that influence the development of the Borobudur basin, which produces lahar that lines the andesite blocks. Meanwhile, Sumbing volcanic results are beleived to produce pyroclastic deposits in the Progo River in the northern part of the basin. Sumbing Volcano and also Merapi Volcano have produced pyroclastic flows that are transported reaching a distance of 30 km and enclose short-aged lakes in the Borobudur Basin (Gomez et al. 2010). The activities of Merapi Volcano which have greater intensity and impact than other volcanoes become the main factors that contribute to the disappearance of Borobudur Lake (Newhall et al. 2000). The role of volcanism which is very strong seems to be more dominant than climate variation factors in causing the disappearance of Borobudur Lake. This condition is different from the process of lake sedimentation in other regions with non-volcanic landscapes (Romashkin and Williams 1997; Zolitschka 1998; Sapelko et al. 2019) or volcanic areas accompanied by strong tectonism influences (Liu et al. 2015). However, the role of human activity factors in land use that causes lake sedimentation shows similarities with other regions (Ahn et al. 2006).

Paleolandscape conditions and its influence on the selection of community residence locations

Borobudur area has been occupied for a long time and become one of the centres of ancient civilization in Central Java. The most monumental relics as evidence of past civilizations is temples that were built from the 8th century to the mid-10th century, including the Borobudur Temple, Mendut Temple, and Pawon Temple (Degroot 2009). There are 20 temples in this study area. The temple as a relic of the past can be used as a proxy to identify the existence of the settlements and their distribution.

Temples as a symbol of belief definitely correlate with the lives of people who have settled in the region. In building the temple, the area around the temple was functioned as a place for settlements. Therefore, in choosing the construction site of the temple, various factors are considered such as resource availability and land stability (Kramrisch 1946) for the sake of building good settlements and meeting the basic needs of people living in the area. The observations that have been carried out on 26 temples in the Progo Valley show that the location of the temples are next to springs or rivers. Moreover, the land has a dark texture and is generally located on the fluviovolcanic plains (Ashari 2015). The relationship between the temple and the people living around can be viewed from various activities during the construction phase of the temple (Darini 2013; Harto 2005).

The existence of the temple indicates the existence of community settlements in the area. Community settlements are possibly located next to the temple. During the construction of temples in the 8th century, a settlement as a permanent city which had good arrangements for water management infrastructure was not found in Central Java, as it was found in the Hindu-Buddhist period in East Java several centuries later (Wirjomartono et al. 2009). Thus, the community settlement was close to the temple and had a simple layout. An ancient settlement between the 6th century and the 10th century found in the Liyangan site also indicated the connection between the temple and settlements. Spatial structures in the ancient Liyangan neighbourhood show the existence of residential, worship, and agricultural areas (Riyanto 2015).

When community settlements developed in the 8th century, the Borobudur Basin area was still a lake landscape. This lake landscape in the history of Borobudur Basin evolution is the last generation of paleolake in this region. Compared with paleolake which was firstly developed in the Late Pleistocene, paleolake in this period has undergone many changes, especially shrinking the lake area and increasing intensive sediment deposition, thereby reducing the area of the lake. Gomez et al. (2010) explain that paleolake in the Borobudur basin had existed up to the historical time. Paleolake in this period was limited to paleochannel gullies. Spatial analysis of the distribution of temples in the Borobudur Basin shows that the temples were mostly built next to this paleochannel. The number of temples based on the distance from the paleochannel are as follows: two temples at a distance of 100 meters, six temples at a distance of 200 meters, 9 temples at a distance of 300 meters, 12 temples at a distance of 500 meters, 15 temples at a distance of 800 meters, and 18 temples at a distance of 1000 meters (Figure 3). Two other temples located at a distance of more than 1000 meters from the paleochannel turned out to be located near the present river. The spread of this temple shows that past settlements developed close to river gullies which might be part of the paleolake edge.

Gomez et al. (2010) analyse the relationship between the distribution of the temple and the river. The results of the analysis indicate that there is a link between the temple and following the river network. This further strengthens the existence of the link between the temple – as settlement representation – and river gullies, both paleochannel as part of paleolake and actual river. The landscape condition in the past which was dominated with lakes and swamps limited the selection of settlement locations. This might contribute to the limited development of settlements around the paleochannel. The toponym of Bumisegoro and Sabrangrowo hamlets (Murwanto 2015) affirmed the existence of the swamp landscape at that time. In addition to physical conditions, settlements that are located next to the river are possibly due to people's motivation in obtaining resources (and transportation infrastructure?). Besides, a factor of belief also contribute to the relationship between the temple and the river (Darini 2013; Harto 2005; Kramrisch 1946). In summary, the evolution of the lake landscape at that time has created a landscape condition in such a way that the people who occupy their territory might adapt to that condition.

Based on the results of the average nearest neighbour analysis conducted on 20 temples in the study area, the pattern of temples distribution in the Borobudur Basin is random. The random pattern is influenced by the distribution of paleochannel which is also random in the boundaries of the study area. The z-score shows that the distribution of paleochannel in the study area is very random. The results of the analysis which indicate a random distribution of temples are aline with the distribution

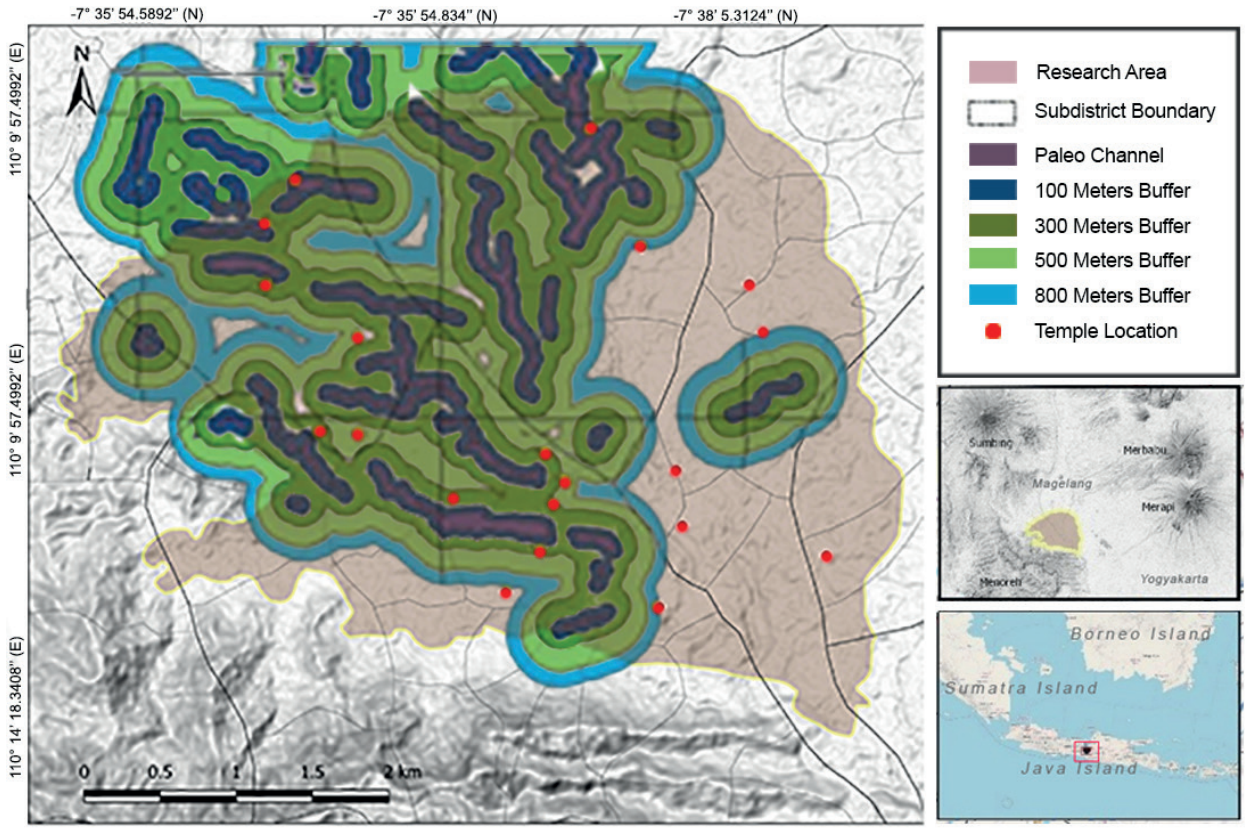

Fig. 3. Buffering analysis of temple distance from paleochannel

of paleochannel which are also random, supporting each other with the results of buffering analysis in which the temples were built close to the paleochannel. Although in general the spread of the temple in all research areas is random, the z-score on the temple's distribution pattern which is negative shows a slight tendency to be cluster patterns. Viewed in a narrow scope in the area around the paleochannel, for example in a 800 meter buffer, the spread of the temple does indeed show a tendency to cluster (Fig. 4).

The pattern of ancient settlements in the Borobudur Basin of which the distribution pattern is random becomes the main finding of this analysis result. Furthermore, based on the results of the buffering analysis, this random settlement pattern correlates with the paleochannel distribution pattern which is also random in nature. The author predicts that the distribution of settlements which tends to be located next to the paleochannel is due to the existence of water resources and the factor of belief. This condition is similar to that of found by Singh et al. (2017) which shows that urban areas that developed in the Bronze-age of Indus Civilization spread around the big Himalayan river due to the existence of water resources. The distribution of settlements develops along the paleochannel which is currently inactive, but the location was the provider of water resources to meet the needs of the community in the past. Ancient settlements built near rivers due to water sources availability is also shown by Lu et al. (2019) in Songshan Mountain, China, and Wilkinson (1998) in the Balikh Valley, Syria, in which the development of settlements correlates with water resources availability in the region over a very long period of time.

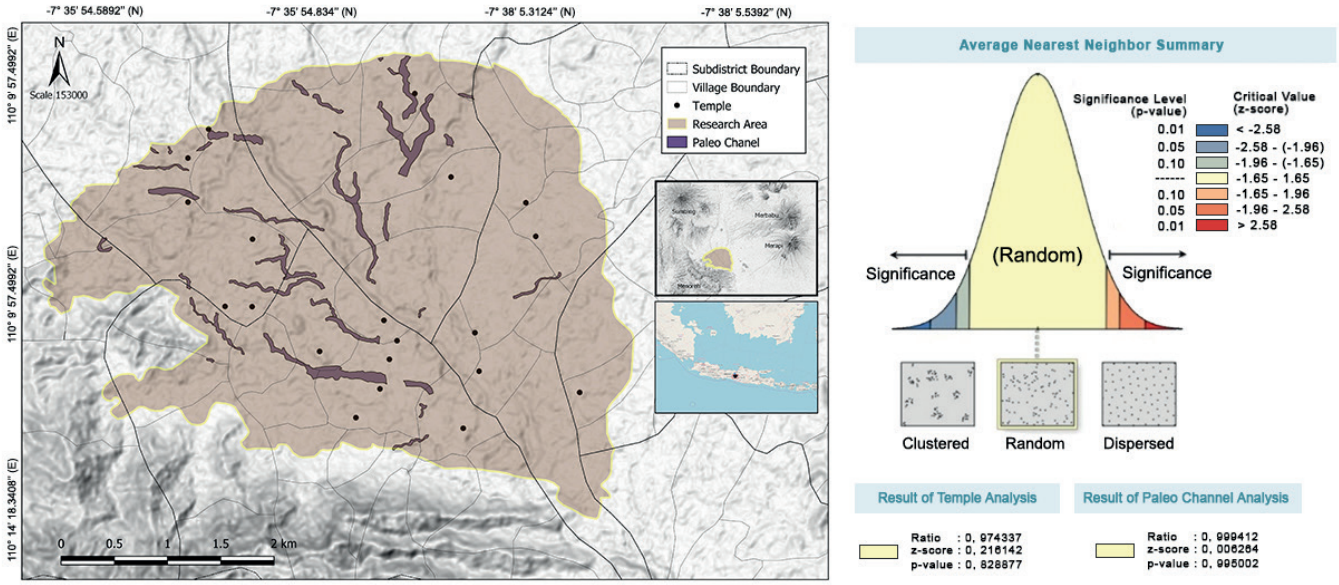

Fig. 4. Left: distribution of temples in the research area (after Gomez et al 2010 and Murwanto 2015). Right: results of average nearest neighbour for temple analysis and results of average nearest neighbour for paleochannel analysis

Why aren't ancient settlements dispersed distributed in the Borobudur Basin? It seems that the topographic barrier in the form of a swamp in the area is a factor that inhibit settlements from being widely distributed. This condition is the same as that of expressed by Lü et al. (2019) where fluvio-lacustrine aggradation is characterized by an increase of flood which causes uninhabitable hydrological and geomorphic conditions. This condition further influenced the pattern of settlement development which was then located along the basin. A similar situation is explained by Kidder (2006) in which the increase of flood volume in river valleys foster people to abandon the ancient settlements and push them to move to new or more suitable locations. Honegger and Williams (2015) also explain that climate changes that cause changes of the conditions in the Nile River, influence the development of settlements in the region. Meanwhile, Smith et al (2021) showed that in addition to natural factors, demographic and political factors also influenced the shift of settlements in the river valley.

Environmental conditions dealing with suitability of settlement locations as well as spatial and temporal changes are factors that influence settlement patterns in the Borobudur Basin. This condition is also found in other places, including areas with different climatic and landscape environmental characteristics. Climate change, as explained by Kidder (2006), Honegger and Williams (2015), Li et al. (2017), Lü et al. (2019), and Nikulina (2019) becomes a factor that greatly determine the changes of environmental conditions which later on influence the development of settlement. Bolikhovskaya et al. (2010) describe relatively similar conditions, based on the finding that climate evolution in the lower Volga region during the holocene, is closely related to changes in climatic conditions in the region. Slightly different conditions are found in the Borobudur Basin in which the very active volcanic activity of the various volcanoes around the Borobudur Basin becomes a very influential factor in the change of the landscape in this region.

The Condition of Landscape and Distribution of Actual Settlements

The Borobudur Basin has now developed as a form of alluvial plains. Some rivers that cross this region greatly contribute to the development of the present landform. As a plain landform, the Borobudur Basin currently has a topographical impression as a flat land (Fig. 5) Viewed from the morphoarrangement aspects, the position of the Borobudur Basin which is surrounded by volcanoes and Menoreh Mountains also influences the development of current landforms, although the geomorphological processes that take place at this time are different from that of the past. The deposition of massive volcanic materials do not occur in the modern era. This is due to the reduction in volcanic activity in today's era. Among several volcanoes that surround the Borobudur Basin, Merapi Volcano is the only volcano that is still active in the last few centuries. However, the volcanoes around the Borobudur Basin still become a source of material deposited in this region. Human factors that utilize land for agriculture also play a role in influencing the denudation process in the upstream area, thereby increasing the amount of sediment deposited through the river.

The conditions of different settlements are also found in the today's era as it was in the beginning of civilization

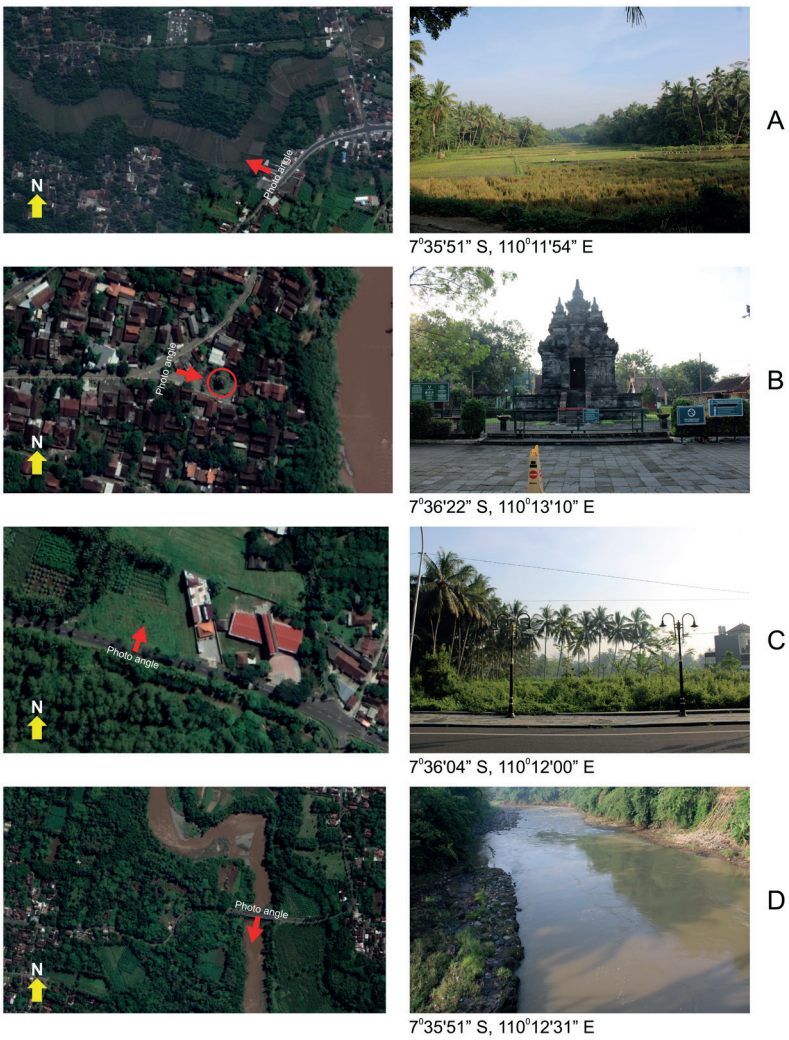

Fig. 5. Geomorphological conditions of several locations in the Borobudur Basin. A: palaeochannel in Wringinputih Village. B: Pawon Temple, located on the edge of the present river valley and 650 meters from paleochannel. C: flat-sloping topography around Borobudur hill. D: fault structure in breccia rocks in the Progo River (Source: Field data 2002 and Google Earth 2020)

in the 8th century. In the 8th century, the settlements developed around the paleochannel and spread randomly in the Borobudur Basin whereas in the modern era settlements were relatively dispersed (uniformly). In summary, community settlements in the modern era currently occupy various parts of the Borobudur Basin area and are not limited to certain areas (Fig. 6).

The uniform distribution of settlements in the Borobudur Basin is also influenced by landscape conditions in this time. Geomorphological conditions of Borobudur Basin in the form of alluvial plains allow a more widely settlements development. Compared with the final period of paleolake which was still in the form of swamps, the current conditions enhance the development of settlements more evenly in various regions. The changes of landscape conditions from time to time in the Borobudur Basin have influenced the way of life of the community, especially in utilizing land for residential locations. Another important factor which influences the development of settlements more broadly in modern times is the high population. As stated in the previous section, there were approximately 475,502 people living in the Borobudur Basin area in 2021. The high number of population require high needs of land both for settlements and agriculture. This factor supported with the geomorphological conditions encourage the development of settlements in various parts of the Borobudur Basin.

Based on the observations of remote sensing images and topographic maps, the author have identified settlement units in the research area. The current area of settlements is 28% of the total area of the study area. The buffering analysis results show that 72% of residential units are located in an area of 800 meters from paleochannel and 28% outside the paleochannel area. This condition provides information that the settlements develop to a wider area outside the paleochannel. The current settlements are not only limited to the paleochannel which in the past became the centre of a residential area. Viewed from the distribution and density of paleochannel in the study area (see Fig. 3), areas with a distance of 800 meters from paleochannel have covered most of the study area which is 82%. The rest is only 18% of the total area included in the area outside the 800 m distance from the paleochannel. This 18% turned out to be 28% of residential units currently. Based on the spread of the temple, the area outside the 800 meters of the river (paleochannel and actual river) is only 17% of the temple.

It is generally known that the changes of the lake environment into alluvial plains greatly contribute to the development of settlements area distribution from the past to the present time. Interestingly, viewed from the distribution of the paleochannel, there is a linkage between the spread of the temple and the current distribution of settlements (see Fig. 4 and Fig. 6) in which the current settlements develop from the expansion of past settlements. The development of settlements in the present time does not take place without order. There is a possibility that the past settlements, may become a starting point for the development of settlements in the later periods. The changes of landscape that provide more space for the development of settlements and the increasing number of people have caused settlements to develop more widely from their initial point. The expansion of residential areas takes place in stages along with shrinking paleolake. In the area near Mendut Temple to the capital city of Magelang Regency, the traces of paleolake were found from 1163-1251 AD (Gomez et al. 2010). The area includes the last part of Paleolake in the Borobudur Basin so that new settlement expansion probably began in the period after that year. The expansion of settlements that developed after the end of the paleolake period differs up to 4 centuries from the heyday of Hindu-Buddhist civilization that built the Borobudur Temple.

The slight different percentage of the number of temples and residential units in each buffer area of the paleochannel further strengthens that the past settlements became the node for the development of settlements in the future. For example, there were 45% of the temples as indicators of past settlements and 54% of the current settlements in a buffer area of 300 meters from the paleochannel. When the buffer distance was expanded to 800 meters, it turned out that there were 75% of temples and 72% of settlements. This condition shows that the spread of the temple tends to be close to the paleochannel while the distribution of settlements is wider. However, there is no contradictory data showing that the temple area is very localized and modern residential areas are dispersed distributed. The development of settlements can occur because paleolake is increasingly shrinking into an alluvial plain (Fig. 7).

The changes of landscape conditions become a factor which influences the settlement development. As explained by Lu et al. (2017), the selection of settlement location is greatly determined by Landform. Lü et al. (2019)

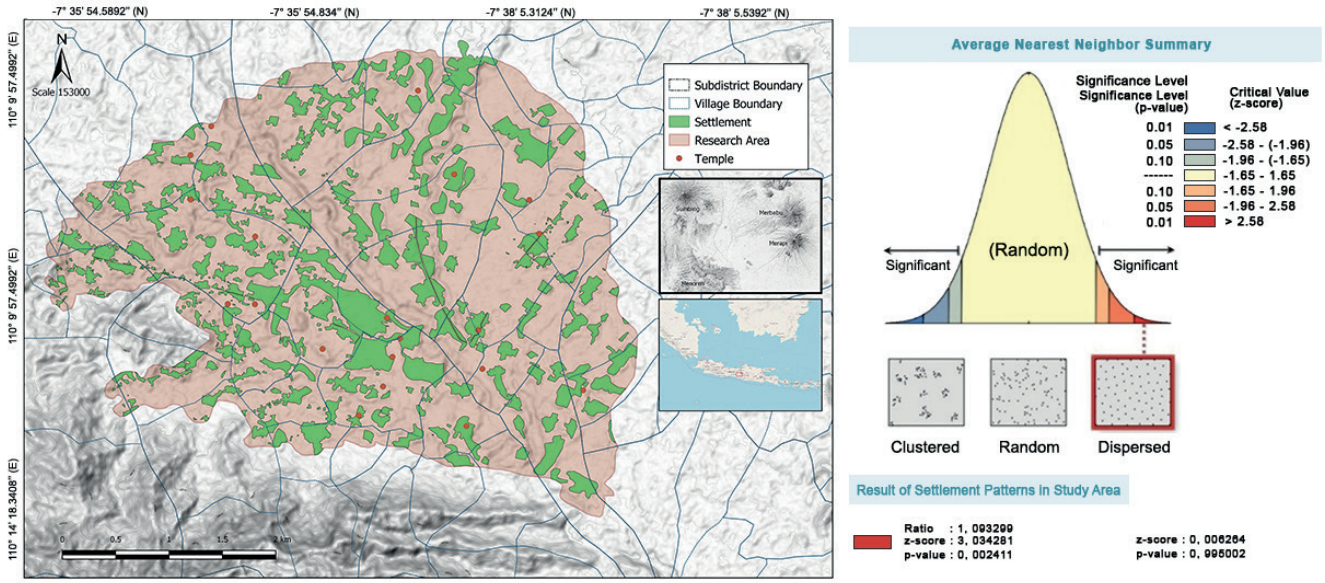

Fig. 6. Distribution of settlements in the study area (left) and results of the average nearest neighbour analysis showing dispersed settlement patterns in the study area (right)

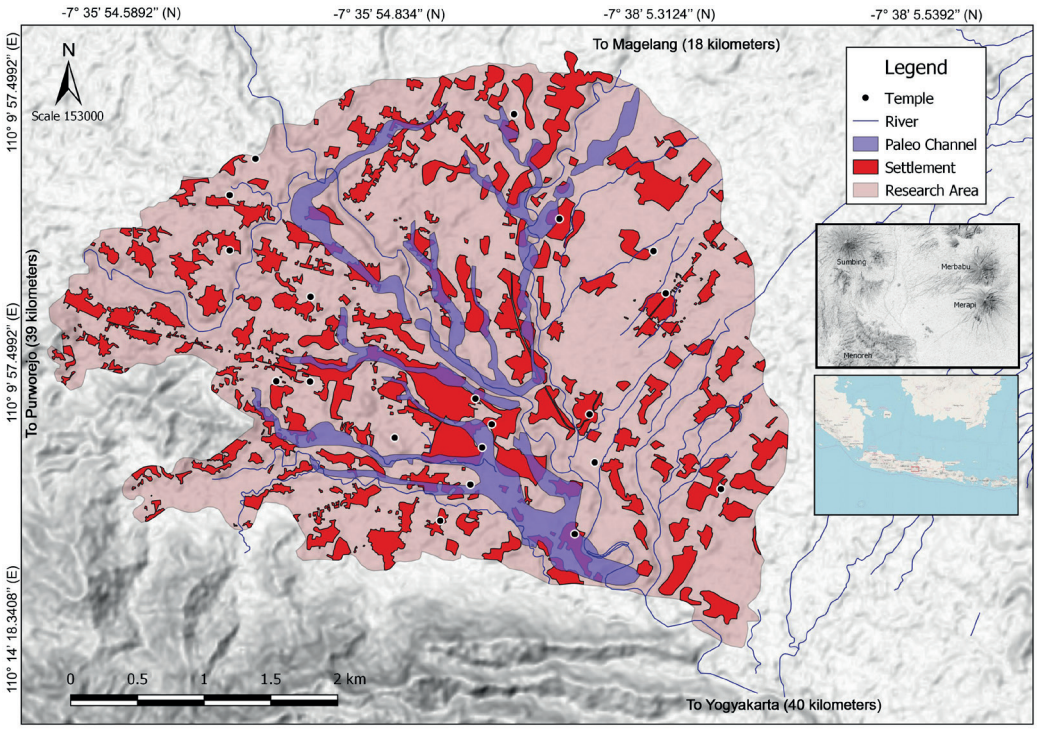

Fig. 7. The distribution of settlements to paleolake. Some residential units overlap against paleolake which indicate the development of settlements after the physical environment changes from the lake to an alluvial plain

explain that the characteristics of human activity deal with local and regional geomorphic changes. Geomorphic changes that occurred in the Borobudur Basin has fostered the development of a dispersed pattern settlement, formerly the pattern was random which was limited to the area around the palaeochannel. The same conditions are also found in various landscape in the world, for example the activities of residents in the Mississippi River valley (Kidder 2006) or the occupation of past inhabitants during the Nile River shrinkage (Honegger and Williams 2015). The findings from Walker et al. (1997) explain that humans try to adapt to the geomorphic processes that take place to decide the location of their settlements. In certain cases, the characteristics of landforms and geomorphological processes determine the type of developed settlement (Stafford and Creasman 2002). This study doesn't investigate the types of settlements in the Borobudur basin, but it is still limited to the spatial distribution pattern of settlements in the Borobudur basin dealing with the evolution of the landscape in the region.

The changes of favorable landscape conditions will further encourage the development of settlements and their distribution over a wider area. Lu et al (2017) say that landforms have a fundamental role in relation to the selection of residential locations. In Songshan Mountain, China, the selection of residential locations is involved over time. Lu et al. (2019) further explain that the development of settlements in Songshan Mountain occurred after the incised river period which made settlements on the river terraces safer from the effects of flooding. Compared with these two findings, the different landform conditions and geomorphic processes in the Borobudur Basin causes different settlement development characteristics. In the Borobudur Basin region, the settlements are growing and dispersed distributed due to the influence of geomorphic evolution in the form of sedimentation in the lake environment.

CONCLUSIONS

The evolution of the landscape that took place in the Borobudur basin during the Holocene period influenced various aspects, one of which was the life of the people in the area which was indicated by the selection of residential locations. The variation of temporal distribution shows that the changes of landscape affect the selection of settlement locations by communities across generations. The evolution of landscapes that provide opportunities for the development of settlements encourages the spatial distribution of settlements into a wider and more dispersed distributed area which differ from the conditions when there are still many natural obstacles. In the Borobudur area, this is indicated by the distribution of settlements which are dispersed distributed in the present times with landscapes in the form of alluvial plains, whereas in the past the distribution of settlements developed randomly under the influence of the landscape at that time in the form of lakes and swamps.

For evaluation purposes, this study is still limited to the comparison of spatial distribution of past settlements, using proxies for temple distribution, and current settlements related to the changes of landscape that occur. Further study on how the pattern and progress of the settlements development from time to time is required. Various relics that enrich the world's cultural heritage may be explored further. Moreover, the current spatial distribution of settlements can be used to give information to support the development, especially increasing accessibility to health, education, resources, and economic equality.

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