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Morphological Variation of the Transitional Area Between Wonosari Basin and Gunungsewu Karst

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ABSTRACT
This research investigates morphological variations in the transitional zone between the Wonosari Basin and the Gunungsewu Karst, an area where lithological heterogeneity, geological structure, and karstification processes interact to shape the landscape. Morphological and morphometric data were derived from Digital Elevation Model (DEM) interpretation, aerial photograph analysis, and field validation of dolines, valleys, and karst hills. The research results show that the transition zone is dominated by dissolution dolines, subsidence, collapses, and valley types that are generally blind valleys with orders of 0 to 3, a basin area of 2.35 km² with a ratio of 0.03, a valley density of 0.26 units/km, and a hill density of 18 units/km². These characteristics reflect the dominance of fluvial processes and indicate a relatively younger stage of karst development, known as fluviokarst. In contrast, Gunungsewu Karst shows a more developed morphology classified as polygonal or cockpit karst with a predominance of order 1 to 3 valleys, a basin area of 0.2 km² with a ratio of 1, a valley density of 0.67 units/km, and a hill density of 18 units/km². The dolines in this region are mostly solution-type with elongated and cockpit shapes, while dry valleys are the dominant type. Karst hills exhibit diverse morphologies, including conical, cone-convex, blunt, and elongated forms, complemented by minor features such as micropits, pits, shafts, and grikes. This study highlights the geomorphological significance of transitional karst evolution and provides essential insights for both theoretical advancement and sustainable management of fragile karst landscapes.

INTRODUCTION

Karst is a geomorphological feature characterized by the dissolution of carbonate rocks, such as limestone, resulting in a distinctive landscape and hydrological system (Aprilia et al., 2021). Karstification, or the process of forming karst landforms, is dominated by the dissolution process. Landform is a specific feature of the terrestrial surface formed by natural processes known as geomorphic processes (Irawan et al., 2025). Karstification plays a critical role in determining the morphology, dimensions, and aperture characteristics of joints, fractures, conduits, and caverns within soluble rock formations (Zerga, 2024). The manifestation and intensity of this process are influenced by a combination of internal and external factors, which may encompass geological (soluble, compact, thick, and possesses fractured rocks, rocks exposed to the surface), morphological, climatological (temperature), hydrological (sufficient rainfall, pedological, biological (forest cover), and anthropogenic influences (Zerga, 2024; Haryono & Adji, 2004).

In tropical regions such as Indonesia, elevated temperatures coupled with high levels of precipitation expedite the chemical dissolution of limestone, thereby promoting the rapid formation of karst landforms, including dolines, uvalas, poljes, and subterranean drainage networks. Nonetheless, in addition to these natural geomorphological processes, karst landscapes within tropical environments are increasingly subjected to environmental degradation driven by land-use modifications, mining operations, and excessive groundwater extraction. These anthropogenic activities pose significant threats to the stability of karst ecosystems and their associated water resources (Haryono et al., 2020).

The karst critical zone constitutes a vertically integrated system that encompasses the range from the vegetation canopy to the karst aquifers (Pu, 2025; Sullivan et al., 2019), and is distinguished by pronounced spatial heterogeneity and dynamic interactions between water and rock (Ravbar et al., 2026; Jiang et al., 2019). Karst landscapes serve as vital human habitats, sources of potable water, prominent tourist destinations, and represent the planet's largest natural carbon reservoirs (Hakim, 2017). Indonesia's karst region encompasses an area of approximately 304,000 km², representing roughly 1% of the global total. This region accounts for approximately 11% of the world's tropical karst areas and 45% of the tropical karst regions within Asia (Adji et al., 2023; Goldscheider et al., 2020). With approximately 25% of the global population relying on karst regions for their water needs, a comprehensive understanding of karst systems is crucial (Zerga, 2024).

One of the karst areas in the tropics in Indonesia is the Gunungsewu Karst, which is directly adjacent to the Wonosari Basin in the north. The Gunung Sewu Geopark consists predominantly of Neogene limestone and karst formations, with an estimated geological age spanning from the Middle Miocene to the Late Pliocene. The karst features within the park are attributed to the Wonosari-Punung formation, which has experienced tectonic uplift during its geological history (Dhamayanti et al., 2023). This geological formation is distinguished by the presence of bedded chalky limestone in its northern sector and massive coral limestone in its southern sector (Haryono et al., 2020).

The Wonosari Basin is a lagoonal limestone basin (Santosa, 2015). The main rock that underlies the peneplain is the limestone of the Wonosari Formation, which was formed during the Upper Miocene (± 16 million years ago) (Pannekoek, 1949). The structural configuration is characterized by a southward-dipping homoclinic structure inclined at an angle between 5° and 15°. Additionally, fracture patterns within the formation predominantly exhibit orientations along northwest-southeast and northeast-southwest axes (Kusumayudha et al., 2015; Adji et al., 2023). These limestones have compact characteristics, are easily dissolved, and possess many fractures due to tectonic activity, which is the movement of the Indian Australian Plate that crashes into the Eurasian Plate.

The transitional karst region is characterized by its primary lithology, specifically the Wonosari Formation. Within this area, two distinct types of limestone are present: massive limestone, which is shaped by the Gunungsewu Karst and exhibits relatively thin stratigraphy, and layered limestone, which is influenced by the geomorphology of the Wonosari Valley. These lithological types are often found in alternating succession within the transitional zone. The contact zone between these two lithologies delineates a unique and prominent morphological feature, thereby defining the distinctive landscape of the transitional karst region (Rachman et al., 2023).

Morphological studies of karst have previously been conducted by several researchers in the Gunungsewu Karst area, but detailed morphological studies of karst in the transition zone have never been conducted. The aim of this study is to characterize and contrast morphological variations between the Wonosari Basin and the Polygonal Karst of Gunung Sewu, using morphometric analysis and satellite and drone image interpretation, and to relate the results to aspects of geomorphological evolution and karst conservation implications in Indonesia. A variety of morphological knowledge is very important to examine as a basis for policies or decisions in karst management.

The heightened susceptibility of tropical karst environments to human-induced impacts underscores the importance of comprehensive geomorphological investigations to inform conservation strategies and promote sustainable management practices (Goldscheider et al., 2020). In addition, a study of the morphology of karst landforms in the transitional karst area is very important as an attempt to strengthen the development of Gunungsewu Geopark, which is the first UNESCO Global Geopark in Indonesia. Furthermore, the Gunungsewu Karst is a conservation area that requires proper protection. Therefore, the development of this area demands a thorough study of karst morphology and landform evolution to align with sustainable regional development, particularly in the agriculture and tourism sectors.

RESEARCH METHODS

The object of study in this research is the morphology of landforms originating from solutional processes in the transition zone between Gunungsewu Karst and Wonosari Basin. This transition zone is so vast that only a small portion of the area is the focus of research. The area covered by this study is 4,282 hectares. Astronomically, the study area is located between 8 ° 0' 10.88“- 8 ° 3' 36.29” South Latitude and 110 ° 33' 7.16“- 110 ° 36' 49.30” East Longitude. Administratively, the research location is in four subdistricts, namely Wonosari, Paliyan, Tanjungsari, and Semanu, which are part of the Gunungkidul Regency. The considerations for selecting the research location are the presence of karst morphological variations and factors controlling karst development. The karst area under study is influenced by allogenic rivers (rivers originating from non-karst areas) in the northern part and by autogenic flows in the southern part. In addition, this area is part of the Gunungsewu geopark site.

This morphological study covers both morphography and morphometry. The morphographic aspects of landforms are assessed qualitatively, while the morphometric aspects are assessed quantitatively. The structured research stages are presented in the form of a research flowchart in Figure 1. The visual interpretation was carried out on Landsat images and DEM (Digital Elevation Model) to obtain morphological information and karst morphometry, including doline, karst valley, and karst hill. The morphometric parameters required are presented in Table 1, and morphometric measurements of closed depressions are measured based on the formula (Williams, 1971; Ford & Williams, 2007) in Figure 2.

Table 1. Morphometric Parameters

Landform Unit	Parameters	Symbol/Equation	Unit
Doline	Number	N_d	-
	Width	W	m
	Length	L	m
	Doline area	A_d	m^2
	Karst area	A_k	m^2
	Density	$D_d = N_d / A_k$	Number/m^2
	Average area	$A_d = 1/N_d \Sigma A_d$	m^2
	Doline area ratio	$R_d = 1/A_k \Sigma A_d$	-
Karst Valley	Order	-	-
	Length	L	m
	Width	W	m
	Depth	D	m
	Density	$D_l = N_l / A_k$	Number/m^2

Karst Hill or Tower	Number	N_B	-
	Height	H	m
	Slope	-	° (degree)

(Source: Data Processing, 2025)

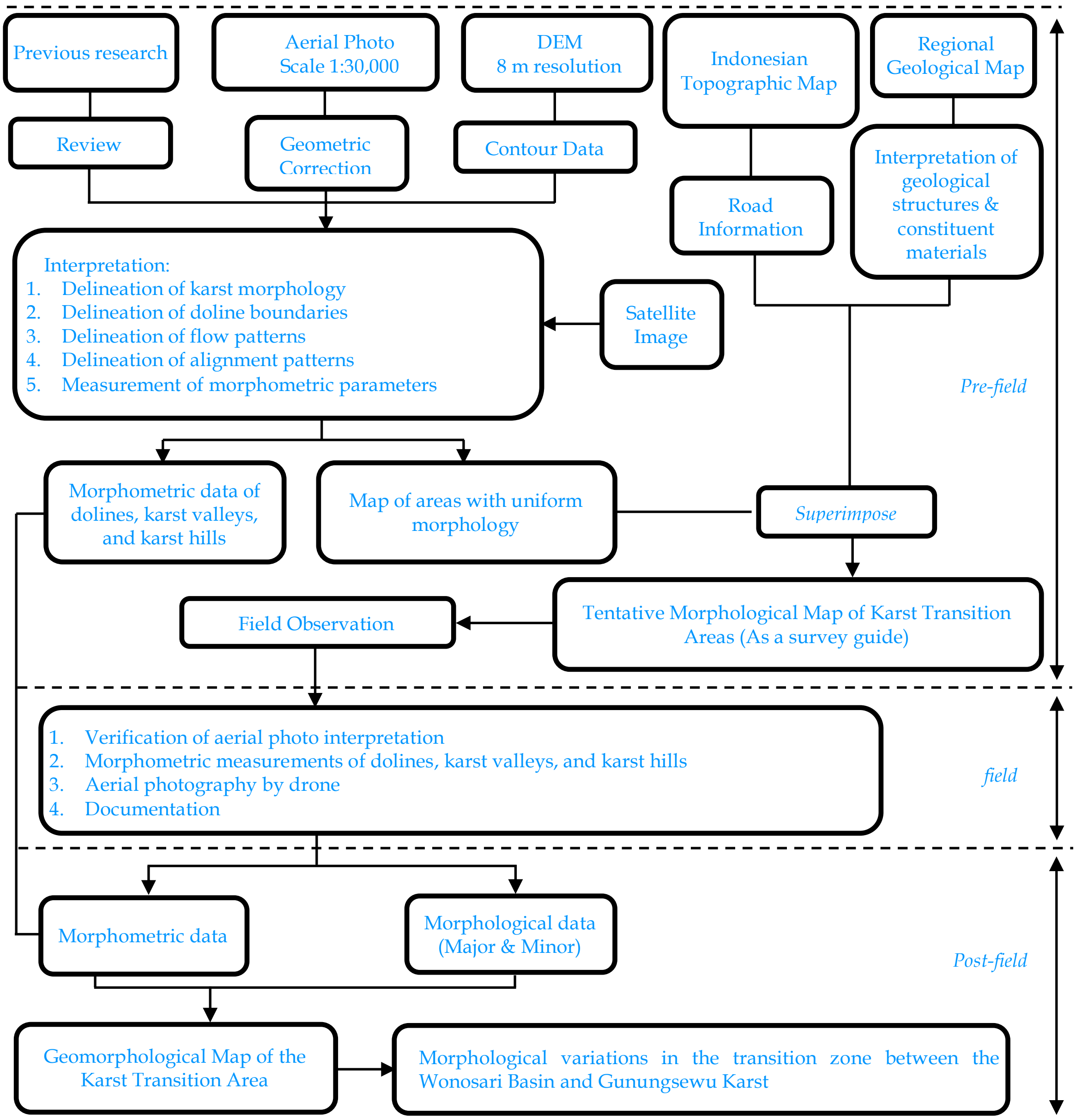


Figure 1. Research flowchart (Source: Data Processing, 2025)

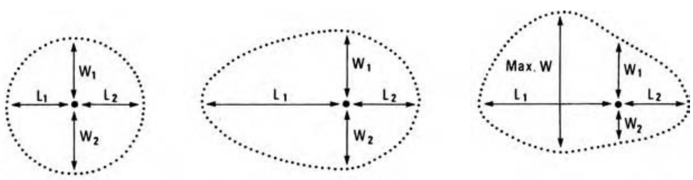


Figure 2. Morphometry of Closed Depressions (Source: Data Processing, 2025)

$$L_1 = L_2$$
$$W_1 = W_2$$
$$W_1 + W_2 = \text{Max. W}$$
$$\frac{L_1}{L_2} = 1 = R_L$$
$$\frac{W_1}{W_2} = 1 = R_W$$
$$R_L \,.\, R_W = P_S = 1$$
$$\frac{\sum L}{\text{Max. W}} = 1 = R_{Lw}$$

$$L_1 \neq L_2$$
$$W_1 = W2$$
$$W_1 + W_2 = \text{Max. W}$$
$$\frac{L_1}{L_2} = \frac{4}{2} = 2 = R_L$$
$$\frac{W_1}{W_2} = 1 = R_W$$
$$R_L \,.\, R_W = P_S = 2$$
$$\frac{\sum L}{\text{Max. W}} = \frac{6}{4} = 1{,}5 = R_{Lw}$$

$$L_1 \neq L_2$$
$$W_1 \neq W2$$
$$W_1 + W_2 \neq \text{Max. W}$$
$$\frac{L_1}{L_2} = \frac{4}{2} = 2 = R_L$$
$$\frac{W_1}{W_2} = \frac{2}{1} = 2 = R_W$$
$$R_L \,.\, R_W = P_S = 4$$
$$\frac{\sum L}{\text{Max. W}} = \frac{6}{4} = 1{,}5 = R_{Lw}$$

Description:
R_L : Closed depression length ratio
R_W : Depression width
P_S : Symmetry product
R_{LW} : Length and width ratio

The above formula is used to identify major morphology such as dolines, valleys, and hills. Meanwhile, minor morphology measurements are carried out directly in the field using a roller to obtain data on width, length, and depth. Field studies were carried out to validate the karst morphological zoning maps and to obtain other information. The sampling technique for validating interpretation data was carried out using the transect and traverse techniques by making parallel plots in each part of the non-karst area, transition area, and karst zone. The validation process was carried out by measuring the morphometry of dolines, karst valleys, and karst hills at 16 sample locations with an area of 1 km². Drone mapping was carried out to obtain morphometric data on some of the karst morphologies found at the sample location. In addition, the drone was also used to document karst morphology in the study area.

Site Description

The Southern Mountain Zone is a mountainous area located in the southern part of Central Java; the area stretches from the southeastern part of the Special Region of Yogyakarta and extends eastward along the south coast of Southeast Java. The Southern Mountain Zone is divided into two parts: Wonosari Basin with the karst topography of Gunungsewu in the south and igneous and volcanic rocks in the north. The southern and northern parts of the Southern Mountain Zone are separated by the Wonosari Basin and the Baturetno Basin.

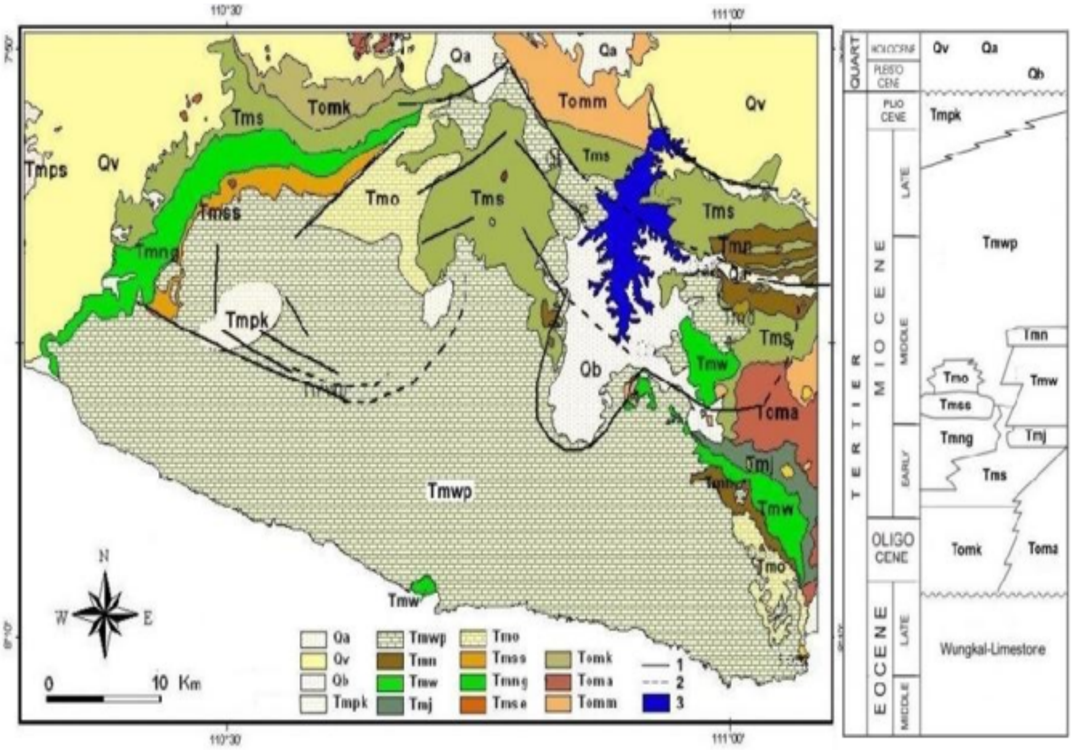
The Wonosari Formation began to form in the Middle Miocene, indicating that the carbonate rocks had been formed extensively. The Wonosari Formation was dominated by layered limestones aged Middle Miocene-Pliocene (Hafiz et al., 2023). There are two types of limestone found at the research site, namely rudstone and packstone. Rudstone is found in the southern part in the form of a massive rock, while packstone is found in the northern part in the form of rock layers (Haryono et al., 2020).

In general, the geomorphology of the Gunungkidul region has three main morphological units. The morphological unit consists of Baturagung Hills in the north, Wonosari Basin in the middle and Gunungsewu Karst in the south. The difference in the morphological units indicates a strong role for endogenous and exogenous factors. The endogenous factors that influence are the diversity of lithology and geological structures, while the exogenous factors that work are erosional and dissolving processes that form erosional strips and karst landscape.

These structural hills are formed by a diatropic process in the form of multilevel faults. The topography of these hills has a sloping slope at the bottom (15-30%) and steep at the top (30-45%). There is a ridge extending from south to north in the west, and from west to east in the north, with a very steep slope (> 45%), which is an escarpment. Regionally, the geological structures found in the Baturagung Hills are faults, joints, and folds with little foliation. The fold consists of an anticline and a syncline, which have a northeast-southwest direction with a small angle (3° - 15°). Fault is generally in the form of a descending fault with an antithetic fault block pattern (Bemmelen, 1970). The main fault is directed northwest-southeast and locally directed northeast-southwest (Santosa, 2015).

Geomorphologically, the Wonosari Basin is a basin with flat and undulating topography, which is bounded or surrounded by a series of Baturangung Structural Hills in the north and west, massive stages in the east, Gunungsewu Karst in the south and west (Santosa, 2015). Wonosari Basin is a limestone lagoon basin. This morphological unit has a flat topography with slopes of 0-3% to undulating slopes of 3-8%; there are light, sparse, and dense incisions. Geomorphological condition is genetically formed by the process of elevating and folding of the plateau with the main limestone rock, and geodynamically is influenced by the depositional process of shifting the slopes of the surrounding hills (Santosa, 2015).

Gunungsewu Karst is a morphological unit that originated from the dissolving process, which is called karst. Karst is a landscape that has distinctive relief and drainage due to the higher degree of dissolving rock compared to other types of rock (Santosa, 2015). Gunungsewu Karst has a slope ranging from 8-> 40%. The research location, based on the regional geological map, is shown in Figure 3.



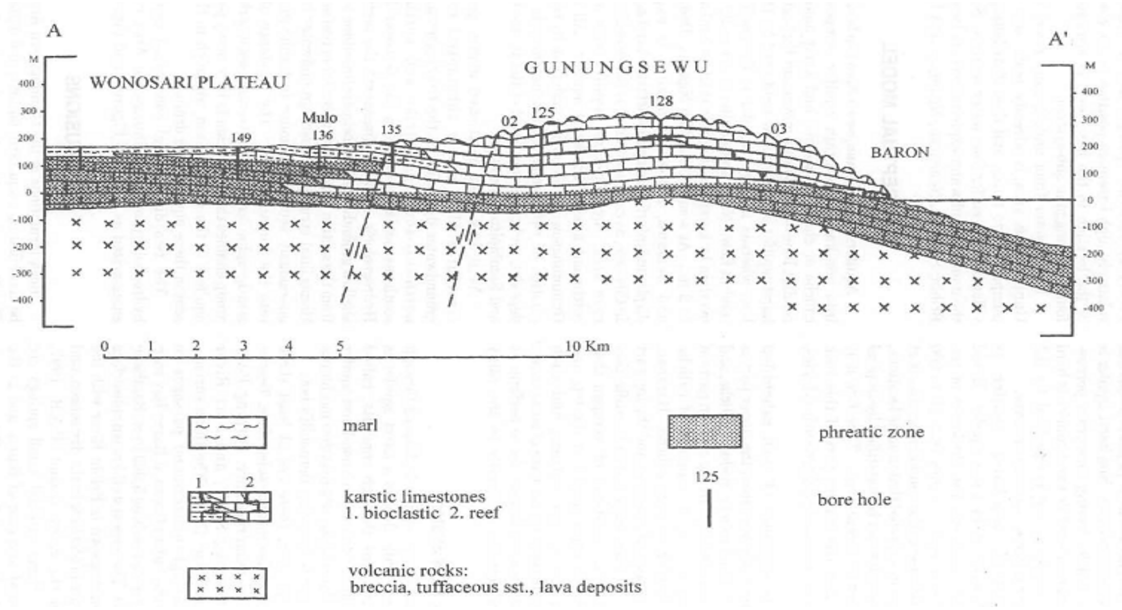


Figure 3. Research Locations Based on Regional Geological Maps (left) (Source: Haryono et al., 2017, with modifications) and Sketch of the Research Location (right) (Source: Notosiswoyo & Kusumayudha, 1999) with modifications)

Climate and Land Use

The climate in the Gunungkidul region is a dry tropical climate with constant air temperatures. The average rainfall is 1,602 mm/year, with an average of 103 rainy days. There are 7 wet months, while there are 5 dry months. The rainy season begins in October-November and ends in April-May each year. Peak rainfall occurs in December-February. Central Gunungkidul Regency has the highest rainfall compared to the northern and southern regions. South Gunungkidul has the latest rainy season. Rainfall is the main solvent in the karstification process. The greater the rainfall, the greater the dissolved medium, so that the rate of dissolution that occurs in carbonate rocks will be higher.

The average daily temperature is 27.7° C, minimum temperature 23.2°C and maximum temperature 32.4° C. Relative humidity ranges from 80% to 85%, not significantly affected by altitude but more by the season. The highest humidity occurs between January and March, while the lowest occurs in September.

The Gunungsewu karst region is characterized by recurrent drought phenomena. The scarcity of water resources is primarily attributable to geological factors, specifically the development of dissolution corridors that influence subsurface hydrology. These geological features have led to surface aridity, consequently resulting in water shortages for local communities, particularly during the dry season (Cahyadi et al., 2020; Zhou et al., 2024). Consequently, the deficiency of surface water resources constitutes a principal factor contributing to agricultural drought in karst regions (Liu et al., 2022; Liu et al., 2023; Zhou et al., 2024).

The most dominant land use in Gunungkidul Regency is dry fields, farms, and gardens. This is because the majority of the population of Gunungkidul Regency works in agriculture. Land use in the Wonosari Basin is dominated by settlements and dry fields, with only a small portion consisting of forest land and water bodies. Land in the Gunungsewu karst is generally used by the community as rain-fed rice fields or dryland agriculture, with crops such as gaga rice, vegetables, peanuts, corn, and other types of secondary crops (Pannekoek, 1949). Agricultural activities in the Gunungsewu Karst are carried out in the valleys between the karst hills and on the slopes of the karst hills using terracing techniques.

RESULTS AND DISCUSSION

The karst transitional area had quite unique morphological variations, including major karst morphology, such as caves, dolines, springs, karst valleys and minor morphology such as micropits, pits, shafts and others. This variation was because the transitional area contain a fairly thin thickness of massive limestone which was above the layered limestone of the Wonosari Formation, so that it had a fairly sloping rock layer area with the result that transitional area hold many blind valleys which had function as water control of wonosari Basin area (non karst) to an underground river system in the Gunung kidul Karst Area which had thick massive limestone.

Major Morphology

1) Doline

The doline found in Gunungsewu Karst had a doline order which was quite varied compared to the transitional area. The indication is that the karstification process that occurs in Gunungsewu Karst is more intensive than in the transitional area. Limestone in the Wonosari Basin did not undergo a karstification process, so no doline was found in this area. The doline ratio in the Gunungsewu Karst was 1, which was higher than in the transitional area, 0.03. There were more dolines in the Gunungsewu Karst than in the karst transitional area. There were 89 units of doline in the Gunungsewu Karst and 5 units of doline in the karst transitional area.

Dolines found in Gunungsewu Karst had a larger size than the dolines in the transitional area. The density of doline in the Gunungsewu Karst was denser than in the transitional area. The doline density in the Gunungsewu Karst was 5.1 units/km^2, while the doline density in the karst transition was 0.43 units/km^2. Morphometric analysis was carried out on all doline units in the study area. Doline morphometric data in the study area are presented in Table 2.

Table 2. Doline Morphometry

Morphometric Aspects	Wonosari Basin-Transitional Area		Gunungsewu Karst	
	Range	Average	Range	Average
Order	0	0	0 - 3	3
Doline Area (m^2)	3.368-254.654	62.856	22.980-1.018.336	197.016
Length (m)	95 - 645	249	177 - 1592	650
Width (m)	57 - 588	200	123 - 858	371

(Source: Data Processing, 2025)

Dolines found in the karst transition area genetically consist of solution, subsidence and collapse dolines. The solution doline was formed due to the dissolving process. This doline was covered by an alluvium deposit, whereby above the fracture, as a result of the dissolution, is the underground drainage system. The dissolving doline found in the transitional area has a bowl-like shape. A collapse doline was formed when a cave or channel near the surface collapses due to the inability to support the roof. The collapse doline found in the transitional area has a shape resembling a well. All types of dolines found in the study area can be seen in Figure 4.

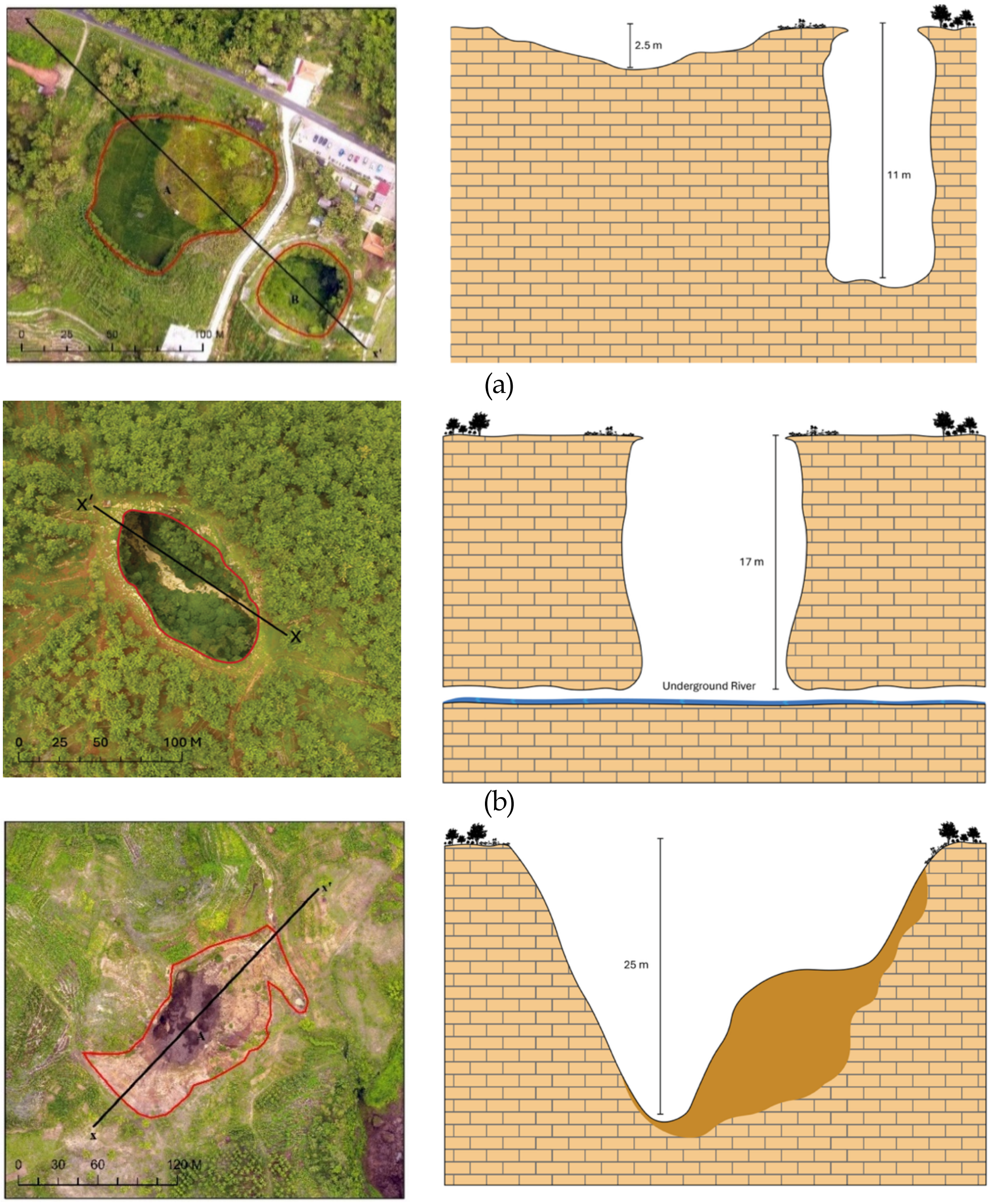


Figure 4. Alluvial doline (A) and collapse doline (B) in Geosite Ngingrong (a), Collapse doline located in Gua Ngeleng (b), Subsidence doline in Luweng Blimbing (c)
(Source: Data Processing, 2025)

Doline subsidence exists in the karst transition area, which was found in Luweng Blimbing. This doline has a funnel-like shape. The chrysolite tropical cyclone that occurred in 2017 caused Luweng Blimbing to undergo significant changes both in terms of shape and area. The doline continued to experience changes in shape and area, there were five dynamic stages of Luweng Blimbing including: 1) the occurrence of flood due to the overflow of the underground river and the Tumbul Alogeneic River located in the east of Luweng Blimbing, 2) the occurrence of rapid recede which was followed by material sedimentation brought during the flood and the collapse of the doline wall, so that the ponor was clogged, 3) the formation of the lake within a few days, 4) The occurrence of subsidence which opened the ponor so that the lake receded and dried up, and 5) the expansion of the doline wall which was still occurring until now with smaller intensity (Haryono et al., 2020).

Genetically, doline found in Gunungsewu Karst was a solution doline. This doline was formed because of the dissolving process, which concentrates in the joint, the widening of the rock pores, or because of the differences in the carbonate rocks' mineralogy. The Elongated doline, which was formed by the dissolution along the height, in some places, created the cockpit. Cockpit doline has a star-like shape. The Elongated doline and cockpit doline are presented in Figure 5.

Figure 5. Elongated doline (left) and cockpit (right) located in Gunungsewu Karst
(Source: Field Documentation, 2025)

Dolines found in the karst transition area were the result of the karstification process of rock gaps/fractures due to tectonic processes. The dissolution that occurred in the fracture formed several types of doline, including bowl doline and funnel doline, according to the Cvijic classification (Williams, 1971). The karst transition area has a dendritic-parallel flow pattern with outlets in the form of sinkholes that directly enter the underground river system.

The Gunungsewu Karst area has a multibasinal flow pattern with sinkholes located at the lowest part of the closed basin, so that water flows into the sinkholes from various sides of the basin. The distribution of sinkholes in the karst transition area tends to cluster in several areas, such as at the Ngingrong Geosite, where there are four sinkholes, Luweng Blimbing, and Ngeleng Cave. These sinkholes channel surface water directly into the underground river system. The Gunungsewu Karst area has a relatively random distribution of sinkholes, but they tend to point north. This occurs because of the difference in elevation between Gunungsewu Karst and the lower Wonosari Basin, so that surface flow tends to head north.

2) Karst Valley

Karst valleys are relatively narrow plains located between karst hills. Generally, the topography of karst valleys is in the form of plains or depressions with a slope of 0-3%. Morphometric analysis was carried out on the karst valley in the transitional area and the Gunungsewu Karst. The Karst valley in the transitional area had a density of 0,26 unit/km^2, while the valley in Gunungsewu Karst had a density of 0,67 unit/km^2. The morphometry of other karst valleys is listed in Table 3.

Table 3. Karst Valley Morphometry

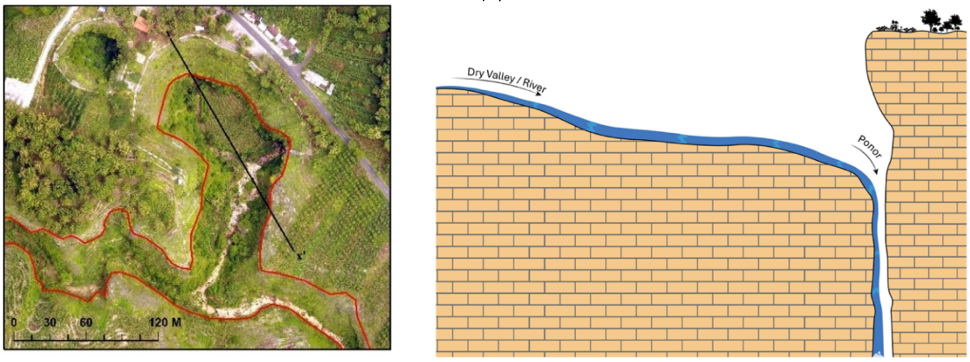
Morphometric Aspects	Wonosari Basin-Transitional Area		Gunungsewu Karst	
	Range	Average	Range	Average
Order	0-3	0 & 3	0-3	2 & 3
Length (m)	81-19.174	4.845	766-2.723	1.691
Width (m)	11-61	31	46-170	75
Depth (m)	5-20	13	28-62	39

(Source: Data Processing, 2025)

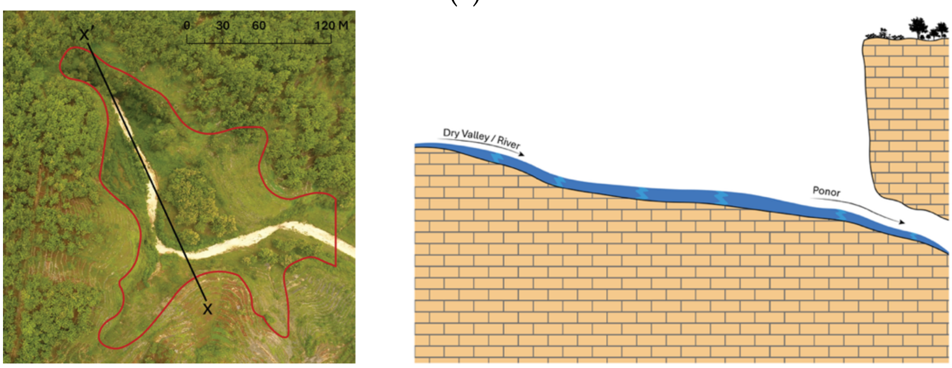
Most of the karst valleys in the transitional area were blind valley type and dry valley type, except for the karst valley in the Gunungsewu Karst, which belonged to the dry valley type. These valleys are composed of alluvial material resulting from the sedimentation of karst hills eroded by surface runoff and colluvial material or slope debris resulting from rock weathering. Karst valleys are local aquifers that store rainwater as soil moisture.

The blind valley in the karst transitional area had functioned as a water control from non-karst areas or from their surroundings. The water will flow through the valley and will enter through the ponor at the end of the valley and into the underground river system in the Gunungsewu Karst area. The blind valley in the transitional area can be seen in Figure 6.

(a)



(b)



(c)

Figure 6. Blind Valley, located in Serpeng (a), Ngingrong Geosite (b), Ngeleng Cave (Source: Data Processing, 2025)

The blind valley in the transitional area had surface flow throughout the year that flows into the ponor. The distribution of ponors tends to be dense and randomly distributed in the Gunungsewu Karst Area. This is also in line with research conducted by Haryono (2008) on part of the Gunungsewu Karst located in the Panggang Area and its surroundings. The study states that the randomly distributed porosities in the Gunungsewu Karst Area indicate that secondary porosity has undergone further development. This porosity allows surface water to directly enter the percolation system. Limestone is exposed quite high above sea level, marked by the presence of karst hills with heights of more than 200 meters above sea level. This allows for vertical water drainage. This is evident from several types of caves formed by vertical dissolution, resulting in vertical cave corridors. One example is Serpeng Cave.

The influence of the geological structure on the karst valley was that it corresponded to the orientation of the strike direction. The main karst valley generally forms a lineament. The straightness of the valley reflects the direction of faults and fractures. The orientation of the valley was dominated by the northwest-southeast and northeast-southwest directions. This direction was the result of compression in the south-north direction caused by the movement of the Indian-Australian plate crashing into the Eurasian Plate (Haryono, 2008). Furthermore, Tjia (2013) revealed that the pre-carbonate topography of the hilltop was thought to have an effect on the formation of the depositional pattern of carbonates, reefs, and clastic limestone. The muscular pattern, fractures and faults correlated with the straightness of the hill and valley of Gunungsewu Karst.

3) Karst hill

The karst hill in the study area consists of several shapes, which were conical and elongated (ridge), conical shape consists of a cone (conical karst), convex-cone, convex, and a blunt cone (dome). The conical karst formation had conical ridges; the convex cone had a conical shape with a convex peak. Karst hill with a convex shape had a relatively convex peak, and the dome shape had a dome-like hilltop with a relatively flat igir surface. The elongated hill formation had elongated ridges. The interpretation of the aerial photographs, satellite imagery and DEM data found that the total number of karst hills in the study area was 314 units. The karst hills in the Gunungsewu Karst Area can be seen in Figure 7.

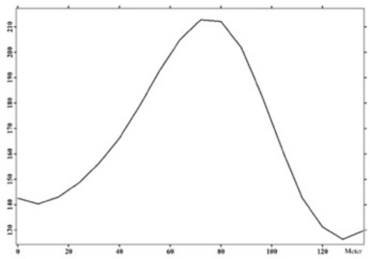
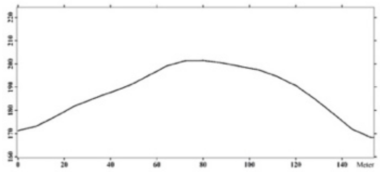
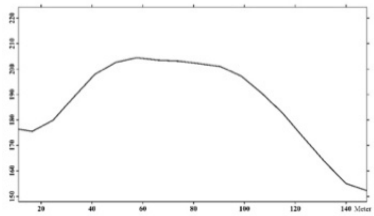
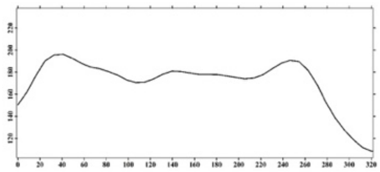
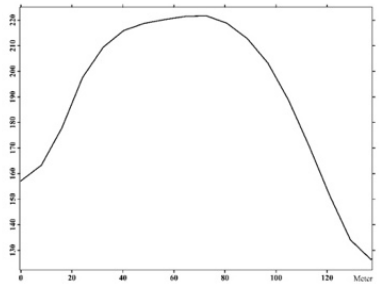
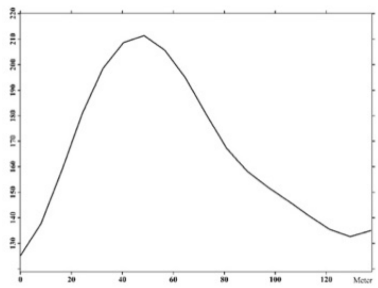
(a) (b) (c)

Figure 7. Karst Hills in the Gunungsewu Karst Area (a) Ridge
(b) convex cone, convex, blunt cone (c) conical (Source: Field Documentation, 2025)

The density of conical karst in the study area reached 0.18 units/Ha, or 18 units/km2. Karst hill in the karst transition area had an altitude ranging from 150 to 250 masl. The conical formation tends to be scattered randomly in several locations in the study area, which were included in the Gunungsewu Karst area. The conical karsts were only found in karst areas, and a small part was found in the transitional area between karst and non-karst. This conical distribution was the most dominant in the southern part, leaning towards the center. This was because the karst area was where the solutional and karstification processes occurred, resulting in the establishment of karst hills as remnants of these processes. Karst areas that had a large basin index in the field were characterized by the presence of a cone hill (Haryono, 2008).

The patterns of joints and faults correlate with the straightness of the hills and valleys of the Gunungsewu Karst. The position and thickness of the rock layers also control the shape of the hills. Thin, tilting rock layers produce conical hills, thick layers produce convex hills, while flat rock layers produce various types of hilltops, namely domes, convexes, and elongated shapes (Kusumayudha et al., 2015). Karst areas with a large basin index in the area are characterized by the presence of conical hills (Haryono, 2008). Morphometric data of karst hills in the Gunungsewu Karst can be seen in Table 4.

Table 4. Morphometry of Several Karst Hill Samples

Sample	Location	Crossection (m)	Elevation (m)	Slope (°)	Hill shape	Description
A	8°2′22.58″S 110°33′43.09″E		217	60	Conical	Karst Transition Zone
B	8° 2'31.22"S 110°35'4.29"E		201	36	Convex	Karst Transition Zone
C	8° 2'17.01"S 110°36'21.88"E		204	45	Convex cone	Karst Transition Zone
D	8° 3'13.70"S 110°33'44.99"E		198	52	Ridge	Gunung sewu Karst
E	8° 3'12.24"S 110°35'3.73"E		226	60	Blunt cone	Gunung sewu Karst
F	8° 3'16.15"S 110°36'24.31"E		212	45	Conical	Gunung sewu Karst

(Source: Data processing, 2025)

Minor Morphology

The morphology of minor karst in the research area was dominated by the formation of micropits, pits and shafts. Micropit was a karst formation (micro karren) dissolved by water sized less than 1 cm. This micropit formation can be found in almost all research locations. Pit was a micro karren formation that had a round or irregular oval shape and had a diameter of more than 1 cm. Pit formations can be found in several research locations, such as at the top of Karst Hill and near the mouth of the cave. The measurement results of several pits found in the field have diameters ranging from 1,2 cm to 7,5 cm and had a depth ranging from 3,5 cm to 12,5 cm.

Shafts are karrened with a downward tunnel-like shape and interconnected to resemble small caves (protocaves). This formation had varying diameter and depth, with a diameter ranging from 2,2 cm to 8,5 cm and a depth ranging from 7,5 cm to 21 cm. In addition, there was also a minor karst morphology type, namely grikes. This formation was a solutional result controlled by a major fracture or fault, with a length of 1 - 10 meters. Figure 8 shows the appearance of micropit and pit found on the tops of karst hills, and also the shafts and grikes found at the research location.

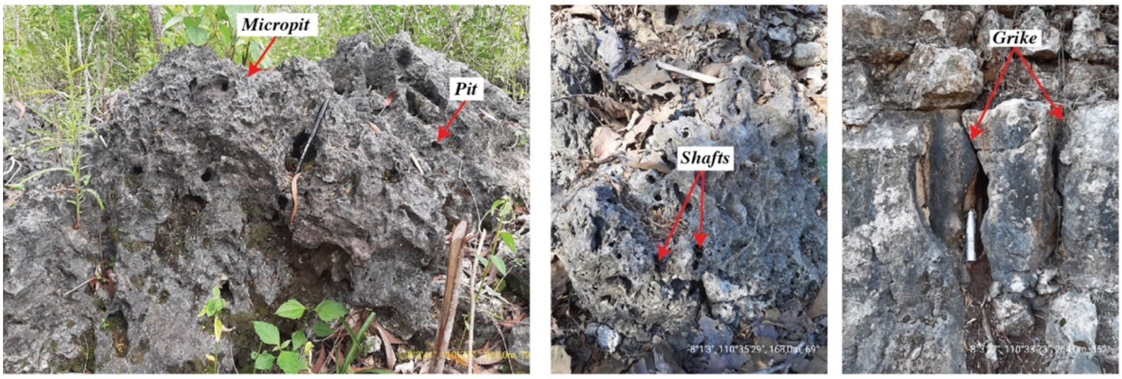


Figure 8. Karst Minor Morphological Appearances (a) Mikropit and pit (b) Shafts (c) Grikes (Source: Field Documentation, 2025)

Haryono et al. (2017) mentioned that the history of elevation had an important control on morphological differentiation between the upland section and the slope section. The slope of the 2% in the south controlled the karst development indirectly through the increase in runoff, which produces more basins or valleys. This was also in line with research conducted by (Kusumayudha et al., 2015), which stated that the morphological variations of the Gunungsewu karst were influenced by physical variations in lithology, such as rock hardness, internal friction angles, geological structures, including solid orientation, presence, position and thickness of rock layers.

The karstification process in the karst transitional area was still ongoing. Research conducted by Zhu et al. (2023) showed that Ca mineral dissolution was faster than Mg mineral dissolution. The dissolution in the Gunungsewu Karst transition area and Wonosari Basin occurred intensively because it had an average Ca content of 74% (Diah et al., 2021). Massive limestone in the transitional karst was above layered limestone, which tends to be thin. These two types of limestone created a unique morphology, such as the formation of doline, cave and blind valley with ponor. These morphological variations were the result of fluvial and solutional processes. The geomorphological map of the karst transition area can be seen in Figure 9.

Morphological transformations of karst are not only controlled by geology and karstification, but are also significantly impacted by human interventions. Karst landscapes are highly sensitive to changes in land use, deforestation, development, and extractive activities due to their connection to surface and subsurface hydrological systems. Disturbances to land cover can accelerate erosion, increase sediment transport, and modify the dissolution processes that form dolines and karst valleys (Zerga, 2024). In tropical fluviokarst systems, anthropogenic impacts can be more intense due to the direct interaction between surface runoff and underground systems. Vegetation clearing and agricultural activities increase runoff and sedimentation into karst systems, which can potentially alter local hydrological and morphological dynamics, including modifying the shape of dolines and natural flow networks (Tavares et al., 2025).

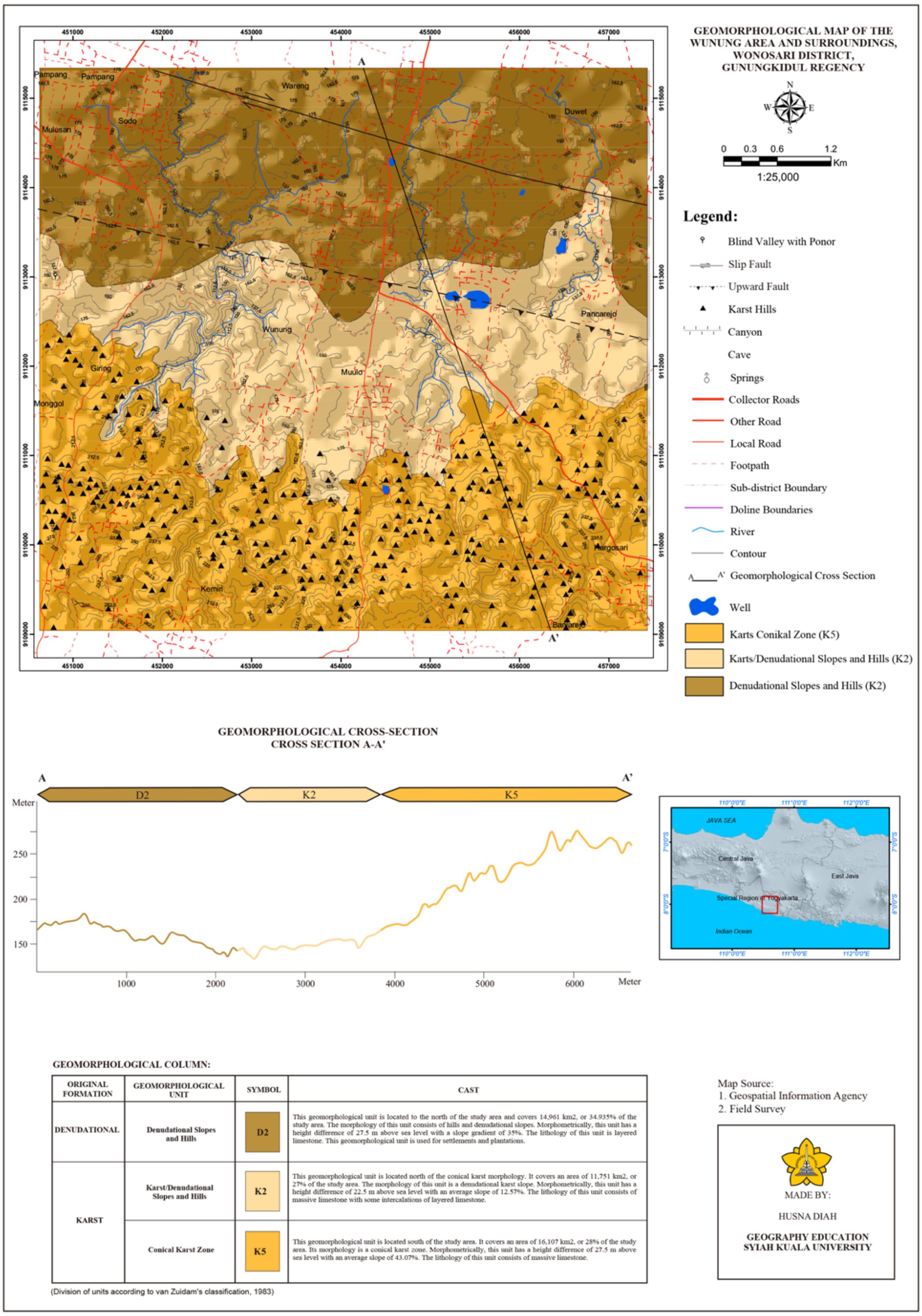


Figure 9. Morphological map of the transition area between the Wonosari Basin and Gunungsewu Karst (Source: Data Processing, 2025)

Comparison of Karst Morphological Characteristics

Karst geomorphology research has been conducted throughout Indonesia and globally. Each karst landscape has similarities and differences in karst morphology. This occurs due to differences in the controlling and driving factors at each karst landscape. Indonesia has quite a number of karst landscapes spread across several islands. A comparison of the karst morphology of the study area with other karst morphologies in Indonesia and other countries is shown in Table 5.

Table 5. Comparison of Karst Morphology in the Study Area with Others

Karst Region	Major Morphology			Minor Morphology	Karst Typology	Source
	Doline	Karst Valley	Karst Hills			
Transitional Area of the Wonosari Basin-Gunungsewu Karst, Yogyakarta, Indonesia	Solution, subsidence , collapse doline	Dry Valley & Blind Valley	a small number of cone-shaped karst hills, convex cones, convex	micropit, pit, shafts & grikes	Fluviokarst	This Study
Gunungsewu Karst, Yogyakarta, Indonesia	Elongated doline & cockpit	Dry Valley	Ridge, convex cone, convex, blunt cone, conical	micropit, pit, shafts & grikes	Polygonal/ Cockpit Karst	This Study
Maratua Karst, East Kalimantan, Indonesia	Solution & collapse doline	Structural valley	Conical, tower karst, mesa hills, and undulating low hills	Karren	Platformkarst	(Haryono et al., 2018)
Sangkulirang-Mangkalihat Karst Area, East Kalimantan, Indonesia	Solution doline	Dry Valley & Polje	Tower & cone karst	splitkarren & rillenkarren	Fluviokarst	(Hakim, 2017)
Dinaric Karst, Slovenia-Croatian	Polygonal & collapse doline	Dry Valley	Limited hill formation	Ponors, shafts, solution karren	Classical Karst	(Ravbar et al., 2026b)
Karst Critizal Zone, South China	Polygonal doline & cockpit	Subsurface -controlled valleys	Tower & cone karst	Karren, Fissures, vertical shafts	Polygonal/ Cockpit Karst	(Jiang et al., 2019; Chen et al., 2025)
Tropical Karst (Global review)	Solution & collapse doline	Dry Valley	Conical, tower, and residual hills	Karren, Shafts	Polygonal karst	(Zerga, 2024)
Tropical karst (Brazilian Cerrado region)	Solution, subsidence doline	Active surface drainage, Blind Valley	Moderate hills	Fissures	Fluviokarst	(Tavares et al., 2025)

(Source: Data Processing, 2025)

Comparison with karst areas in China, the Dinaric karst in Europe, and other classic carbonate regions reveals that the study area exhibits a unique combination of morphological elements, such as solution dolines, dry valleys, and residual karst hills developed within a relatively narrow transition zone. This configuration reflects active geomorphological adjustment processes between denudational processes in the basin area and intensive karstification processes that are characteristic of tropical karst environments.

The karst transition area has morphological characteristics that are undulating, while the Gunungsewu Karst Area is hilly, consisting of cone-shaped and elongated hills. Based on the karst development model according to Haryono (2008), this karst transition area can be categorized as a karst area in its early stages of development. In addition, several surface rivers are found in the karst transition area. The karst type in the early stage tends to be more appropriately categorized as fluviokarst.

Hydrogeological studies of tropical fluviokarst indicate that the interaction between surface flow and underground systems is a key aspect in landscape evolution prior to full transformation to predominantly underground karst drainage (Tavares et al., 2025). These conditions confirm that fluviokarst is characterized by a network of active fluvial valleys and mixed doline morphology, representing the early to middle stages of karst evolution, where fluvial and dissolution processes occur simultaneously and form a topography that is not yet fully integrated into the karst system.

Fluviokarst areas can be managed for dryland agriculture and agroforestry development, as they still have surface runoff, river valleys, and thicker soil compared to mature karst. However, management at this stage must remain conservation-oriented, as fluviokarst is the early stage of karst system formation and is sensitive to land use changes. If left uncontrolled, damage at the early stage can accelerate environmental degradation, reduce infiltration capacity, and disrupt the future development of the karst hydrological system. Therefore, fluviokarst should be managed as a restricted-use zone that supports sustainable production, soil and water conservation, and as a buffer zone for mature karst areas that have a higher protective function.

In contrast, the Gunungsewu Karst Area can be said to have undergone mature karst development based on the karst development model according to Haryono (2008) or can be said to be polygonal karst or cockpit karst. This indicates an advanced stage of development that requires strict conservation measures and should only be used sustainably for ecotourism and cultural heritage preservation.

A literature review on karst topography confirms the importance of large-scale dissolution processes that form classic karst morphology, such as cockpit dolines, depressions, and complex residual hills in the advanced stages of karst evolution (Zerga, 2024). In the cockpit karst phase, surface drainage is almost completely transferred to underground conduits, resulting in a high density of dolines and a distinctive relief pattern as a manifestation of the dominance of chemical solutions over fluvial processes. These patterns correspond to high morphometric parameters such as large valley ratios, high valley density, and smaller basins, which indicate a mature karst system.

Karst transition zones are generally sensitive areas because they are the interface between surface and subsurface flow systems. Therefore, a detailed understanding of the morphological variations in this zone can assist local governments and stakeholders in determining conservation priorities, restricting extractive activities, and controlling land use so as not to disrupt the hydrological balance of karst. This information is also highly relevant to support spatial planning, disaster mitigation, and water resource management in karst areas known to have high ecological vulnerability.

CONCLUSION

The transition zone between the Wonosari Basin and Gunungsewu Karst has complex morphological characteristics and exhibits distinctive landforms, including dolines, karst valleys, karst hills, and minor morphologies that reflect the intensity of solution processes and the dynamics of karst landscape development. Morphological variations in the transition area between Gunungsewu Karst and Wonosari Valley are influenced by geological factors (lithology and geological structure), anthropogenic activities, and karstification processes. These findings indicate that the transition zone between the basin and karst hills not only represents topographical changes but also reflects the dynamic interaction between geological structures, dissolution processes, and continuous landscape evolution.

The research results emphasize the importance of a landscape-based approach in karst area planning, where each zone has different ecological and hydrological functions that require specific management strategies. Thus, a comprehensive understanding of morphology not only strengthens scientific contributions to karst geomorphology studies but also plays an important role in supporting conservation policies, protection of karst landscapes, and sustainable water resource management in Indonesia's karst regions.

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