

**A GIS-BASED ASSESSMENT OF THE SURFACE RUN-OFF VULNERABILITY
IN THE BORDER AREA OF ANCIENT VOLCANO IMOIRI SUB-DISTRICT,
YOGYAKARTA, INDONESIA**

Muhammad A.I. Wardoyo^{*1} and Nurul Khotimah

¹Geography Education Master Program, Universitas Negeri Yogyakarta, Indonesia

ARTICLE INFO	ABSTRACT
<p><u>Article history:</u> Received 16 Sept 2025 Revised 08 Oct 2025 Accepted 10 Nov 2025</p> <hr/> <p><u>Keywords:</u> Surface Run-off, Cook Method, GIS</p>	<p>The Imogiri region originated from an ancient volcano and has subsequently transformed into a Fluvio-Volcanic plain. As an ancient environment significantly affected by external variables of a humid tropical climate, possible hazards such as geomorphological risks and surface runoff areas must be acknowledged. This study seeks to assess the vulnerability of surface runoff by determining the surface runoff coefficient by the Cook Method utilizing Geographic Information Systems. The Cook technique categorizes watershed features into three components to determine the runoff coefficient: topography, soil type, and vegetation cover. Data analysis employs the Geographic Information System (GIS) utilizing ArcGIS 10.3 software. The analytical results indicate that a value of $C = 0.592$ was achieved in 2025. In Imogiri Sub-District, 59.2% of precipitation is classed as surface flow, indicating a high value. Understanding the hazards associated with surface run-off is crucial for the implementation of effective and sustainable disaster management strategies.</p>

A. INTRODUCTION

Land use has a spatial dimension related to land use patterns and the temporal dimension of land use. The rapid growth and development of the population have led to changes in cultivation from productive agriculture to non-agriculture (Ismail et al., 2015). The effect of changes in land use from forest to non-forest and from agriculture to non-agriculture has brought social and economic benefits (Tang et al., 2005). This advantage makes people forget about environmental sustainability which reduces soil quality. Soil degradation in Indonesia is usually

caused by rainwater erosion (Fatahillah et al., 2022). The erosion rate is also exacerbated by abundant surface runoff because water is one of the leading causes of erosion (Nursa'ban, 2006; Wardoyo et al., 2021).

Surface runoff that occurs in the area is caused by the amount of rain that exceeds infiltration (Fatahillah et al., 2022; Ismail et al., 2015). Runoff is the relationship between runoff and rainfall volume (Wahyuningrum, Nining; Pramono, 2007). Once the infiltration rate is reached, water begins to fill the depressions or hollows on the ground



*Correspondence address: muhammadasrori.2022@student.uny.ac.id

surface. When the filling is complete, the water will flow freely onto the ground surface. Surface runoff is denoted by the letters C or Q, the value of C or Q can be used as an indicator of physical disturbance in a catchment area (River Watershed) (Asdak, 2014; Hudson, 1993). A measure of surface runoff, which takes into account the physical properties of the soil: the more impermeable the soil surface is, the higher the runoff coefficient. The steeper the slope, the greater the surface runoff. In addition, the better the soil properties, the less surface runoff occurs (Hudson, 1993; Ismail et al., 2015; Palar et al., 2013; Wahyuningrum, Nining; Pramono, 2007).

Changes in soil physical parameters that most affect changes in the value of the flow coefficient are soil and vegetation infiltration. Therefore, to obtain the value of the hydrological function, it is necessary to know the discharge coefficient that occurs in the area. According to (Hudson, 1993), calculating the physical characteristics of a watershed to calculate the surface runoff coefficient in the Cook method requires information on land use, land slope, and soil type. Surface run-off coefficient data is very useful for determining the vulnerability of surface run-off at a location.

Imogiri sub-district is located on the east side of Bantul Regency, Special Region of Yogyakarta with eight villages in it, namely: Girirejo Village, Imogiri,

Karangtalun, Karangtengah, Kebonagung, Seopamioro, Sriharjo, Wukirsari. According to the Bantul Regency Government's (BAPPEDA) slope map, the slope in this area has between steep (25-45%) and steep (> 45%) classes.

Moreover, Imogiri Sub District is an area that was once a volcanic landform, which morphogenetically is a landform from various kinds of active volcanoes. However, the Imogiri sub-district is now an area that has been denuded by fluvio-volcanic because the volcano had active conditions or a constructive phase in the Late Oligocene to Lower Miocene (Bronto, 2013; Mulyaningsih et al., 2018; Mulyaningsih & Sanyoto, 2012), this explains that the Imogiri sub-district has variations extreme slope. The wide slope of hilly and steep slopes results in higher surface runoff rates and volumes.

In addition, according to the Bantul Regency Land Use Map, land use in this area is dominated by plantations, dry fields and settlements. Land use with low vegetation cover causes water to fall to the ground directly and accelerates the soil saturation point. According to (Statistik, 2024), annual rainfall in this area averages 805-2527 mm with a high category which affects the peak discharge value and can cause surface runoff in the area.

Imogiri's unique condition as a transitional landscape between ancient volcanoes and fluvio-volcanic plains,

which has implications for differences in infiltration and other geomorphological hazards such as surface run-off.

Geomorphological hazard studies generally only address erosion and land mass movement. However, studies of surface runoff in volcanic-fluvial transition areas like Imogiri Sub-District are still limited, despite the region exhibiting extreme topographic dynamics and increasing land use pressures over the past two decades. Furthermore, Imogiri Sub-District is a popular tourist destination (Statistik, 2024). Therefore, this study is crucial for assessing the level of surface runoff vulnerability based on Geographic Information Systems (GIS) using the Cook Method approach.

Referring to the problems above, it is necessary to have technology such as a Geographic Information System (GIS) so that it can provide data acquisition that is used in determining hydrological conditions such as surface run-off hazards more effectively and efficiently. Knowing some descriptions of the physical condition of Imogiri Sub-District, plus this area has experienced several volcanism activities in the past.

However, in the era of denudation, exogenous factors due to climate certainly also dominate and it is necessary to monitor surface runoff quickly by integrating geographic information systems. The important role of information regarding the surface runoff

coefficient in Imogiri Sub-District, Bantul Regency, considering the condition of the study area has varying slopes. Information regarding surface runoff in Imogiri Sub-District has not been studied much, so it is necessary to do research on the level of vulnerability of surface runoff.

The main objective of this research is. analyze the level of vulnerability of surface runoff by calculating the coefficient of surface runoff using the Cook Method based on Geographic Information Systems. Research on geographic information systems also aims to generate alternative information to support spatial planning and provide alternative modeling information about potential hazards of Surface Run-off. This will be very helpful and necessary to support regional spatial planning.

B. METHOD

This research uses a system with a quantitative-descriptive research method. Descriptive research aims to dig up facts from the results of interpretation and analysis with a research process that is more oriented towards finding a problem or situation rather than a fact. This method is used to explain the interpretation of runoff analysis according to the parameters of the Cook method by combining several parameters such as land use, land slope and soil type (Hudson, 1993).

The Cook method is more suitable for use in narrow areas. This is different from the SCS-CN method, which is relatively used on a larger regional scale and requires complete hydrological data. The SCS-CN model is a very widely used method for estimating runoff volume based on the "Curve Number (CN)" figure. Because hydrological data (such as river discharge, rainfall intensity per event) in the area may be limited, the Cook method, which does not require complete intensity/discharge data, becomes an option.

The Cook method also allows for mapping and visualization of each factor that influences runoff spatially (Gafuri et al., 2016; Samaawa, 2016). The output results in the form of a runoff coefficient map or runoff vulnerability class will be very easy to present to policymakers (for example, for flood/runoff mitigation) compared to using the SCS-CN model, whose output is more in the form of runoff volume, and requires further conversion to be classified into risk or vulnerability classes and mapped.

Descriptive analysis methods are also used to describe the symptoms and phenomena that appear on the map against

real-time conditions in the field. The approach applied in this study is a geographical approach, namely a spatial approach. With this approach, this study aims to identify and describe several spatial phenomena and physical conditions in the study area to investigate possible surface reduction hazards. This study also uses place and location themes to analyze interpretation results and potential runoff.

Validation was conducted through a field survey at 20 random stratified points in normal to extreme class areas. Field data were spatially verified using GPS (accuracy ± 5 m). Parameters of land use, land slope, and soil type, are then used to calculate the value of the flow coefficient using the Cook method. The weight of each parameter is presented in **Table 1**.

The map overlay method is used with the aim that the information possessed by one map can be combined with information on other maps. The results are used to determine the value of the flow coefficient. Calculation of the flow coefficient using the weighted average method of the overlapping area unit value.

Table 1. Weight of Physical Characteristic That Give Rise to Surface Run-Off

Physical Characteristics	Extreme (100)	High (75)	Normal (50)	Low (25)
Slope	Steep (>30%)	Hilly (10%-30%)	Wavy (5%-10%)	Flat (0%-5%)
Weight	40	30	20	10
Soil Infiltration (Soil Texture)	No effective ground cover, thin soil layer, negligible infiltration capacity	Slow to absorb water, clay material or other soils with low infiltration capacity	Clay with infiltration approximately the same as prairie soil	Deep sand or other soil that can absorb water quickly
Weight	20	15	10	5
Vegetation Cover (Land Use)	Settlement, Vacant land	Irrigated rice fields, rainfed rice fields, moor	Mixed gardens, Less dense forest	Dense forest
Weight	20	15	10	5

Source: (Hudson, 1993)

Samaawa (Samaawa, 2016) to calculate the runoff coefficient using Cook's method, use the following formula:

$$C = \frac{C1A1 + C2A2 + CnAn}{A1 + A2 + A3}$$

Where:

- C : Surface Run-Off coefficient
- C1, 2, n : variable of flow coefficient
- A1, 2, n : variable area

Total surface runoff coefficient is determined by the sum of the coefficient

values for each variable using the following formula:

$$C_{total} = C_{slope} + C_{soil} + C_{landuse}$$

Where:

- C_{slope} : Slope coefficient
- C_{soil} : Soil infiltration coefficient
- C_{landuse} : Land use coefficient

The final value from the calculation of the total weighting of each parameter is then classified based on the criteria for the flow coefficient value with the Cook's Method, as presented in **Table 2**.

Table 2. Classification of Flow Coefficients Cook's Method

No	Surface Runoff Coefficient Classification	Score
1	Low	0 - 25%
2	Normal	25 - 50%
3	High	50 - 75%
4	Extreme	75 - 100%

Source: (Hudson, 1993)

Runoff coefficient According to (Asdak, 2014), the runoff coefficient is a number that shows the relationship between surface runoff and the rain that causes it. The runoff coefficient, often abbreviated as C, is a number that shows the ratio between the amount of running water and the amount of rainfall. For example, the C of a forest is 0.10, which means that 10% of all precipitation is runoff. This coefficient number is one of the indicators to determine if there has been (physical) disturbance in the watershed.

A high C value indicates more rainwater that becomes rainwater. This is less profitable than conserving water resources because the amount of water formed as groundwater is reduced. Another disadvantage: the more rainwater flows, the greater the risk of erosion and flooding. The number C varies from 0 to 1. The number 0 indicates that all rainwater is distributed as infiltration water and especially as infiltration. While the number $C = 1$ shows that rainwater flows as runoff. Basically, the value of C is greater than 0 and smaller than 1. The closer the coefficient is to one, the more likely the area will experience surface runoff (Asdak, 2014).

Observations were made using two methods, namely digital observation (image interpretation) using Geographic Information System (GIS) software and field observations. Field observation

locations were determined after conducting a Surface Run-Off Vulnerability analysis. The intended field survey area refers to areas that have the most Extreme classifications and to see real-time conditions in the study area. Other secondary data collection uses literature and documentation. A literature study was conducted to obtain secondary data which used, among others, books from (Hudson, 1993) and (Asdak, 2014).

Further strengthening of secondary data collection was by using documentation to obtain secondary data from various documents containing maps in the research area such as RBI maps, DEM SRTM 30M D. I. Yogyakarta Map, and soil type map is the FAO Soil Atlas of Asia 2023. Other secondary source documents such as rainfall data for the Research Area were taken from the Central Bureau of Statistics for Imogiri Sub-District. The use of a 30m DEM resolution has limitations in detecting micro-topographic variations. However, it can still be considered valid for spatial analysis at regional scales, such as sub-districts or sub-catchments. In the context of sub-district-level spatial analysis with large analysis units and the need for surface runoff vulnerability mapping, a 30m DEM is still suitable.

The secondary data is intended to analyze various physical conditions of the study area with predetermined parameters, with the final result being the

creation of a Surface Run-Off Vulnerability Map in Imogiri sub-district. The relationship between data types, data

collection methods, instruments, and data sources in this study is shown in **Table 3**.

Table 3. Types of Data, Methods of Collecting, and Instruments

No	Data	Methods of collecting data	Instrument/data source
1	Real-Time Condition in Research Area	Observation	GPS, observation sheet, and digital camera
		Imagery Interpretation	Surface Run-Off Vulnerability Map of Imogiri District (Analysis by researchers, 2025)
		Literature Study	Hudson, 1993 (Hudson, 1993) and (Asdak, 2014)
2	Slope		<i>Peta Rupa bumi Indonesia</i> or RBI map, Peta DEM SRTM 30M (Indonesian Topographical map)
3	Landuse	Documentation	RBI map, and Citra Google Earth
4	Soil		Geological and Soil Type Map

The data analysis technique used in this study is descriptive analysis balanced with a spatial approach. The use of descriptive analysis by considering the spatial aspect was obtained from a review of the literature in reference books and from the interpretation of images to study field conditions. The analysis begins by identifying the physical conditions of the study area, such as land use conditions, slope variations and soil types. Map interpretation was carried out using overlay analysis techniques using ArcGIS software following the instructions for the surface runoff coefficient of the Cook method. Overlay analysis aims to obtain surface vulnerability data with four

classifications, namely: low, normal, high, and extreme in the study area

Descriptive-spatial analysis by applying the location theme was carried out to analyze the physical appearance of land use, slope variables, and soil types on the output value of the Surface Run-Off coefficient in the study area. As a validation of the results of the analysis that has been obtained, then a field condition check is carried out. The results of the descriptive-spatial analysis were then used in making a simulation of land use change and its effect on the Surface Run-Off coefficient in the Imogiri sub-district. The design plans and research procedures carried out can be seen in **Figure 1**.

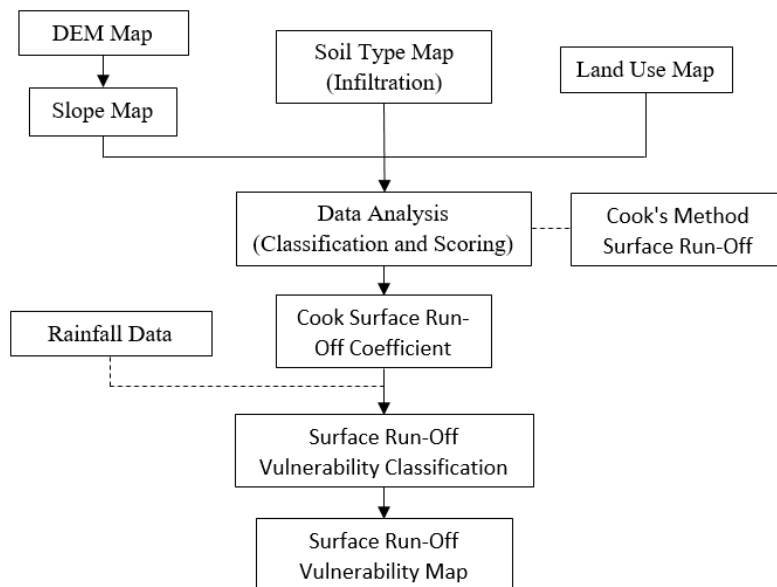


Figure 1. Research Procedure

C. RESULT AND DISCUSSION

C.1. RESULT

Study Area

Imogiri Sub-District is located in the Opak-Oyo watershed (DAS) which is located in Bantul Regency, Yogyakarta Special Region Province. Administratively, this area has 8 villages in it, namely: Selopamioro Village, Sriharjo Village, Kebonagung Village, Karangtengah Village, Girirejo Village, Karangtalun Village, Imogiri Village, and Wukirsari Village (Statistik, 2024). Geographically it is located at 9127425 mU - 9117688 mU and 429401 mT - 437395 mT with the conversion of Universal Transverse Mercator (UTM) Zone 49S coordinates with a total area of research reaching 5267 ha.

The research area is seen from its physical appearance, which is located in a

cluster of several ancient volcanoes namely: Mount Siluk, Mount Sudimoro, Mount Plencing-Sindet, and Mount Dengkeng. The ancient volcano in Imogiri Sub-District is a sequence of 11 ancient volcanoes in four groups, one of which is the Parangtritis-Imogiri ancient volcano group.

There are three stages of the growth of the ancient volcano in Imogiri and its surroundings, namely: the first stage is the formation of monogenetic volcanoes, the second stage is the composite cone, and the third is the eruptive caldera volcano. However, what dominates the Imogiri sub-district are caldera volcanoes such as the ancient volcanoes of Imogiri and Plencing-Sindet (Bronto, 2013). The map of the research area can be observed in **Figure 2**.

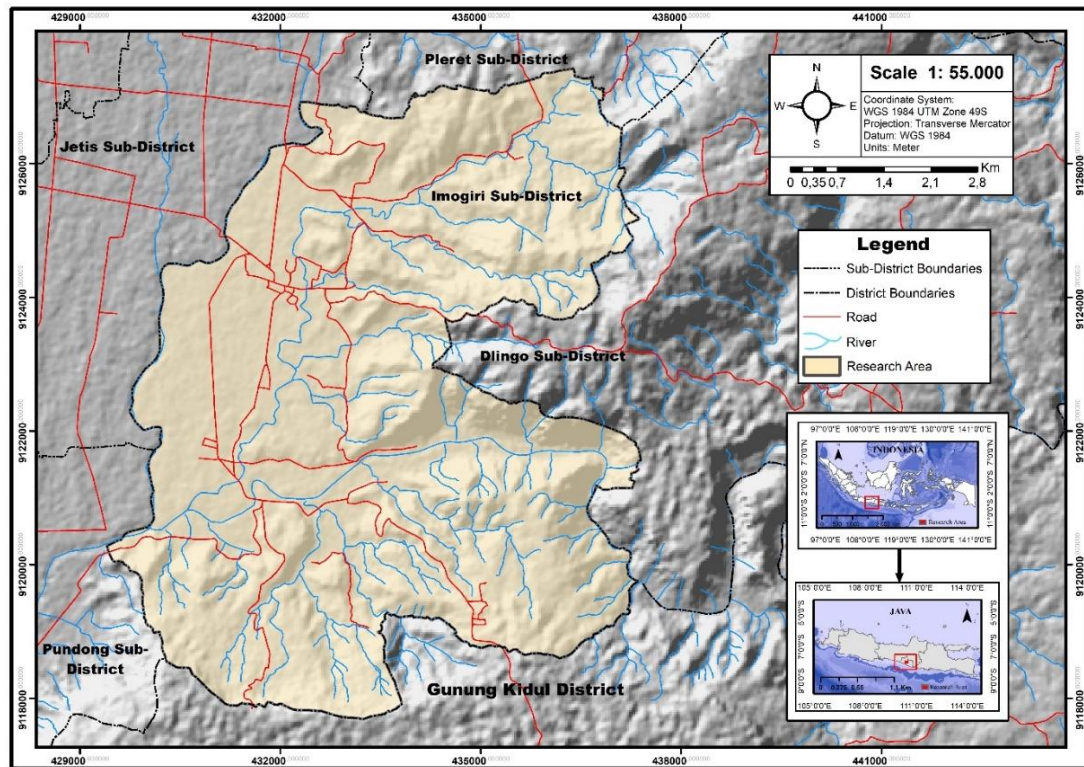


Figure 2. Research Area
(Source: Author, 2025)

Physiographically, Imogiri Sub-District can be seen that its physical appearance includes Mount Sudimoro which is the highest peak of volcanic fossils in the Imogiri Sub-District area (+507 masl). To the east is exposed the ancient volcanic breccia layering of Sudimoro, to the west the landscape is in the form of a semicircular basin opening to the northwest, which is thought to be a former volcanic crater, besides that there are plains and hills of Imogiri, which is the downstream part of the Kali Oya watershed until its confluence with Kali Opak. To the south of Mount Sudimoro is the Ancient Volcano Imogiri. This

mountain is characterized as a plain surrounded by escarpment features. On the northwest side, you can find andesite intrusion on Mount Plencing.

On the west side, there is also the appearance of very thick pumice breccia deposits which are widely distributed, this indicates that the Imogiri region also has very explosive volcanism comparable to caldera volcanic eruptions (Bronto, 2013). This statement is reinforced by research from (Mulyaningsih et al., 2018; Mulyaningsih & Sanyoto, 2012), which states that the condition of the active or constructive phase of the mountains in the Imogiri region occurred in the Late

Oligocene to Lower Miocene. The volcanic activity lasted for a very long time, resulting in a constructive effusive eruption produced by andesite-more alkaline basalts and destructive explosive eruptions produced by the more acidic hornblende andesite-type magma. Now, the conical body of the volcano is no longer visible, as in Merapi Volcano, because of its explosive activity and erosion along the late Tertiary-Quaternary.

The geomorphology of the Imogiri area was formed by processes of ancient volcanism which have now ended and active tectonics which were still ongoing, as well as terrestrial factors which produced mass movements, weathering, and erosion (denudation). Imogiri Sub-District is a Fluvio-Vulcanic area that is part of the Opak and Oyo watersheds. The Opak and Oyo watersheds are two of the three watersheds in the Special Region of

Yogyakarta. The two watersheds in the context of the Imogiri Sub-District area are part of geological and geomorphological formations that are still tied to the genesis of the Ancient Volcano in the region.

The environment of the two watersheds is located in an ancient-denudational volcanic area and structural mountain range of the Southern Mountains and is made up of old volcanic rocks that flow into the broad alluvial plains in the southern part of Java. The climatological conditions of the study area are also relatively the same as other places in Indonesia, which have a wet tropical climate type. Data regarding the amount of rainfall and the amount of daily rain in Imogiri Sub-District, sourced from the Central Bureau of Statistics for Bantul Regency (Statistik, 2024), can be seen in **Table 4**.

Table 4. Conditions of Rainfall in Imogiri Sub-District in 2020-2023

Years	Rainfall (mm)	Rainy Days
2020	805	108
2021	680	142
2022	3029	191
2023	1198	86

Source: Central Bureau of Statistics for Imogiri Sub-District (Statistik, 2024)

The characteristics of the months with the highest rainfall peaks in the sub-district are those that occur at the end of the year, precisely in November and December. While the character month with low rainfall usually occurs in July and August. According to the Bantul Regency Government and the Bantul Regency BPS 2024 (Statistik, 2024), the Imogiri sub-district has a climate like a lowland area in the tropics with hot weather as its trademark. The highest temperature recorded in Imogiri sub-district was 26°C with the lowest temperature 23°C.

High rainfall, like the general population of tropical climates, makes this region vulnerable to various natural disasters, one of which is the vulnerability to Surface Run-Off. This is based on the fact that climate is an important part of the erosion agent and the forming agent of landscape evolution, as well as the main cause of surface runoff. In addition to this, rain is also a hydrological cycle process that must occur and areas that are not suitable for receiving large rain capacities will have an impact on disasters that arise due to rain, one of which is Surface Run-Off.

Topographical Conditions

Landform conditions are discussed in terms of morphogenesis this research area is a volcanic area that is now dead and

has become a denudational phase. The classification of morphogenesis describes the appearance of the surface morphology of the study area. In addition to describing the morphology, the appearance of the structure and constituent rocks also indicates events that occurred in the past, an overview of the surface appearance (morphology), the structure and constituent rocks, and the processes that resulted in the formation of landforms (J., 2011; Pramono & Ashari, 2014; Verstappen, 2013).

The slope map of Imogiri Sub-District was extracted from the Digital Elevation Model SRTM 30 M Map (Indonesian Topographical Map) using measurements according to the Cook Method and analyzed that the slope is divided into four classes which can be seen in **Figure 3**. Samaawa (2016) and Hudson, 1993 state that there are four categories of slope identified in the Cook method analysis, namely flat (0% -5%), wavy (5% -10%), hilly (10% -30%), and steep (> 30%). Four slope classes are included in the weight, for example, 10: flat, 20: undulating, 30: hilly, and 40: steep. This score indicates the magnitude of the slope's influence on surface runoff. The steeper the slope, the higher the score and hence the higher the runoff coefficient value.

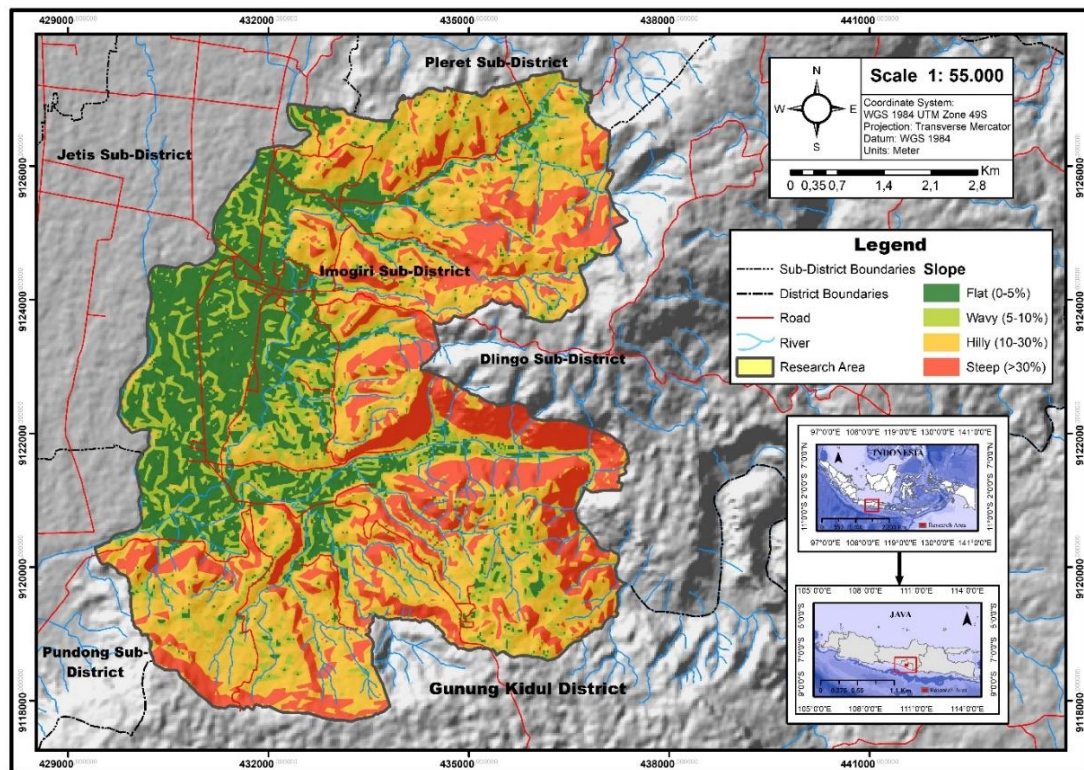


Figure 3. Slope Map of the Study Area

(Source: Author, 2025)

Calculation of the value of C or the value of the runoff coefficient is also carried out according to the formula that shows the slope parameter of this slope. Slope class and C values are shown in Table 5. Spatially weighted values

indicate several degrees of slope from highest to lowest in the study area conditions. The value of C Slope indicates how strongly the gradient or topography affects the runoff coefficient.

Table 5. Slope Class and C Value Slope of Imogiri Sub-District

No	Slope Classification	Slope Grade (%)	Weight	Area (Ha)	Area (%)	k Value (Weight x Area)	C Value (Total (k)/ Total Area)
1.	Flat	0-5	10	1106,63964	21	110,66	0,265 = 26,5%
2.	Wavy	5-10	20	809,662733	15	161,93	
3.	Hilly	10-30	30	2153,771208	41	646,13	
4.	Steep	>30	40	1196,917668	23	478,76	
Total				5266,990883	100	1397,49	
				= 5267			

Source: Research Analysis Results (2025)

The C value of the slope parameter in this area is the main controlling factor for the surface run-off that occurs. It can be seen that the C Value reached 26.5%. This value becomes the controller for area runoff. The fact is that this area is a hilly remnant of an ancient volcano that once existed. According to (Husein & Srijono, 2010), for now the Imogiri Region is an area with dominant geomorphological structures S3 (moderately dissected structural mountains) and S4 (highly dissected structural mountains) and is equipped with a small portion of F3 (Inactive alluvial fan), F4 (bed river), and V4 (moderately dissected volcanic footslope). The formations in this area are also dominated by the ngelanggeran formation and the dominant geomorphic processes are a fluvial and mass movement. It can be seen on the map that the dominant slope in this area is Hilly with an area covering 41% followed by Steep with an area of 23%, while areas with flat slopes are only 21%.

Soil

Soil types were obtained using soil maps and geological maps of the Special Region of Yogyakarta. This soil type map is used to determine the type of soil infiltration in the study area. Observing (Samaawa, 2016) and (Hudson, 1993), it is known that the Cook Method includes four categories of infiltration in its analysis, namely fast, medium, slow, and very slow.

Four slope categories are included in the weights listed, such as 5: fast, 10: moderate, 15: slow, and 20: very slow. Based on the map interpretation results, four soil types are formed in the Imogiri region, namely: Gray Brown Regosol, Litosol, Brown Mediterranean Complex and Litosol and Gray Alluvium are shown in **Figure 4**. As in the slope class, high weight values indicate worse soil infiltration conditions, while lower weight values indicate better infiltration quality in the study area. The C value or runoff coefficient value is also calculated for this infiltration parameter according to the formula presented. Infiltration class and C value are listed in **Table 6**.

It is not different from research from (Ismail et al., 2015) in which the research area included three types of soil, namely brown andosol and brown regosol associations, reddish brown latosol, and yellowish red podzolic complex. This research area is also dominated by Regosol, Litosol, and Mediterranean soils. Based on the results of the analysis of the four types of soil, four types of soil textures were obtained, namely: 1) Regosol soil Regosol soil is a type of soil that is still developing. The fraction shows that this soil is dominated by the sand fraction (82.62%) followed by the silt fraction (13.16%) and the clay fraction (4.22%) so it is included in the loamy sand texture class.

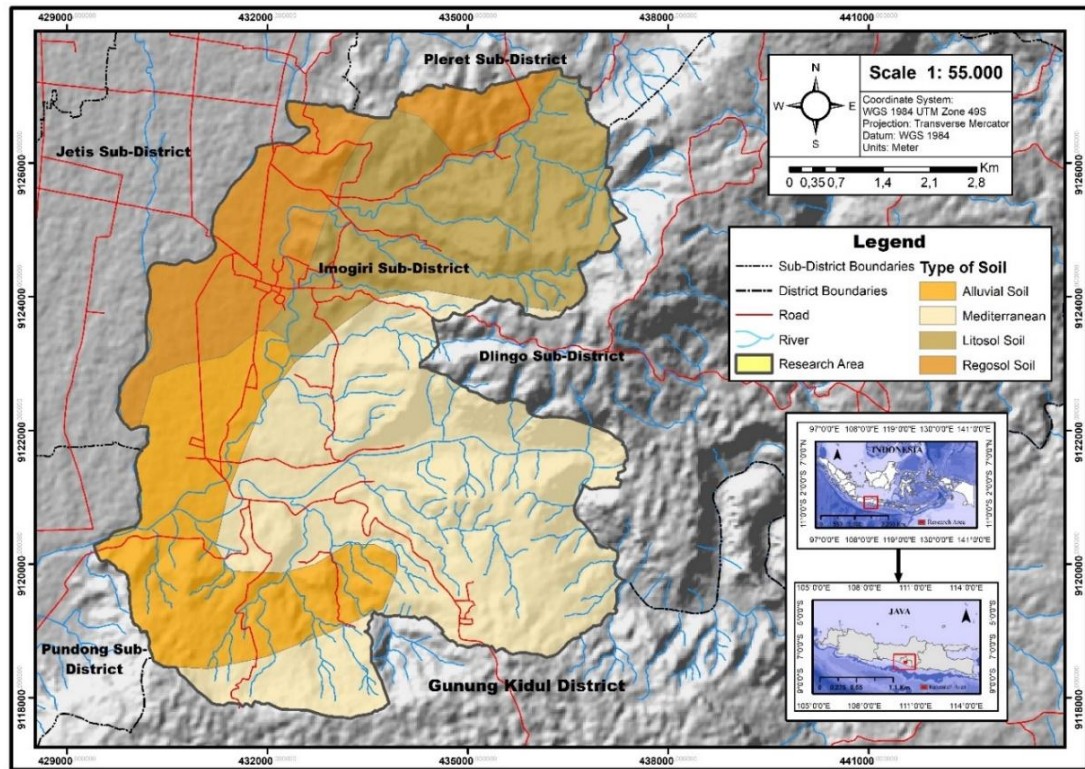


Figure 4. Map of Soil Types in The Study Area

(Source: Author, 2025)

Table 6. Infiltration Class and Infiltration C Value in Imogiri Sub-District

No	Soil Type	Infiltration	Weight	Area (Ha)	Area (%)	k Value (Weight x Area)	C Value (Total (k)/ Total Area)
1.	-	Fast	5	-	-	-	
2.	Litosol	Medium	10	1187,61558	23	118,76	
3.	Regosol	Slow	15	808,617532	15	121,29	
4.	Mediterranean	Very Slow	20	2259,786636	43	451,95	0,169 = 16,9%
	Alluvial	Very Slow	20	1010,971135	19	202,19	
Total				5266,990883 = 5267	100	894,20	

Source: Research Analysis Results (2025)

Regosol soil has several problems such as the ability to absorb and store water which is very low and sensitive to

nutrient leaching (A, 2014; Nikiyuluw et al., 2018); 2) Litosol soil, this soil has the characteristics of coarse grains in the form

of gravel. Basically, litosol soil is soil that has just experienced development and is still young soil. Formed from climate change, topography, and volcanism. The texture of the soil is sand, loamy dust, where the percentage of SAND is 53.6%, silt is 33.8% and relatively little clay is 12.7% (Risman, 2017); 3) Brown Mediterranean Complex Soil, this type of soil is formed from the weathering of sedimentary rock and limestone. This land is found in a mountainous topography. Mediterranean soil texture usually has a clay fraction.

The distribution of this fraction of land shows a fairly advanced development. Because it shows the texture of loamy clay. (Nurcholis et al., 2003; Rachman & Teapon, 2016; Sudiarsana et al., 2019); 4) Gray Alluvial, Alluvial soil is young soil that comes from deposition. This soil is the result of river deposition and runoff, so it is often found in wetland agricultural areas such as rice fields and river swamps. This soil is usually gray in color. This soil has a clay sandy dust texture with a texture of sand 18.3%, dust 49.3.7%, and clay 32.7%, from this analysis the soil conditions are in the rather critical category (Risman, 2017).

Based on the explanation regarding soil texture, it can be seen that the infiltration ability of Regosol soil is slow, Litosol soil is medium, and Mediterranean soil and alluvial soil are very slow. Data regarding soil texture is

needed in determining the infiltration capacity of the soil and the value of the surface runoff coefficient. The soil texture that has very low infiltration is the dominant soil in the study area, namely Mediterranean soil with an area of 43% of the total research area. Meanwhile, soil texture with fast infiltration conditions was not found in this study area. This makes a large part of the research area prone to inundation and crashing into surface runoff. Soil is an important component in a surface runoff process.

The soil type parameter in this study has a surface runoff coefficient of 16.9%. Even though the C value is not as large as the slope, soil processing factors must be needed to anticipate prolonged surface run-off considering that the study area is a Fluvio-Vulcanic area which is the meeting area of the Opak and Oyo watersheds that flows throughout the year. The nature of this soil is further clarified because the research area is an ancient volcanic area where the soil material tends to be more clayey and has aquiclude properties, meaning that soil can store water but cannot release water in significant quantities (Putranto & Kuswoyo, 2008).

Vegetation Cover

The land cover factor is the next parameter in the same assessment as before using the Cook method. The land use data used is secondary data obtained from the interpretation of the 1:25,000

scale RBI Map and Google Earth Imagery. Based on the interpretation analysis, there are six types of land use, namely Plantation, Ricefield, Moor, Settlement, Grassland, and Shrubs. The

six land uses can be seen spatially in **Figure 5** and mathematically in **Table 7**.

If we look at the total land cover of the study area in the table above, it can be seen that the largest land cover in the-

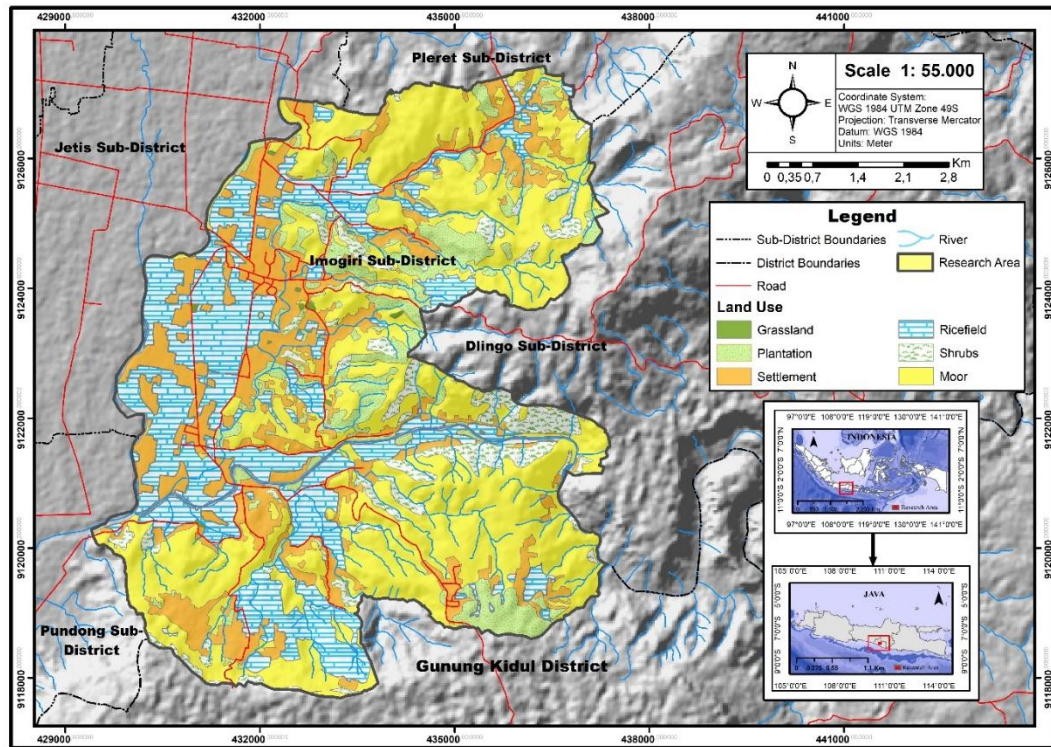


Figure 5. Map of The Types of Land Use in The Study Area

(Source: Author, 2025)

Table 7. Land Use Types and Landuse C Values in Imogiri Sub-district

No	Type of Land Use	Weight	Area (Ha)	Area (%)	k Value (Weight x Area)	C Value (Total (k)/ Total Area)
1.	Forest	5	-	-	-	
2.	Plantation	10	498,826582	10	49,88	
3.	Ricefield	15	1181,704729	21,7	177,25	
4.	Moor	15	2177,691376	42	326,65	
5.	Settlement	20	1071,881591	20	214,37	
6.	Grassland	20	8,986924	0,1	1,79	
7.	Shrubs	20	327,900003	6,2	65,58	
Total			5266,990883 = 5267	100	835,54	0,158 = 15,8%

Source: Research Analysis Results (2025)

Imogiri area is the moor which accounts for 42% of the total area of the study area. The use of moor in the study area is unfortunate because most of the land is located on slopes with steep slopes, thereby increasing the potential for disasters such as runoff, landslides, and erosion. This is in accordance with the research of (Wardoyo et al., 2021) whose study area is in the Outer Dieng area which has a dominant moor land use and causes a higher geomorphological disaster. The second land use with the highest score is a settlement with an area of up to 20%. Settlement development continues from time to time due to the need for human habitation. As stated by Ismail (2015) (Ismail et al., 2015), areas with good vegetation cover tend to have a low run-off flux coefficient.

This research area, based on the data above, states that the dominance of moorlands has a negative influence on infiltration, of course, this also has an impact on the potential for a Surface Run-Off disaster that will occur. The C Value Parameter of land use in the study area shows the number 0.158, which is equal to 15.8% of the role of land use in the formation of surface run-off. This value is also obtained because in terms of map interpretation that the Imogiri Sub-District area does not have protected forests or dense forests which in the end the rain that falls with its kinetic energy will directly

impact the surrounding land and soil. Even though this value is not too high compared to other parameters, it is it should be underlined that land use will always be and will be the main factor of human intervention. Theoretically, proper land use will make the ecosystem more balanced.

Surface Run-Off

After all the parameters are obtained, they are then given a score according to the characteristics of each landform according to the Cook method. The surface run-off coefficient is obtained through an overlapping process in the ArcGIS software. The emphasis on overlapping is based on several previous parameters that have been classified and scored.

Parameters performed overlapping according to the Cook method include slope maps, soil type maps, and land use maps. Based on the results of the analysis that has been matched with the coefficient criteria of the Cook method, the overall results of the research area have a high level of coefficient classes and it can also be seen that there are 3 classes of surface runoff coefficients spread across the area of Imogiri Sub-District, such as: normal, high and extreme. Low coefficient values are not identified in this research area. In general, the value of the surface runoff coefficient describes the physical condition of the study area. Visually

spatially the surface runoff coefficient values can be seen in **Figure 6**, while the surface runoff coefficient values in the form of data can be seen in **Table 8**.

Normal coefficient values on the map are shown in green, high values are shown in yellow, and extreme values are shown in color red.

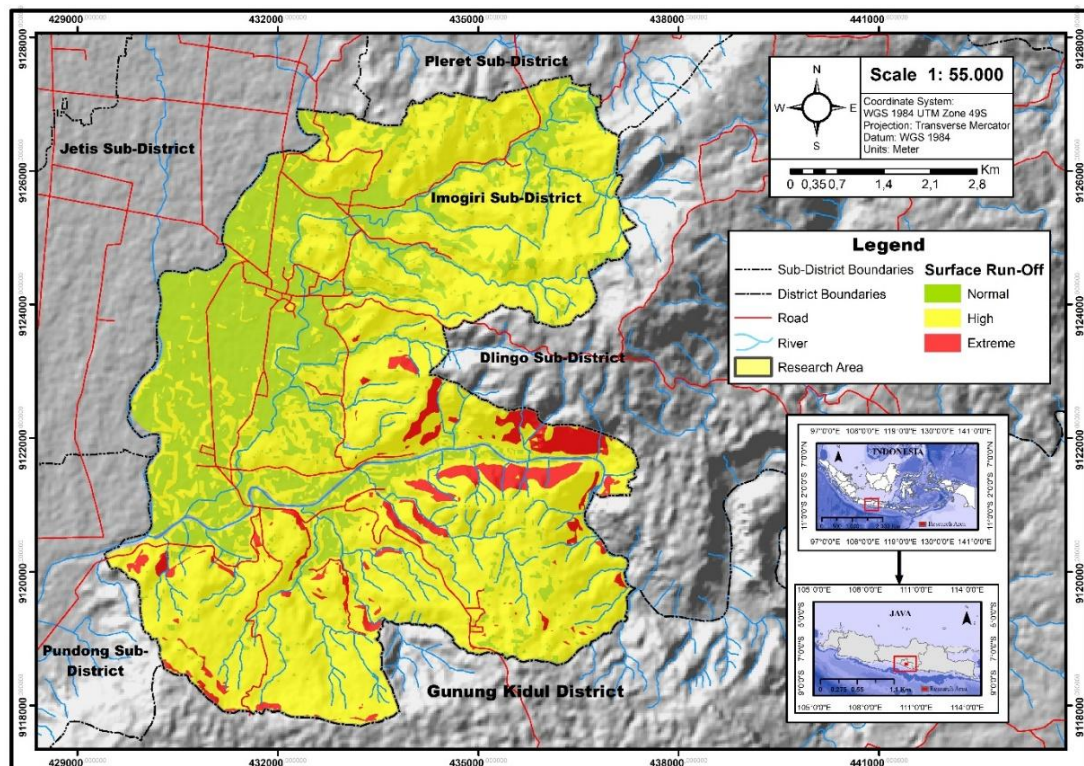


Figure 6. Surface Run-Off Vulnerability Map of Imogiri Sub-District

(Source: Author, 2025)

Table 8. Types of C Values and Classification in Imogiri Sub-District

C Value for Slope	C Value for Soil Texture	C Value for Land Use	Total C Value	Total C Value Percent (%)	Classification
0,265	0,169	0,158	0,592	59,2%	High

This means that 59.2% of rainwater that falls on the research object will become surface runoff

Source: Research Analysis Results (2025)

The runoff hazard map above shows that almost the entire study area is colored yellow, indicating runoff vulnerability with a high coefficient. This is based on the fact that several physical factors enter into the

flow efficiency distribution calculated by Cook's method. These factors include land slope, soil infiltration, surface water storage, and land cover. Surface run-off often occurs when the rainfall intensity is

greater than the infiltration rate. The surface runoff coefficient factor is always less than 1 (Tay & Afshar, 2014). The value in this study was clarified by calculating the sum of these three parameters and producing a C value of 0.592 or 59.2% of the rain that occurred in the study area was directly processed by the environment to become surface run-off. This value also means that around 40.8% of rainwater will be absorbed by the soil.

This indicates that each side of the study area is prone to surface runoff. In fact, this value is higher than similar studies such as Ismail's research in 2015 (Ismail et al., 2015) which showed a C value of 54.63%, and Nganro's research in 2019 (Nganro et al., 2019) which showed a C value of 47.34%. This high classification value is related to the slope factor which is the full controller of surface runoff. The condition of the research area which is dominated by the morphological conditions of Hilly and Steep means that the rainwater that falls will be directly transformed into surface runoff.

C.2. DISCUSSION

The research area which is now a Fluvio-Vulcanic area was formerly a place of volcanic activity. It was the activity of ancient volcanism that played a role in the morphology of the research area (Bronto, 2013; Mulyaningsih et al., 2018; Mulyaningsih & Sanyoto, 2012). Even though it is now experiencing a denudation

phase and the volcano is no longer active, the remnants of this activity have made the Imogiri Sub-District area have a very extreme relief situation. Data on the C value of the slope plays a role in the formation of surface run-off, it can be seen that the value is 0.265 and the appearance of the yellow and red colors in Figure 6 is evidence that the steeper the relief, the more severe the impact of surface run-off.

This is coupled with the annual rainfall, which averages 805-2527 mm in the high category, which affects the peak discharge value. (Kasmawati, Hasanah & Rahman, 2016) found that the steeper the slope at the bottom, the higher the velocity of surface water flow, resulting in more soil components being eroded. (Dela & Mardiatno, 2012) found that the flow rate increases with increasing slope value and the carrying capacity of the crushed soil particles increase so that the erosion process increases. The same thing happened in the research of (Ismail et al., 2015) and (Fatahillah et al., 2022) who stated that hilly terrain manifestations dominated their research area.

In contrast to research by Nganro, et al (2019) (Nganro et al., 2019) the coefficient of surface runoff on the surface of Makassar City is relatively lower because the surface area of Makassar City is flatter. The relief in the study area plays an important role in controlling surface

run-off and is a parameter that is difficult to change or modify.

The morphogenesis factor in the study area which is an ancient volcanic area also controls the type and texture of the soil, the soil in the study area has an average clay texture so infiltration is low. As explained above, in the study area, the type of soil texture that dominates has aquiclude properties. This type of clay makes at least organic matter in the soil which impacts the lack of defense of the physical properties of the soil which helps the development of plant roots and the smoothness of the soil water cycle. This of course also has an impact on the difficulty of soil pore formation. The relationship that occurs between constant infiltration rate and soil porosity is directly proportional.

It is possible that the vacant land has already been compacted by people or animals and it could also be caused by rainwater hitting so that the possibility of microorganism activity is very low. The high soil water content will be followed by a long infiltration rate because the water content in the soil is already high so that at one time the soil will not be able to enter water anymore so the constant infiltration rate will be longer (Wirosedarmo et al., 2009). The explanation for the low infiltration rate in this study is supported by research from the same location, Rikumahu

and Gobel (2016) (Rikumahu & Gobel, 2016) stated that the infiltration rate in the study area was less than 0.5 cm/hour. Infiltration is affected by pore size, pore stability, water content, and soil profile. The soil in this area has impermeable clay with small pore sizes because it does not drain water quickly, so the soil is not well aerated. Small pores thanks to very fine composition. The tiny pores also prevent air from escaping the soil quickly, which allows water to penetrate the soil for a long time. The tiny pores prevent water from getting into the soil because they are clogged with clay. Soil type with low infiltration clay content is also an important factor for high surface runoff in several similar studies.

The pattern of land use types also has an interesting impact when viewed from the results of the high surface run-off coefficient in the study area. As stated by Ramadhani et al, (2021) (Ramadhani et al., 2021) Vulnerable sub-watersheds tend to be dominated by the conversion of land use to dry land agriculture, settlements, and paddy fields. Based on the data above, land use in this area states that the area will be moor with an area of 2177.7 Ha. Meanwhile, paddy fields and settlements also have relatively the same area value. Rice fields have an area of 1181.7 Ha while settlements have an area of 1071.8 Ha. Based on the statement of Ramadhani et al

(2021) (Ramadhani et al., 2021), it can be explained that the land use conditions in this area usually cause surface runoff. Runoff from each land use will of course have a different runoff value. Changing the function of water-absorbing (permeable) areas to become water-resistant areas causes hydrological imbalances and negative impacts. Changes in the area's vegetation affect the timing and amount of runoff, resulting in an increase in runoff volume. According to (Sari, 2011), the high surface runoff is directly proportional to changes in land use which change the water catchment area into a watertight area.

Good land use causes a low runoff coefficient, while on the contrary, bad land use causes a high runoff coefficient (Pertiwi et al., 2020). In fact, a study by

(Hu et al., 2019) directly linked land use in China's urban areas to urbanization. Although urban slopes are not as extreme as mountainous areas, the urbanization factor increases the impermeability of the surface, which increases surface runoff. Increasing impermeable soil increases runoff, but more forest and well-irrigated agricultural land can reduce surface runoff.

The next discussion is to examine the distribution of surface run-off coefficient that are spread over the Imogiri Sub-District area. Data on the distribution of surface runoff coefficients in the study area can be seen statistically in **Table 9** below. The field survey steps were also taken based on the results of the analysis of the surface run-off coefficient in the Extreme class using the Cook Method guidelines.

Table 9. Distribution of Surface Runoff Coefficient Classification in Imogiri Sub-District

No	Surface Runoff Coefficient Classification	Surface Run-Off Coefficient Score	Area (Ha)	Percentage (%)
1	Low	0 - 25%	-	-
2	Normal	25 - 50%	1548,788777	29,41
3	High	50 - 75%	3472,188195	65,92
4	Extreme	75 - 100%	245,991815	4,67
Total			5266,968787 =5267	100

Source: Research Analysis Results (2025)

Imogiri Sub-District is an area that has a total area of 5267 Ha. Landscape and land use variations make this area divided into three categories of surface runoff coefficient according to the criteria by the

Cook Method, which is spread over several areas. Low classification with a coefficient value between 0 - 25% is not found in this area. Normal classification in the study area covers 1548.8 Ha. The high

classification in this study covers an area of 3472.1 Ha. The last classification in this study is the extreme classification with an area of 245.9 Ha. The high coefficient is the widest coefficient criterion in this study, while the extreme coefficient is the coefficient with the lowest area in this study.

The surface run-off coefficient with normal coefficient class (25-50%) is a class that is spread on the western side of the study area. This class has relatively low slope dominance, namely flat slope (0-5%) to wavy (5-10%). The type of soil that dominates the place with this normal classification is Alluvial and some parts of the Regosol and Mediterranean soils. The level of infiltration in this area is also based on the type of soil seen from the texture of the soil.

The infiltration rate that dominates in this normal classification is very low because this soil is the result of precipitation from the results of the above soil collapse and becomes river sedimentation and is found in many wetland areas such as rice fields. The dominant land use is rice fields and settlements. Even though paddy fields and settlements are land uses with great value in the sense that they are land uses with the potential to produce large surface run-off, the slope factor plays a bigger role in the formation of surface run-off. This is

reinforced by the statement (Dela & Mardiatno, 2012; Kasmawati, Hasanah & Rahman, 2016; Mujiyo et al., 2021) that the topography of the area has a slope which is a factor to consider starting from land preparation, planting, and harvesting. and soil protector. Land with a high slope is more easily disturbed or damaged. The steeper the slope, the faster surface runoff and erosion.

There was no low coefficient classification (0 to 25%) in this study, even within the normal coefficient range we did not find a small number of low classifications due to a lack of cultivation or canopy vegetation. This is reflected in the study of Fatahillah et al. (2022) (Fatahillah et al., 2022) explained that surface runoff is controlled by rapid soil infiltration and plant canopy which reduces raindrops. This weakens the effect of rainwater splashing on the ground surface and allows rapid soil infiltration over a long period of time, slowing the occurrence of surface runoff.

The surface run-off coefficient with a high class (50-75%) has the most dominant area in the study area. Areas with this high classification are found almost entirely in Imogiri Sub-District. Starting from the north, west, central, and south sides of the Imogiri Sub-District. This high coefficient area is dominated by litosol, Mediterranean, and partly alluvial soils.

This type of soil is a type of soil that tends to be clay in texture and has a very low infiltration type. This high clay content will certainly have an impact on the depletion of organic matter, and the material from the Ancient Volcano causes a high iron content. The lack of organic matter causes a lack of soil porosity and permeability so the physical properties of the soil tend to be damaged. This is confirmed by (Murphy, 2015), organic matter can improve soil physical properties such as increasing aggregate stability, and increasing soil porosity, and permeability. The condition of the high coefficient is exacerbated by the topographical conditions in which the

study area is dominated by hilly slopes (10-30%) and steep (> 30%). As explained above steep slopes will not provide a good response to surface runoff. The dominance of the use of dry land which is evenly distributed is also a major problem in the research area. A total of 2259.8 Ha of the research area is used for agricultural activities leading to the clearing of dry fields. Moor contributes high value in surface run-off. The last condition of the surface run-off coefficient class is the extreme class which is evidenced by field surveys and directly several samples of the distribution of extreme coefficients can be seen in **Figure 7**.

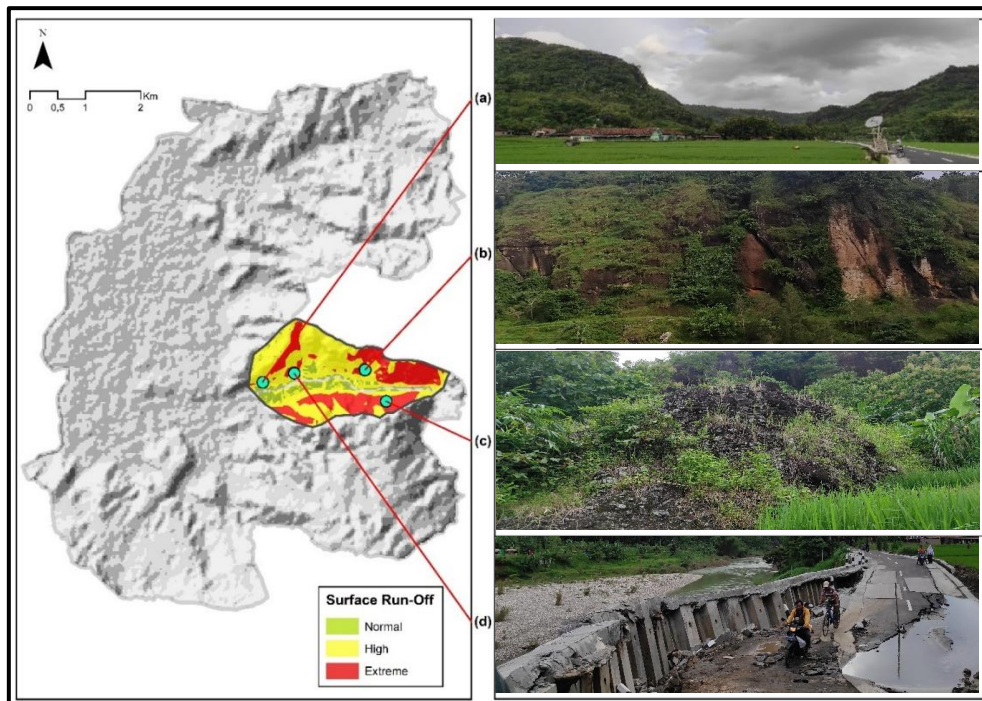


Figure 7. Description of the Extreme Hazard Surface Run-Off Location in Imogiri Sub-District (a) Semi-circular landscape; (b) Steep slope conditions; (c) Leftover rock formations of past volcanism; (d) The phenomenon of landslides in areas commensurate with the river (Source: Author, 2025)

The semicircular landscape shown in **Figure 7a** which opens to the northwest is thought to be a former volcanic crater. At present, the central facies of this ancient volcano is occupied by the plains and hills of Imogiri, which is the lower reaches of the Oya River area until its confluence with the Opak River. In this area there is also the appearance of very thick pumice breccia deposits which are widespread, this indicates that the Imogiri region also has very explosive volcanism (Bronto, 2013). One example of the Imogiri hills is shown in **Figure 7b** which shows a steep slope with a slope of >45%.

The surface of the slope in the figure also shows that the soil layer is very thin and only grows grass and shrubs. This phenomenon is very common because on this slope the soil cannot accumulate and when weathering occurs the rock will immediately fall to the bottom. The class of steep slopes and thin soil which is in the extreme coefficient class explains the high coefficient of surface run-off in Imogiri Sub-District. The appearance of past volcanism in the Imogiri Sub-District can also be seen in **Figure 7c** which shows that there is an andesitic bedrock and pyroclastic breccia which are the source rocks in the study area. According to (Mulyaningsih et al., 2018; Mulyaningsih & Sanyoto, 2012) apart from explosive

eruptions the Imogiri area has also experienced an effusive phase like the existing Stratovolcano massif, the appearance of the result of this type of effusive eruption is its constructive nature produced by a more alkaline type of andesite-basalt magma.

In addition, this opinion is also strengthened when looking at the geomorphological conditions of Imogiri Sub-District and in the extreme surface run-off coefficient section of the geomorphological side including S3 (moderately dissected structural mountains) and S4 (highly dissected structural mountains). This condition is also part of the andesite rock formation which has parent materials in the form of andesite breccia, tuff, lapillial tuff, agglomerates, and andesite lava (Husein & Srijono, 2010).

The thin layer of soil, there are still lots of large parent rock appearances that have an impact on existing land use in this extreme area, the dominant land use at this location is shrubs and grass, but on the lower side of the slope, there are agricultural areas and several settlements public. Several phenomena, from the slope of the slopes, the thin layer of soil, and land use that cannot reduce the splashing of rainwater, resulting in this extreme region

immediately responding in the form of surface run-off when rain occurs.

According to several statements by the local people who live below the surface run-off coefficient area with high and extreme classes, they often find that floods do not originate from the river, but when it rains, their houses are hit by floods from the top of the slopes. That flood is a surface run-off phenomenon that comes with material in the form of soil erosion at the top so that the run-off that hits people's homes also comes as mud. This phenomenon is also directly proportional to other geomorphic hazards, namely erosion, and landslides.

Landslides were also seen when the authors conducted a site survey as shown in **Figure 7d**, this landslide phenomenon was the result of several physical features in the study area. This is inseparable from the research area which is already in the denudation phase because the volcanism factor is no longer constructive. According to (Wardoyo et al., 2021) who conducted research in the Dieng area, which has a landscape structure that has undergone a denudation phase.

The area is also prone to erosion and landslides. This is reinforced because the area is highly eroded by exogenous factors so that the constructive properties of endogenous factors such as tectonic and volcanic factors are no longer dominant.

The many types of geomorphological hazards in the study area indicate a relationship between high climatic factors affecting the area.

One of the preventive actions that should be taken besides being wise in cultivating land is to pay attention to and manage the land properly. Evaluation of the surface runoff coefficient is one of the most important parameters in technical hydrology. Rapid runoff causes erosion in the area. Therefore, estimating the optimal run-off coefficient is very important because it helps to calculate the surface run-off when flowing over the soil. Without surface run-off, the water cycle is incomplete and water is not available because water does not affect the flow cycle.

One of the proportions of the function of surface runoff is the production of water-powered electricity. However, a high coefficient of discharge may indicate that the area is prone to high surface run-off, as water moves rapidly over the ground toward river channels or valley floors. Therefore, it is important in terms of establishing runoff management channels and delineating potential runoff hazard zones (Tay & Afshar, 2014). Drainage, wetlands, and gravel materials are recommended to enhance the replenishment function of water resources (Son & Kwon, 2022). Meanwhile,

(Heryani et al., 2013) also argues that the use of mulch is good for controlling surface runoff. This is due to the nature of mulch which can reduce evaporation and increase the soil's ability to hold water because mulch holds evaporation from the soil. The use of mulch can improve soil conditions and increase the soil water content.

The use of straw mulch can increase the holding capacity of groundwater and improve the physical properties of the soil, as well as reduce runoff and evaporation rates, as well as increase the water stored in the soil profile. According to (Arsyad, 2012), a layer of mulch increases surface roughness thereby slowing down the process of intercepting rainwater and can slow down surface runoff thereby reducing the runoff coefficient. Delayed runoff can also increase rainwater infiltration during rainfall events. Mulch can inhibit run-off, reducing run-off speed and carrying capacity. The implementation of runoff control zones and increasing deep-rooted vegetation on steep slopes is recommended to reduce the C value to <0.45 . This is because the reduction in anopi tree cover can have a direct impact on runoff (Arsyad, 2012; Suprayogo et al., 2020).

This finding is relevant for the development of a spatial plan for Imogiri District based on hydrological mitigation. Recommendations for the government in the form of hill-based mitigation include:

increasing deep-rooted vegetation cover/canopy and agroforestry on slopes, applying mulch or ground cover to increase infiltration and reduce surface erosion, and constructing runoff control channels and infiltration areas. Research by Suprayogo et al. (2020) on Volcanic Slopes in the Rejoso Watershed, East Java, which is similar to this study area, also shows that higher vegetation cover (canopy $>55\%$) is associated with a very low runoff/rainfall ratio on volcanic slopes.

D. CONCLUSION

Based on the results of The analysis using the Cook method indicates that Imogiri Sub-district is generally classified as a high surface run-off vulnerability zone, with an overall runoff coefficient (C) of 0.592, meaning that approximately 59.2% of rainfall becomes surface run-off, while only 40.8% infiltrates into the soil. This condition reflects the dominance of hilly (10–30%) and steep ($>30\%$) slopes, underlain by denudational landforms of an ancient volcanic system, which collectively accelerate overland flow formation.

The spatial pattern of high and extreme runoff coefficients emphasizes that topography and soil texture are the main controlling factors, influencing land-use suitability and hydrological response. Without proper management, continued

population growth and land-use pressure may intensify runoff-related hazards such as erosion and mass movement. Therefore, this study highlights the need for hydrology-based spatial planning that integrates runoff control zones, deep-rooted vegetation, and agroforestry systems on steep slopes to reduce the runoff coefficient below 0.45 and enhance landscape resilience against surface runoff hazards.

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