Understanding geomorphological hazard in Watumalang Area post Bisma volcanic era. Denudational or multihazard?

A. Ashari
Department of Geography Education, Faculty of Social Sciences, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
Email: arif.ashari@uny.ac.id

Abstract. The combination of endogenous processes in the form of volcanic and mountainous formation with exogenous processes in the form of wet tropical climate produces very complex geomorphological conditions in Java. From this geomorphological complexity there are various kinds of processes that often cause disasters for people's lives. Watumalang Area in Wonosobo Regency, is one of the regions in Java Island with complex geomorphological conditions. Based on the genesis, this region was formed by volcanic activity in the past, some of which were affected by the structural process. Bisma Volcano is the last part of volcanism in this region that has stopped since thousands of years ago. At this time landform denudation is a dominating process and causes many disasters. However, does the threat of hazard only come from the denudation process? This paper aims to identify the geomorphological conditions of the Watumalang Area and the potential hazard. To achieve these objectives field observations were carried out using geomorphological survey methods. Observations are supported by remote sensing image interpretation, study literature, and documentation. Spatial analysis with a geomorphological approach supported by GIS analysis was used to describe the geomorphological hazard distribution. The results show that the Watumalang area is geomorphologically arranged by structural and volcanic units. The denudation process is so dominant that the potential for geomorphological hazards comes mainly from this process. However, the presence of faults can also trigger earthquakes. Meanwhile the existence of Bisma Volcano which is currently not active does not act as a trigger. In areas with such complex geomorphological conditions, the multihazard approach needs to be prioritized rather than limited to one type of hazard, although one hazard has a tendency to be more dominant.

1. Introduction
Throughout the geological time, the surface of the earth continues to change. Various endogenous and exogenous processes such as mountain formation, volcanism, mass movement, erosion, sediment deposition, and others are responsible factors for morphological changes on the earth's surface. These processes take place naturally as part of the dynamics that occur on the surface of the earth. However, with the increasing population and landuse for life, it is not uncommon for the process to take place naturally causing disruption to the community's life system.

Referring to the Law of the Republic of Indonesia Number 24 of 2007 concerning Disaster Management [1], if the natural process has a negative impact on humans, namely the disruption of people's lives and livelihoods, it can be called a natural disaster. Natural disasters can occur by a variety of causes, one of which is caused by a geomorphological process. In geomorphology there are known
geomorphological hazard, namely various things related to landscape changes that affect the human system, such as soil erosion, mass movement, coastal erosion, and fluvial erosion. Extreme geomorphological events are repeatedly known to cause loss of life and property damage [2]. Considering that landscape changes that pose a hazard to humans are natural processes, the understanding of the hazard posed by geomorphic processes in an area is very necessary in disaster management activities. Efforts to identify hazards due to geomorphic processes are carried out through non-structural mitigation as part of risk management. In this activity, geomorphologists have a role, namely by geophysical mapping, hydrology, surface materials that trigger failure, fire, inundation, drought, erosion, and submerge [3] or in general with focusing on the dynamics of the landform [2].

The Watumalang area is one of the sub-districts in Wonosobo District, Central Java Province. This region is dominated by hilly to mountainous reliefs. Stötter and Monreal [4] explain that mountains are the most potential areas for disasters compared to other regions in the world. Since settlements and land use develop intensively in mountainous areas, various risks related to natural hazard processes such as rock fall, debris flows, avalanches or floods, have been part of the specific human-environment system in this region. According to the Geology Map of Banjarnegara and Pekalongan [5] this region has a volcanic genesis that is indicated by the existence of volcanic rocks. Volcanism in this region has taken place in the past. The activity of the Bisma Volcano which produces the lower part of the Dieng Volcanic Rock is the last episode of volcanic activity in this region. The age of rocks in the Bisma Volcano which has reached 2.53 million years [6], [7] proves that volcanism in the Watumalang Area has been dormant for a very long time. The process of denudation by climate that works on volcanic results during this period produces landforms in the form of structurally denudated mountains with rough relief and irregular flow patterns. Bisma Volcano itself, still has a composite cone morphology that undergoes deepening of the valley in all parts of the slope.

The dominance of the climate denudation process in Watumalang Subdistrict affects the number of disasters related to the denudation process, especially the mass movement. The Indonesian Geological Agency (Badan Geologi) [8] for example, reported that Watumalang Sub-district had the potential of medium to high mass movements. High potential allows mass movements that have occurred in the past to be active again. Watumalang Sub-district is one of five sub-districts in Wonosobo District which has high mass movement potential, out of all 14 sub-districts which generally have intermediate hazard levels. The question then is that even though the Watumalang Area is identical with the hazard of the mass movement, does this mean that it is possible to cover other potential hazards? To build a good disaster management system, complete and accurate information is needed. Various types of potential hazards are related to geomorphological characteristics in Watumalang region and how much potential level needs to be identified. Bisma Volcano that has been active in the past has an important position in determining the type and level of hazard at this time. Meanwhile on the other hand the Watumalang area is also occupied by many people. Data from Indonesian Central Agency of Statistics (Badan Pusat Statistik / BPS) [9] shows that in 2016 the total population in Watumalang Sub-district was 49,346 people, continued to experience growth compared to 2015 as many as 49,266 people and in 2014 there were 49,166 people. Population density in 2016 reached 723 people/km², continuing to increase from 2015 and 2014 which were 721 and 719 people/km² respectively. The number of vulnerable people in 2016 reached 33.85%. The large number of people in vulnerable areas further increases disaster-related problems. This condition shows that good disaster management is needed to be built in an effort to reduce disaster risk, including with information support related to geomorphologic hazards.

This paper attempts to provide alternative information regarding the geomorphological conditions in Watumalang Area and the geomorphological hazard potential they cause. This information can be used to support disaster management that has been carried out, especially in the context of reducing the risk of natural disasters. Next the rest of this paper is organized as follows. Section 2 describes the scope of geomorphological hazard, Section 3 describes the research method, section 4 explains the results and discussion, and section 5 explains the conclusion of this work.
2. Theoretical framework

The term hazard is widely known both in disaster management and disaster research activities. Hazard is a threat that can be a disaster. Conversely disaster is a hazard that has struck or affected human life. Conceptual confusion often occurs in the use of hazard and disaster terms [10]. In the Law of the Republic of Indonesia Number 24 of 2007 [1] used the term threat of disaster, which is an event that can cause disaster. Dangers can come from natural, non-natural, or social factors. Natural hazard is a threatening condition that originates from natural phenomena in a certain space and time, or in other words threatening events that can produce damage to the physical and social space. These hazards do not only occur when events occur but are also long-term in nature from the associated consequences [11], [12]. It must be understood that damage caused by natural hazard can extend for a long time so that it exceeds when it occurs. Natural hazard is often associated with geological, geophysical and hydrometeorological processes, but because natural hazard is mostly related to the dynamics of the earth's surface, it must also be seen and analyzed from a geomorphological point of view [12].

Understanding of hazard is very important in disaster management activities. Hazard analysis is a key element of any disaster risk analysis [13] and in disaster risk reduction a natural hazard assessment along with an early warning system is a very important component [14]. Geomorphological hazard itself is an important component to be assessed in the assessment of natural hazard [15]. In Indonesia, research on natural hazard has been carried out and more than half of it has focused on volcanic eruptions, tsunamis and earthquakes [16]. Geomorphological hazard as an important part of the analysis of natural hazard still seems to need to be explored as an alternative information to support disaster management.

Natural hazard is actually a research theme that has been carried out in geography. This is mainly because natural hazard is a form of conflict between physical processes and human systems. One part of the conflict between the physical environment and the human system is the development of landforms which can also cause catastrophic impacts on the human system. In this case there can be fatalities and property damage due to extreme geomorphological events [2]. Thus it can be concluded that geomorphology as part of geography has a role in the study of natural hazard, namely because geomorphology studies landform changes, while extreme landforms affect human life. In other words, the geomorphological process is a form of conflict between the physical environment and the human system.

Geomorphological hazard is a landscape change that affects or threatens the human system [2]. This threat occurs because of the instability of the appearance of the earth's surface [2] otherwise known as geomorphological instability [17]. Another definition explains that geomorphological hazard is a material, in this case landforms and processes, which have a possible impact on the dynamics of the earth's surface in space and time [12]. Emphasis on geomorphological hazard is on the response of the landscape to the process, not from the original source that produced the process [2], [11]. Gares et al [2] in detail explain as follows. Threats in geomorphological hazard arise from the response of landforms to the surficial process, even though the emergence of the process can come from a distance from the surface of the earth. Referring to this definition, earthquakes are not included in geomorphological hazard but landform changes that occur due to an earthquake if it causes a threat to humans can be categorized as geomorphological hazard. In another example, sea level rise is not a geomorphological hazard, but an increase in coastal erosion as a result of sea level rise is included in geomorphological hazard. It can be concluded that processes such as wind, flood, and tsunami are not geomorphic hazard until the process changes landscape. That is why these processes are more appropriately classified as atmospheric or hydrological hazards. While the geomorphic hazard is the impact resulting from the atmospheric or hydrological process. Alcantara-Ayala [12] also explained that physical phenomena, such as volcanic activity, seismicity, floods and landslides, turned into geomorphic hazards when they pose a danger to the landscape, both culture and nature. Brandolini et al [18] give an example in his research, geomorphological dynamics in the study area are marked by landscape and gravity-triggered processes, flowing water, and by marine process work. These processes cause geomorphological hazard. With regard to the forces involved, geomorphological hazard is categorized into three namely endogenous, exogenous, and climate change and land use [12].
Gares et al [2] further explained events with high magnitudes, such as earthquakes or hurricanes, are more frequent and have resulted in the largest number of victims. In contrast, geomorphic hazards such as landslides, are less frequent and cause fewer deaths. However, it should be noted that although high magnitude events often produce spectacular changes, intermediate frequency events often produce more cumulative activity over a longer period of time. Thus we can know that the geomorphic component of the hazard tends to be more at the end as a continuation of the hydrological or seismic hazard. In addition to lower magnitude and higher frequency, geomorphic hazards will generally have a slower onset speed, longer duration, wider area, more diffuse spatial distribution and more regular temporal distance.

Included in the geomorphological hazard are soil erosion, landslides, river hazards, marine hazards, glacial and perennial hazards, and volcanic and earthquake hazards that cause mass movements [17]. Gares et al [2] give examples of geomorphological hazard including soil erosion by water, mass movements, fluvial erosion and coastal erosion. In addition, there are also other types of geomorphic hazards such as sedimentation by wind, lava, glacial movements, periglacial effects such as frost, or solitary effects such as drain holes. The study of geomorphological hazard, among others, relates to the identification of physical parameters such as magnitude, frequency, duration, area, speed of onset, spatial dispersion and temporal interval [12]. In addition there are five important things for hazard evaluation, namely the dynamics of physical processes, predictions of events, determination of spatial and temporal characteristics, understanding of the impact of characteristics on people's perceptions, and knowledge of how physical aspects can be used to formulate adjustments to events [2], [12].

Human activities also influence the geomorphological process. This causes a reciprocal relationship between geomorphological processes and human activities, which results in geomorphological hazard. Remondo et al [19] explained that geomorphological hazard was also accelerated by human activity in influencing landform changes. The evidence obtained from the study shows that there is an increase in the frequency of slope instability and the level of denudation and sedimentation due to an increase in indirect geomorphological changes. This increase in indirect changes is more due to human actions than climate change. Meanwhile Lazzari et al [20] shows, based on integrated analysis between territorial data (geology, geomorphology and climate) and historical documents it is known that the dangers of geomorphology have been emphasized by intense human activity. Human intervention that occurred during the historical period has become a determining factor in increasing the level of danger and accelerating the morphological processes that already existed before. Rosenfeld added, while considerable scientific debate remained around the issue of global climate change, geomorphologists were well aware of the indirect effects of human activities. Some examples of this are deforestation causing landslides and increasing the frequency and peak of floods, excessive grazing accelerates the effects of drought and erosion, as well as groundwater utilization and irrigation diversion affects natural vegetation and microclimate.

3. Method
This research was carried out with a geographic approach that is a spatial approach and based on the use of geographic themes in approaching problems. The spatial approach is used to record and describe variations in geomorphological conditions and their distribution in relation to geomorphological hazard potential in the study area. The geographic theme used is mainly location and place. This theme is used to produce a description that sharpens the discussion of the spatial aspects of geomorphological conditions in the study area, which is reflected in the question of what geomorphological phenomena exist in the study area? where are these phenomena? in what environmental conditions are these geomorphological phenomena? the pattern of distribution? The data collected in this study are primary data and secondary data. Primary data in the form of geomorphological data including morphography and morphometry of landforms, geomorphological processes, lithology, and environmental conditions. The data was obtained through field observations. Secondary data are data on geomorphological conditions, land use, settlement distribution, and demographic data. Secondary data is obtained from previous research, literature, and data contained in the publication of statistical data and maps.
Data collection is done by observation method, remote sensing image interpretation, study literature, and documentation. Observations were made with geomorphological survey methods. Field observations and measurements in this observation process were carried out in several locations selected as samples. Determination of the sample location was done purposively in each terrain unit in the study area. Terrain unit express variations in geomorphological conditions in the region. Remote sensing image interpretation is carried out to obtain geomorphological data, distribution of settlements, and regional infrastructure. The geomorphological data in question is landform data obtained from landsat imagery and morphometric data from DEM SRTM. Geomorphological data obtained by observations are complementary with data obtained from the interpretation of remote sensing images. Image interpretation is also carried out to obtain geomorphological data from areas that are not possible to be reached by terrestrial surveys. Conversely, geomorphological data obtained from terrestrial surveys also serve as verification controls for data from image interpretation, considering the results of field surveys tend to be more detailed and accurate. Meanwhile, to obtain data on settlement and regional infrastructure distribution, birdview images are interpreted in Google Earth. Data collection through document search is carried out for population, settlement and geological conditions obtained from BPS data, Geological Maps, and Topographic Map (Peta Rupabumi Indonesia). The relationship between data types, data collection methods, instruments, and data sources in this study is shown in Table 1.

Furthermore, to answer the problems in this study we describe the results obtained from the field by taking into account the spatial aspects and geographic themes supported by geographic information system analysis (Figure 1). The analysis begins with identifying geomorphological conditions and the potential geomorphological hazard in the study area. In identifying geomorphological conditions and geomorphological hazard potential, the analysis was carried out by emphasizing the type and distribution in the study area. To sharpen spatial analysis, the analysis of geographic information systems is then used through an average nearest neighbour analysis and intersect. Average nearest neighbour analysis is used to determine the distribution pattern of settlement distribution in the study area, related to the geomorphological hazard faced. The nearest neighbour's value is obtained from the comparison of the mean value of the observation with the average expectation value, with the z-score as an indicator in determining the type of pattern [21]. There are three types of distribution patterns, namely clustered, dispersed, and random. The clustered distribution pattern is shown by the negative z-score (−), the dispersed distribution pattern is shown by the z-score value the greater and positive (+), and the random distribution pattern is indicated by the z-score 0 or close to 0 [22]. Furthermore, to find out how much geomorphological hazard threat to community settlements, an overlay analysis with intersect was carried out. Through intersect analysis, it can be seen that residential areas are located close to geomorphological hazard sources.

### Table 1. Types of data, methods of collecting data, instruments, and data sources

| No | Data | methods of collecting data | Instrument/data source |
|----|------|---------------------------|------------------------|
| 1  | Landform | Observation | GPS, observation sheet, digital camera |
|    |       | Imagery | Landsat Imagery |
|    |       | Interpretation | |
| 2  | Slope | Observation | Yallon, abney level, roll meter |
|    |       | Documentation | Peta Rupabumi Indonesia / Topographic map |
| 3  | Relief unit | Observation | Yallon, abney level, roll meter |
|    |       | Documentation | Peta Rupabumi Indonesia / Topographic map |
| 4  | Rock type | Observation | Observation sheet, geological compass, GPS |
|    |       | Documentation | Geologic Map sheet Magelang and Semarang |
| 5  | Paleo processes | Study Literature | Harijoko et al (2010) [6], Harijoko et al (2016) [7] |
| 6  | Distribution of settlements and centers of community activities | Documentation | Peta Rupabumi Indonesia / Topographic map |
It should be emphasized again that geomorphological surveys and mapping are an important part of this study. Through surveys and geomorphological mapping, terrain analysis is then carried out as a first step to be able to analyze geomorphic hazards in the study area. The field survey was carried out by combining analytical geomorphological survey methods with the terrain synthetic survey method. The consideration in combining the two methods is that the research objectives can be achieved, namely not only limited to identifying geomorphological conditions but also analyzing geomorphological hazard as another specific goal. According to Verstappen's explanation [23], [24], analytical geomorphological surveys provide complete geomorphological information, including processes and genetics. Analytical geomorphological survey methods are suitable for application in large-scale detailed surveys, so that they are relevant to this study. However, for surveys that are problem-oriented such as natural disasters, analytical geomorphological survey methods still do not provide information about other environmental parameters needed. For this reason it is necessary to use a complementary approach with a synthetic field survey as a support. Both surveys, according to Verstappen, are complementary.

Furthermore, in doing terrain classification, landscape approach is used. This approach is one of three approaches used in terrain classification and evaluation, in addition to the genetic approach and parametric approach. The use of landscape approach is based on the consideration that this research will conduct a survey on a semi-detailed scale, with a relatively broad scope of research area, relatively
homogeneous units, short survey duration, limited samples, and supported by image usage [25]. There are several steps taken in terrain analysis and classification in the study area in relation to the potential of geomorphological hazards, namely: (1) step 1 field data collection based on landform detection related to geomorphological, geological, soil, hydrological and vegetation / land use processes, (2) step 2 delineating the main relief unit, (3) delineating terrain units based on geomorphological units, and (4) step 4 selection and delineation of terrain characteristics related to potential geomorphological hazards. For a more detailed discussion, this step can be continued in step 5, which is the value of terrain characteristics against geomorphological hazards. Step 5 has been part of the terrain evaluation stage as a continuation of terrain analysis and classification.

The geomorphological conditions analyzed are then presented in a geomorphological map. Verstappen [24] explained that the specific purpose of geomorphological mapping is the representation of a field with landform as the main subject. In an analytical approach, landform information is elaborated into four different types, morphological information, morphogenetic information, morphometric information, and morphochronological information. Lithology and processes are also content contained in geomorphological maps based on analytic surveys [26]. Another relatively similar opinion explains that the content contained in the geomorphological map includes morphography and morphometry, materials, and processes which also include genesis [27]. These explanations underlie us to determine the content that will be included in the geomorphological map in the study area. The description of the content on the map is also very much related to the map scale used. In this study a geomorphological map was made on a scale between 1:10,000 to 1:25,000. The land feature taxonomy for this scale is landform complex [28] or landform type [29] which is at the geomorphological unit level [25]. Referring to these provisions, the main characteristics featured in geomorphological maps are no or minor generalizations in classess areas and the classification of the main criteria using relief, lithology, and genesis. The use of symbols and colors for geomorphological maps compiled through this research refers to the standard rules that have been specifically determined [24], [30], [31], [32].

4. Result and Discussion

4.1. Research Area

This research was conducted in Watumalang Sub-district, Wonosobo Regency. Watumalang Sub-district is located to the west from the capital of Wonosobo Regency. Astronomically the study area is located at coordinates 366705 meter east (ME) to 378302 ME and 9185787 meter north (MN) to 9198386 MN at UTM coordinate 49S zone. The total area is 53 km². Administratively, Watumalang sub-district is bordered to Kejajar sub-district in the north, Wonosobo and Mojotengah sub-districts in the east, Leksono sub-district in the south, and Banjarnegara district in the west. Physiographically this area is located between volcanic landform and structural mountains with old volcanic rocks namely the Dieng Volcanic Complex in the north, Sindoro Volcano in the east, and the Serayu Mountains in the south and west. Figure 2 shows the border of the study area.

Watumalang District based on geological map [5] composed of material from Dieng Volcanic Rock, Jembangan Volcanic Rock, breccia members of Ligung Formation, and breccia members of Tapak Formation. All rocks except the Tapak Formation are quaternary rocks. Dieng volcanic rocks which are included in this region are the lower part in the form of andesite lava and quartz andesite and volcanic clastic rocks, with relatively lower silica content compared to younger parts. Jembangan volcanic rocks in general in the form of andesite lava and volcanic clastics. In the study area this rock is also characterized by lava, and alluvium deposits consist of volcanic materials, lava flows, and breccia deposited on a gentle slope located some distance from the eruption center. This information shows that the Watumalang region is still affected by the eruption of Jembangan Volcano that is older than Dieng Volcano, but is located far from the center of the Jembangan volcano so that it is included in the medial or distal facies. The breccia members of ligung formation are volcanic breccias (agglomerates) composed of andesite, hornblenda andesite lava, and tuff, which are part of the Ligung Formation. While breccia members of Tapak Formation are volcanic breccia and tuffaceous sandstone.
The climate in the study area is characterized by high annual rainfall. BPS data [9] showed that in 2014 rainfall in Watumalang Sub-district reached 2014 mm with 203 rainy days, in 2015 rainfall was 2545 mm with 242 rainy days, and in 2016 rainfall was 2444 mm with 231 rainy days. The peak of the rainfall occurs around the turn of the year, while rainfall and minimum rainy days occur in the middle of the year. This high rainfall, in a geomorphological context, acts as a geomorphic agent and is a very important factor in determining the evolution of landscapes in this region. As for the air temperature aspect, Watumalang Sub-district has an average temperature that is relatively lower compared to 12 other sub-districts in Wonosobo Regency. The air temperature in Watumalang ranges from 16°C to 27°C, but in the dry season it can reach below 16°C.

Figure 2. Map of the research area (source: RBI Map, Birdview imagery from google earth)
Water resources in this region are characterized by the number of springs. Spring is the main water source that is widely used by the community by channeling it to settlements using a pipeline. The hilly to mountainous relief conditions are factors that hinder the ease of access to groundwater. In this region there are also many rivers. Regarding geological and geomorphological conditions, river flows form dendritic patterns in some regions and radial patterns in some other regions. Dendritic patterns exhibit denudational landform characteristics while radial patterns are related to the form of stratovolcano landform, namely Bisma Volcano in the northern part of the region. Land use varies in the form of forests, shrubs, moor, mixed gardens, and rice fields (see Figure 2). The forest is still found in the northern part of the cone of Bisma Volcano. Mooring is the most dominating form of land use in the north and steep slope areas. Rice fields are quite common in valleys, especially in the south. The population in 2016 based on BPS data [9] is 49,226 people. Population distribution is not evenly distributed and concentrated in parts of the city with a density of 3017 people/km². While the lowest population density is only 243 people/km². The most type of occupation in Watumalang District is farmers, farm laborers, and traders.

4.2. The geomorphology of Watumalang Area

Geomorphology is the study of landforms [33], by emphasizing on genesis, future development, and its relation to the environment [23]. The discussion of geomorphological conditions is inseparable from aspects of geomorphological studies [34]. Huggett [35] explained that in geomorphology there are several points of view when emphasizing aspects of the study, as examples of aspects of structure, process, and stadium according to Davis; tectonic and climate aspects according to Penck and Penck; morphology, material, and process aspects according to King; or aspects of landform, genesis, process, and environment according to Verstappen. According to Verstappen [23], [24], the study aspects that we use to discuss geomorphology in the study area include static geomorphology related to actual landforms, dynamic geomorphology related to short-term processes and changes, genetic geomorphology related to long-term relief development, and environmental geomorphology related to landscape ecology.

Viewed from the aspect of genesis, the Watumalang Area is generally divided into two groups, namely volcanic and structural. Volcanic Genesis is characterized by a volcanic cone morphology with a radial flow pattern. The part that characterizes volcanic genesis is specifically found in the northern part of the Watumalang Area, namely the cone of Bisma Volcano. The Cone morphology of the Bisma Volcano, supported by lithological information in the region in the form of andesite lava and quartz andesite and volcanic elastic rocks from the Old Dieng Volcanic Rock, is very clear evidence that shows the existence of volcanic genesis in this region. Other volcanic rocks from the Jembangan Formation are older parts and form the basis of the Bisma volcanic cone [5]. According to Verstappen [36] there are four types of volcanic landforms in Indonesia namely volcanic cones, caldera, volcanotectonic depression, and volcanic complexes. Judging from its morphology, Bisma Volcano has cone volcanic characteristics but at the top it forms a wide crater opening to the southeast which is probably the result of a large eruption. Appearances such as those found in Bisma Volcano are common and also important volcanic geomorphological features [37]. As for when viewed in a wider scope, Bisma Volcano is part of the Dieng Volcanic Complex [7]. This information further strengthens the evidence that there are volcanic genes in the northern part of Watumalang Region.

Structural Genesis occupies most of the Watumalang area. The existence of structural genesis is indicated by fold structure characteristics. However, the structural characteristics in the field do not appear explicitly because they have begun to undergo a denudation process. The fold structure can be identified based on the rock coating pattern found in the field (Figure 3). Symptoms of denudation that occur are indicated by characteristics in the field, namely in the form of rough reliefs, the structural appearance begins not clearly identified, thick and homogeneous rocks, and the pattern of dendritic flow as a further development of the trellis flow pattern. By paying attention to these physical characteristics, this unit is hereinafter referred to as a structural denuded unit of genesis. The mountains and structural hills that have been demuded in the Watumalang area mainly develop on breccia rocks from the Tapak
Formation and breccia rock of the Ligung Formation [5]. This structural-denuded mountain is associated with mountainous systems in Central Java, namely the Southern Serayu Mountains and Northern Serayu Mountains. The process of denudation by the influence of climate factors occurs in the structural mountains in the form of folds. Pannekoek [38] explained that in the central part of Central Java there is a mountainous path known as the Southern Serayu Mountains. This mountain range stretches from east to west and is an area affected by strong folds. The eastern boundary adjacent to the Sumbing volcanic plain is located east of the Watumalang area. The North Serayu Mountains are a partial folding zone to the west of the Dieng and Jembangan Volcanic Complex which include the northern part of Central Java.

The development of denudation in these mountainous regions is inseparable from the climate characteristics in Indonesia which are characterized by high temperatures and high rainfall. Verstappen [36] explained that air temperature and high rainfall accelerate the weathering process. This is also supported by cloud cover in Indonesia which reaches 10 to 50 times more often than temperate regions. High intensity rain causes chemical weathering, natural erosion, and rapid mass movements. Non-volcanic denudational landforms are also influenced by continuous interaction between tectonic and denudational forces. This combination of climatic and tectonic factors results in rapid erosion in the tectogen region. The average erosion rate on Java Island is 1 mm per year but under human influence it can increase to 4 mm per year. The South Serayu Mountains are an example of a region experiencing accelerated denudation under the influence of human activities in land management [36], [39].

In the region with volcanic genesis there are units of volcanic landforms, gungapi feet, and volcanic foot plains. The landform units are part of Bisma's volcanic cone. Vulcan Bisma is a horseshoe shaped vulkan [36] which is part of the Dieng Volcanic Complex [7]. Judging from its position on the research area, the morphology of the Bisma Strato cone was not entirely in the Watumalang area but some of it was included in the Garung and Kejajar Districts which were not included in this research area. Overall the landform units contained in the volcanic area consist of caldera, volcanic cones, volcanic slopes, volcanic feet, and volcanic foot plains. The last three landform units are located in the Watumalang area. The combination of Strato morphology with the caldera as found in Bisma Volcano is a symptom that occurs quite a lot in the form of volcanic land in Indonesia [36]. Judging from the stage of development, Bisma Volcano is at the stage of mature development as indicated by the ongoing process of denudation to form rough reliefs in the form of ridge and radial valleys on the slopes to the volcanic feet.

The part of the region with structural genesis has a wider area coverage, but the distribution of landform units is simpler, namely in the form of mountains and structural hills that is weak dissected. As explained earlier, the structural landforms in the Watumalang area have undergone a denudation process. The trace structure of the fold appears from the impression of a trellis-shaped flow pattern which in its development shows developmental symptoms leading to a dendritic pattern. The development of denudation in the tectogen region as explained by Verstappen [36] differs from that in the Indonesian crater region which is tectonically stable. In stable areas there have been forms of other fields and remaining hills while in unstable areas erosion and mass movements in the mountains are preceded by rapid weathering of rocks. Judging from the stage of development, the denudation process is at the young stage which is characterized by erosion while forming valleys erosion of the main structure in the form of folds. This moderate level of denudation is influenced by lithology factors that are quite resistant. Even the process of deepening valleys by erosion and mass movement appears to be stronger in volcanic units compared to structural units that are denuded. Lithological factors indeed determine the rate of denudation in structural landforms. For example, in the degree of vulnerability of the form of structural land that is fractured, resistant constituent rocks will be related to the degree of strong resistance. In terms of morphometry, the study area is generally characterized by steep slope both in volcanic and structurally denuded units. This steep slope cannot be separated from the influence of endogenous processes that occur in this region. The endogenous process comes from tectonic forces that form a structural system since the past, while exogenous processes originate from the influence of climate that changes structural forms and is a process that dominates at this time.
Figure 3. The rock layering pattern that indicates the fold structure. Left image: topographical impression on topographical maps of Indonesia. Figure right 1, 2, 3: coating patterns found in the field

The current geomorphological process takes the form of erosion and mass movements that take place under the influence of climate. The erosion process is found in various types namely sheet erosion, rill erosion, gully erosion including widening and deepening of the valley floor. This geomorphic process is found in all regions, both in volcanic cone and structural-denudational mountainous units. The acceleration of the erosion process also has to do with the influence of humans in land management, especially upland agriculture on steep mountain slopes. An indicator of the rapid rate of erosion is the erosion of soil that takes place massively so that the soil solum becomes thin, even the soil parent material (regolith) in some places is exposed to the surface due to the loss of the top soil layer. Mass movements are found in various types, namely slide, slump, soilfluction, and creep. Slides are the most common type. The high rainfall and the length of rainy days affect the events of mass movements that tend to be wet type. Soilfluction is included in the group of flow type mass movements that occur because of the high water content [35] but the movement is slow. Meanwhile slides and slumps drier with slow to moderate movements [40]. The spatial distribution of various types of mass movements and their relation to the influence of relief factors and topography will be discussed further in the next
section regarding geomorphological hazard. Various geomorphological processes that are now taking place in the Watumalang Area, in the context of geomorphological hazard, are not only natural processes but also geomorphological hazards.

In the context of the environment, the geomorphological conditions of the Watumalang region affect the existence of potential resources and natural disasters. Sutikno et al [41] pointed out that in the region of Merapi Volcano, the availability and distribution of natural resources is influenced by geomorphological characteristics, especially land resources, water resources, biological resources, and mineral resources. The types of natural resources that can be identified related to the geomorphological characteristics of the Watumalang Area are mainly land resources, water resources, and biological resources. Land resources are widespread both in volcanic units and structural-denudational mountain units. The high potential of land resources is mainly found in areas with flat relief, namely on the volcanic foot plains and valleys between mountain ridge of structural-denudational mountain. The potential of this land resource is characterized by a thick soil solum, a loamy soil texture, blocky soil structure, high organic matter content, and a neutral soil reaction. This land is widely used for paddy field. Low land resource potential is found on mountain slopes and Bisma Volcano with steep slopes. The land in this section is characterized by a thin soil solum which is prone to erosion. If evaluated based on land capability criteria, generally land in mountainous slopes has a low class with quite a number of inhibiting factors. The potential of water resources is characterized by the presence of springs as the main water resource used to meet the needs of the population. Springs also provide water supply for rivers so that there are rivers that are perennial flowing throughout the year. However, the steep topography and lithology in the form of weathered rocks have hampered the absorption of water into the ground. The potential of biological resources is mainly in the form of forests and perennials. Forests are found in the Bisma volcanic unit while many perennials are planted by the community on dry land and mixed gardens. In addition to natural resources, geomorphological conditions also affect the potential of natural disasters which will be specifically discussed in the next section. The summary of field measurements in several sample locations is supported by data collection using geospatial technology and documentation shown in Table 2. While the Geomorphological Map of the Watumalang Area is shown in Figure 4.

4.3. The geomorphological hazard in Watumalang Area

As explained in the previous section, various landscape changes include aspects of landforms and processes, as part of the dynamics of the earth's surface that affect or threaten human systems [2][12], are referred to as geomorphological hazards. When viewed from the characteristics of landforms and geomorphic processes that take place, the geomorphological hazard in the Watumalang area mainly comes from the process of denudation by climate in the form of mass and erosion movements. Mass movements occur very much in various parts of the Watumalang Area both in volcanic cone units and in structural-denudational mountain units. These phenomenon indicate that climate influences are more dominant and cannot be balanced by constructive endogenous processes either from tectonic or volcanic forces. Mass movements occur in various types. Types that are quite common in research areas include slide, soilfluction, and creep.

Slide are mostly found in the southern part of the study area. This type of mass movement is mainly influenced by steep slope factors. Cutting the slope for road construction also affects the occurrence of slide type mass movements (Figure 5a). In the field, the slides are found with the length of the affected area reaching 15 meters depending on the slope segment and the length of the slope. Slides are usually characterized by a landslide crown at the top followed by a plane of material slides that are straight and the deposition of material at the bottom. Arborgast [40] explained that this slide process occurs quickly, consisting of rock material, regolith, and soil. Meanwhile Huggett [35] explains that slides occur under the influence of low to moderate water content in material that is experiencing sliding. Slides can be either translational or rotational slides. Translational slides are the type that is often found in the field, which is characterized by a straight slip plane (Figure 5b). When viewed from the type of constituent material, slide type mass movements are often found in areas composed of breccia rock of Ligung...
Formation and Tapak Formation. According to Huggett [35], material in the southern part of the Watumalang Area in the form of weathering from breccia rocks tends to have low porosity so that it triggers many slide type mass movements in this region. As a result of low porosity, the rainfall will be responded to by the surface runoff so there is not too much absorption and tends to cause slide.

Table 2. Summary of results of measurements and observations of geomorphological aspects in several sample locations

| No | Name of Location | Coordinate (UTM) | Altitude (masl) | Slope (%) | Relief Units | Rock type | Landuse / Vegetation | Genesis | Possible terrain unit |
|----|------------------|------------------|----------------|-----------|--------------|-----------|---------------------|---------|----------------------|
| 1  | Siwatu           | 378095 9187023   | 718            | 25,14     | Hilly        | Jembangan Volcanics | Shrubs   | Structural            | Structurally hill |
| 2  | Gondang          | 376889 9187036   | 760            | 12,21     | Rolling      | Jembangan Volcanics | Moor     | Structural            | Structurally hill |
| 3  | Banjaran         | 375428 9187140   | 703            | 27,29     | Hilly        | Breccia Ligung Formation | Moor   | Structural            | Structurally hill |
| 4  | Lumajang         | 374230 9191842   | 1033           | 19,01     | Rolling      | Breccia Ligung Formation | Moor   | Structural            | Structurally hill |
| 5  | Sumber           | 374132 9192110   | 1098           | 3,35      | Undulating   | Breccia Ligung Formation | Mix Garden | Structural            | Structurally hill |
| 6  | Depok I          | 374698 9194826   | 1174           | 70,02     | Mountainous  | Dieng Volcanics  | Moor     | Volcanic              | Volcanic foot    |
| 7  | Depok II         | 374853 9195190   | 1200           | 26,62     | Hilly        | Dieng Volcanics  | Moor     | Volcanic              | Volcanic foot    |
| 8  | Mutisari         | 374469 9195753   | 1232           | 68,60     | Mountainous  | Dieng Volcanics  | Moor     | Volcanic              | Volcanic foot    |
| 9  | Binangun I       | 373361 9194813   | 1187           | 12,27     | Rolling      | Jembangan volcanics | Moor   | Structural            | Structurally hill |
| 10 | Binangun II      | 373287 9194996   | 1157           | 72,65     | Mountainous  | Jembangan volcanics | Moor   | Structural            | Structurally hill |
| 11 | Binangun III     | 373300 9195100   | 1140           | 90,04     | Mountainous  | Jembangan volcanics | Shrubs   | Structural            | Structurally hill |
| 12 | Lengkong         | 372364 9192766   | 1183           | 13,29     | Rolling      | Breccia Tapak Formation | Moor   | Structural            | Structurally hill |
| 13 | Rega             | 371773 9192228   | 1158           | 48,77     | Hilly        | Breccia Tapak Formation | Moor   | Structural            | Structurally hill |
| 14 | Cepekan          | 371739 9191958   | 1150           | 57,73     | Mountainous  | Breccia Tapak Formation | Moor   | Structural            | Structurally hill |
| 15 | Jawaran          | 371200 9191731   | 1086           | 34,10     | Hilly        | Breccia Tapak Formation | Moor   | Structural            | Structurally mountain |
| 16 | Tripis           | 370632 9191896   | 947            | 17,51     | Rolling      | Breccia Tapak Formation | Moor   | Structural            | Structurally mountain |
| 17 | Duglik           | 371719 9191387   | 1096           | 25,98     | Hilly        | Breccia Ligung Formation | Mix Garden | Structural            | Structurally mountain |
| 18 | Karangsari       | 371937 9190791   | 1060           | 33,71     | Hilly        | Breccia Ligung Formation | Shrubs   | Structural            | Structurally mountain |
Figure 4. Geomorphological Map of the Watumalang Area
The northern part of the research area, namely Bisma Volcano, which is composed of volcanic material from Dieng and a fold zone composed of volcanic material from Jembangan has a more diverse mass movement conditions. In this area there are mass movements with types of slides, creeps and soilfluction. Slides are less common, among others, on steep slopes of volcanic feet which have valley deepening (Figure 6a). Besides slides, there are also mass movements of creep and soilfluction. Lithological factors of volcanic results that have greater permeability and porosity are very likely to affect the existence of creeps and soilfluction in this region. According to Huggett [35] and Arbogast [40], creep and soilfluction are mass movements that move at slow speeds. The difference is that creep has a little water content while soilfluction has more water content. Creep is more commonly found in the fold zone which is composed of volcanic rocks Jembangan, while soilfluction is more common in the section of Bisma Volcano with Dieng volcanic rocks. Jembangan volcanic rocks are older than Dieng volcanic rocks. It is very possible that weathering in this region has been more intensive, resulting impermeable soil layers and weathered materials, and reduced rainwater absorption. This condition further affects the amount of creep occurring in this fold area (Figure 6b). Meanwhile on Bisma's volcanic foot more soilfluction occurs. Younger material is possible to be a factor that influences the amount of water infiltration that causes saturation and then soilfluction occur. The section of Bisma Volcano also has relatively higher rainfall than other parts of the Watumalang Area. The stratovolcano morphology of Bisma Volcano plays a role in the formation of orographic rain. Because of the higher rainfall, more water absorption causes more soilfluction to occur in this part of the region. In the study area, creep can be identified from bent tree growth, crack patterns in the road, and sloping electric poles (Figure 6c). Whereas soilfluction can be identified on dryland farms whose irregular pattern of terraces is due to soil movement (Figure 6d).

Various types of mass movements are found in the Watumalang region with altitudes ranging from 900 mdpal to 1200 mdpal, with a slope of about $30^\circ$. Hadmoko et al [42] explained that based on landslide event data in various places in Java between 1981 and 2007, it was known that many landslides occurred on the slope of $30^\circ$-$40^\circ$ in a very intensive weathering zone of old volcanic material. On steeper slopes above $40^\circ$ landslide events are reduced because the material is more stable and there is less community use of land. In accordance with this description, the Watumalang area which is composed of old volcanic material in the form of andesite lava, volcanic clasts, and volcanic breccia allows for many slides to occur. The results of field observations indicate that slides in the Watumalang area occur on slopes between $30^\circ$ to $36^\circ$. On more steep slopes there is no slide event for example on the escarpment west side of Watumalang or on the slopes of Bisma Volcano. Slides in this area are mainly hampered by forest land cover. Creep and soilfluction generally also occur on the slope of the same slope as the

Figure 5. Slide mass movement in the southern part of the watumalang area. (a) mass movement on cutting slopes for road construction. (b) straight slip field on slide events (Source: Field Data. 2018)
slide. There are also creeps on gently sloping slopes below 30°. When viewed from slope morphometry, mass movements are generally found on the middle slopes of the mountains. This condition is similar to the Banjarmangu region, Banjarnegara [43] which is located in the west of the Watumalang region and is part of the same mountain range.

Figure 6. Various mass movements in the Watumalang area. (a) slide in the deepening part of the valley, (b) creep in the fold region, (c) indicators of the occurrence of creep in the field, (d) soil flux on agricultural land

Rainfall is a very influential factor in mass movements in the Watumalang Area. Many mass movements occur during the rainy season and increase during the peak of the rainy season. However, outside the rainy season when there is little rainfall there are also several landslide events in the field. Regarding this rain phenomenon, Hadmoko et al [42] explained that many landslides occur in areas with annual rainfall between 2000 mm and 2500 mm. The rainfall range is an effective rainfall limit for landslides on Java. In rainfall above 3000 mm, landslide events actually decrease because the area with such a large rainfall usually has solid rock and land cover in the form of natural forest. Watumalang sub-district has varied rainfall between 2000 and above 3500 mm.

Data in the five-year period between 2012 to 2016 [9] [44] showed rainfall in Watumalang Sub-district at 3890 mm, 3361 mm, 2014 mm, 2545 mm, dan 2444 mm. Furthermore Hadmoko et al [42] explained that landslides on Java Island were triggered by cumulative rainfall between 300-600 mm and >600 mm for 30 consecutive days. Landslides are also not always triggered by high intensity rain on the day of the landslide. Cumulative rain has an important role in triggering landslides on short time scales. 300 mm antecedent rain for 30 days or 43 mm daily rain can cause landslides in the next period. This is indicated by the existence of a landslide without rain
on that day but precisely caused by the antecedent rain. Field observations carried out during the dry season of July 2018 indicate a former landslide at several points. The landslide may occur at the beginning of the dry season caused by antecedent rain that occurs at the end of the previous rainy season. Data in 2017 shows that at the end of the 2016 rainy season there was 250 mm of rainfall from 29 rainy days in March and 261 mm of rainfall from 18 rainy days in April [9]. If this kind of phenomenon is a permanent pattern in the Watumalang Area, then rainfall at the end of the rainy season is very likely to be a trigger for landslides that occur in the early dry season. This condition provides answer why there are still landslides in the Watumalang Area even though there was no high intensity rain at that time. Mengenai pengaruh curah hujan terhadap longsor, Glade [45] also showed that increased rainfall associated with rainstorm events had an impact on the increase in the frequency of landslides. Some events that occurred in several places in New Zealand, both North Island and South Island, showed these phenomena.

Land use by the community also affects the occurrence of mass movements. Population growth and development of life causes more land to be used by the community including lands that are vulnerable to landslides [46]. On the other hand, land use activities by the community also trigger landslides and various other types of mass movements. based on observations of landslide events on Java Island between 1981-2006 explained that during the period 1981-1990 there were only a few landslides due to the still low demographic and development activities. After the 1990 period there was a dramatic increase in landslide events which turned out to be influenced by increasing population and rapid economic development. Changes in land use from the beginning of the forest were then opened to fields and fields affecting the geomorphic process. The process is characterized by the presence of landslides in the first heavy rains, which have occurred every rainy season since 2000. Dry farming land is the most land use that occurs landslides, then paddy fields, and then forests. In relation to land use, the mass movement in the Watumalang area turned out to also occur a lot in the land use of dry land and cutting slopes used for road construction. Many dryland farms are cultivated up to steep slopes on the middle slope up to the mountains. This condition causes greater potential for mass movements. Landslides that occur at observation sites 10 and 14 (see Table 2) occur in the land use of dry land with slopes of 20° to 30°. The existence of moor that reach the upper slopes of the mountains with terrace farming which accelerated the triggering of these landslides, turned out to be a phenomenon that occurred widely in Java [42].

Changes in land use for people's lives are known to be a factor that increases the potential for landslides in mountainous areas. Relatively the same conditions as happened in Java also occur in other regions. For example in New Zealand [47], anthropogenic land cover changes affect behavior changes from rainfall-triggered landslides. In the region before the arrival of European settlers in the 1840s hilly areas were only slightly affected by human activities. The first Maori tribe who lived generally occupied coastal plains or near lakes and rivers. After the arrival of European settlers there was a change of vast hilly areas from native forests and shrubs to grasslands. This apparently reduces the strength of regolith and makes the slopes more vulnerable to landslides. Thousands of landslides occur on unstable slopes mainly triggered by increased rainfall. Landslide events contribute greatly to sediment production. As a result of deforestation landslides contribute significantly to sediments in deposition basins such as lakes, swamps, estuaries, coastal wetlands, and coastal and offshore zones. Meanwhile in Europe, at the end of the holocene there are many changes in native forests and shrubs to become arable land which results in an increase in geomorphic processes including acceleration of sheet erosion and grooves, opening of tunnel gullying and landslides. Referring to the evidence of the influence of changes in land use on increased landslides in Java and various other places, it can be concluded that changes in land use occurring in the Watumalang region can also affect the increase in landslide events. In Indonesian Topographic Maps (Peta Rupabumi Indonesia) Sheet Watumalang and Wonosobo, compiled from information on aerial photographs in 1993/1994 and field surveys in 1998, hilly land in the area of Watumalang has been used for moorings and mixed gardens and natural vegetation namely bushes and forests. Field surveys conducted in 2018 show that upland land uses tend to develop. This condition further increases the potential for landslides if it is not accompanied by good land conservation methods.
Furthermore, in predicting and monitoring landslides in the future, landslide data that occurred in the past is very important. Glade shows that historical data is needed to analyze the probability of landslides. To comprehensively assess the danger of landslides, a combination of spatial and temporal data is needed. Historical data on landslides in the Watumalang region are relatively less available. On a regional scale, Java Island, historical data on landslides has been provided by Hadmoko et al. [48] and provide important information that landslides on Java Island were in fact influenced by various factors. In an effort to reduce the impact of landslides as one of the many geomorphological hazards that occur in the Watumalang area, information about landslides from time to time needs to be provided.

In addition to mass movements, Geomorphological hazards in the Watumalang area are also found in the form of erosion. In this study, the identification of erosion and the type of erosion in the field was identified, but it did not arrive at the calculation of erosion rates or the determination of the level of erosion hazard. The observation of erosion type shows that there are various types of erosion in the Watumalang Area. Splash erosion and sheet erosion are the most common types. In addition there are also rill erosion and gully erosion. Rain, slope, and land use are factors that greatly influence erosion in this area. Rain has the erosivity which is very dependent on the rainfall intensity and rainfall duration. If the intensity rainfall intensity is high and the duration is long, the erosivity is also greater so that the results of erosion are increasing [49]. Data of 2017 shows the annual average rainfall in Watumalang sub-district between 2012-2016 amounting to 2851 mm [44]. This rainfall rate can have a major influence on erosion especially if accelerated by slope factors and land use. High instantaneous rainfall intensity also affects the increased ability of rainfall to damage soil aggregates so that there is a lot of splash erosion.

Slope is very influential on erosion. The magnitude of the effect of the slope is indicated by the results of erosion which increases more than twice if there is an increase in slope of twice [49]. Observations in the watumalang Area indicate that rill and gully erosion are increasingly developing on slopes with slopes of up to 30°. The steep slope accelerates the surface runoff rate thereby increasing runoff strength in eroding the land being passed. In relation to splash erosion, steep slope affects the amount of soil moved to the bottom of the slope through a splash process. Meanwhile in areas with gentle slopes, sheet erosion dominates. Factors in soil conditions that have undergone further weathering in various places also affect the amount of surface runoff. Soil that has weathered causes reduced permeability so that infiltration is inhibited and increases surface runoff. When the intensity of the rain exceeds soil infiltration capacity, the runoff begins, and then provoking erosion [50].

Land use has a varied impact on erosion. Based on observations in the fieldwork, the land use of dry land has greater erosion compared to shrubs, mixed gardens, and forests. Human influence through landuse change and vegetation clearance indeed has an impact on erosion. The removal of the original vegetation for agricultural purposes is the main factor causing soil erosion in the form of sheets, rill, and gully [50]. Vegetation that is ground cover also affects the type of erosion. On land without a ground cover, rill or gully will develop faster even though there is large vegetation on it. Meanwhile on land where there are grasses as ground cover, the development of rill is more inhibited and usually erosion occurs in the form of sheet erosion at a limited rate. Ground cover is an important factor in controlling soil and water losses [51]. Vegetation and land management carried out by the community greatly influence the magnitude of erosion. In the Watumalang Area, the erosion rate differs between mixed garden with annual crops with dry fields. On dry land, different types of plants between corn, chili, various types of vegetables, and tobacco, also affect the type and rate of erosion that occurs. The difference in erosion in various types of land cover is because basically every type of vegetation has different abilities in interception of rainwater, reducing the speed of surface runoff and destructive forces from rain and surface runoff, the influence of roots and organic matter in strengthening structural stability of soil porosity and transpiration which reduces the moisture content of the soil [49].

Geomorphological hazard in the form of mass and erosion movements poses a potential threat to residents in the Watumalang Area. Based on the population projection at the end of 2016 in Watumalang Subdistrict there were a population of 49,266 people spread across 16 villages. Many residents reside in areas that are categorized as urban [9], while in rural areas people reside in dusun / hamlets (residential
units) that are spread throughout the region both in the valleys, slopes, and mountain ridge. These settlements often reach up to areas with steep slopes. Based on the results of observations of mass and erosion movements, areas with steep slope have higher geomorphic hazard potential. Thus based on these conditions there are still geomorphic hazards to the community in the Watumalang area. To show the distribution of hamlets (residential units) in the Watumalang area, we have analyzed the average nearest neighbor with z-score of 2.03 at significance level of P 0.04. The results of this analysis show that the distribution of hamlets is even distributed in various regions, not only concentrated in certain regions. Settlements developed in all parts of Watumalang Subdistrict, both with a large number of houses and a few, as well as in a variety of morphological conditions.

The results of overlays between residential units and slope in Watumalang area (Figure 7) show that there are still 22.82% of settlements found in areas with steep slopes and very steep. The settlement units are found in all villages with the most number in Pasuruhan, Watumalang, Banyukembar, and Wonosroyo Villages. This condition indicates that the geomorphic hazards in the Watumalang area pose a threat to the population in a considerable amount, both direct impacts on the part of settlements and the impact on people's livelihoods on agricultural land. Good disaster risk reduction efforts are needed in the future to reduce the impact of this geomorphic hazard on the community. This geomorphic hazard is mainly related to rain as a trigger factor. In the rainy season the level of community preparedness needs to be increased because the potential for disasters caused is even greater.

However, the next question that arises is whether this geomorphic hazard is only related to the influence of exogenous processes only? Does the occurrence of geomorphic hazards only relate to the denudation of landforms, or allow other triggers for geomorphic hazards, especially the danger of mass movements?. Regarding this, Hadmoko et al [42] explained that landslides on Java could also be affected by seismic activity. Based on data between 1833 and 2006 there were at least 40 destructive earthquakes on the island of Java with magnitudes from 4.8 to 7.2 SR. The distribution of the epicenter shows the connection with the existence of fault lines which are most prevalent in West Java and Central Java. Earthquake is an important trigger for landslides. There were several earthquake events that occurred in the dry season. Seismic activity usually coincides with landslides. In addition, earthquakes that occur during the dry season can also increase landslides in the next rainy season. Earthquake history data shows that in the past large earthquakes have occurred in the wonosobo region. The history of the earthquake in Wonosobo shows that a large earthquake that occurred in 1924 resulted in 727 fatalities and was one of the earthquakes with the greatest impact among the earthquakes that occurred in 1924-2005 [52]. Relatively new earthquakes also affect this region even though the epicenter is in other regions such as in 2017 [53]. One of the impacts of the earthquake was the occurrence of landslides in hilly areas. The Watumalang Area which has a hilly topography is very vulnerable to landslides triggered by earthquakes. Based on the Geological Map of Banjarnegara and Pekalongan sheets, there is a possibility of fault patterns that could become earthquake pathways. Fault is found in the southern part of the Southern Region, which is in the structural landform system, whereas in the Bisma volcanic land system that occupies the northern part, it is not found.

The structural system that occupies a large part of the Watumalang area with faulty faults is very likely to act as a trigger for landslides as explained by Hadmoko et al. Many other regions of Java have shown earthquakes triggered by earthquakes such as in Majalengka in 1990, Bantul in 2006, and other events that have also occurred in the Menoreh Mountains of Central Java [42]. With the potential of landslides triggered by earthquakes in the Watumalang area, it can be seen that geomorphic hazards in this region are not only triggered by climate influences in denudational processes, but also earthquakes as non-denudational factors. Further investigations regarding the presence of faults and potential fault activities for earthquakes need to be carried out in disaster mitigation efforts. In addition to earthquake mitigation itself is also related to the potential for landslides that can occur in the Watumalang Area, which is around the fault zone and steep slope which is prone to landslides if triggered by an earthquake. If an earthquake occurs in the watumalang area, either with the epicenter located in the region or in other regions, it is very possible that a landslide will occur along with the earthquake or post earthquake due to the weakening of the slope strength after the earthquake.
Figure 7. Map of distribution of settlements to slope
Aktivitas seismik yang berupa gempa tektonik sangat mungkin berperan sebagai pemicu longsor pada masa mendatang. Sejarah gempabumi di Wonosobo juga menunjukkan terjadinya longsor pada wilayah perbukitan ketika terjadi gempabumi besar pada tahun 1924. Berkaitan dengan aktivitas seismik ini, keberadaan Vulkan Bisma sebagai vulkan strato sebenarnya juga memiliki potensi gempa vulkanik. Namun demikian, aktivitas vulkanik Bisma yang pada saat ini tidak berlangsung lagi sebagaimana aktivitasnya pada jutaan tahun yang lalu menyebabkan aktivitas vulkanik tidak berperan sebagai pemicu gerakan massa. Berbagai kejadian gerakan massa di wilayah Vulkan Bisma justru disebabkan oleh proses denudasi oleh pengaruh iklim. Wilayah Watumalang secara genesis banyak berkaitan dengan kejadian vulkanisme pada masa lampau. Namun vulkanisme ini tidak berperan sebagai pemicu geomorphological hazard pada saat ini. Selain proses denudasi, faktor lain yang masih mungkin menjadi pemicu gerakan massa adalah gempabumi tektonik yang berkaitan dengan keberadaan sistem sesar di wilayah Wonosobo.

5. Conclusion
The Watumalang area in Wonosobo Regency, Central Java, is one of the areas that faces geomorphological hazards in the form of mass and erosion movements. This region is composed of various rocks that are related to the process of volcanism in the past. Geomorphologically, the Watumalang region consists of volcanic systems and structural systems. The process of denudation of landforms has been quite intensive. This denudation process by climatic influences is the main trigger for the emergence of geomorphological hazard. Relief factor characterized by steep slope and significant height difference, coupled with intensive rock weathering spurred the development of geomorphological hazard. Mass and erosion movements occur in various places which are controlled by relief and lithology factors. However, it turns out that geomorphic danger is not only related to the denudation process. Seismic activity can also be a trigger for geomorphological hazard. Meanwhile Vulkan Bisma as part of the last active volcanism in this region does not currently act as a trigger for geomorphological hazard. However, taking into account climate factors and seismic activities which together can become geomorphological hazard triggers, it is very good if disaster monitoring in this area uses a multihazard approach rather than just focusing on the denudation process.

There are several things that need further research, including the existence of a fault system in the Watumalang area, how the level of activity is related to its role as a trigger for geomorphological hazard in the future, and slope susceptibility testing that can experience mass movements related to seismic activity. The calculation of hazard level and geomorphological hazard risk along with the mapping also need to be done in the future for more practical purposes in disaster management.

6. Acknowledgement
We express our gratitude to the various parties who have helped in this writing Special thanks go to Edi Widodo and Syarif Jamaludin for assisting in field observation, and Maulana Azkaa Salsabila who has assisted in data analysis and mapping.

References
[1] Undang-Undang Republik Indonesia Nomor 24 Tahun 2007 Tentang Penanggulangan Bencana. Indonesia, 2007.
[2] P. A. Gares, D. J. Sherman, and K. F. Nordstrom, “Geomorphology and natural hazards,” Geomorphology, vol. 10, no. 1–4, pp. 1–18, 1994.
[3] C. L. Rosenfeld, “The geomorphological dimensions of natural disasters,” vol. 10, pp. 27–36, 1994.
[4] J. Stötter and M. Monreal, “Mountain at Risk,” in Challenges for Mountain Regions - Tackling Complexity, A. Borsdorf, G. Grabherr, K. Heinrich, B. Scott, and J. Stötter, Eds. Vienna: Böhlau, 2010, pp. 86–95.
[5] W. H. Condon, L. Pardyanto, K. B. Ketner, T. C. Amien, S. Gafoer, and H. Samodra, Peta Geologi Lembar Banjarnegara dan Pekalongan, Jawa, 2nd ed. Bandung: Pusat Penelitian dan
22

Pengembangan Geologi, 1996.

[6] A. Harijoko, R. Uruma, H. E. Wibowo, L. D. Setijadji, A. Imai, and K. Watanabe, “Long-Term Volcanic Evolution Surrounding Dieng Geothermal Area, Indonesia,” no. 2, pp. 25–29, 2010.

[7] A. Harijoko et al., “Geochronology and magmatic evolution of the Dieng Volcanic Complex, Central Java, Indonesia and their relationships to geothermal resources,” J. Volcanol. Geotherm. Res., vol. 310, pp. 209–224, 2016.

[8] Badan Geologi, “Tanggapan Gerakan Tanah Kecamatan Wonosobo Kabupaten Wonosobo Jawa Tengah 16 Desember 2013,” 2013. [Online]. Available: www.vsi.esdm.go.id. [Accessed: 20-Mar-2018].

[9] BPS Kabupaten Wonosobo, Kecamatan Watumalang dalam Angka 2017. Wonosobo: BPS Kabupaten Wonosobo, 2017.

[10] Sunarto, “Standard Operating Procedure (SOP) Mitigasi Bencana,” in Urgensi Pendidikan Kebencanaan di Indonesia, 2011, pp. 15–26.

[11] I. Alcántara-Ayala, “Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries,” Geomorphology, vol. 47, pp. 107–124, 2002.

[12] I. Alcántara-Ayala, “Geomorphology and disaster prevention,” in Geomorphological Hazards and Disaster Prevention, I. Alcántara-Ayala and A. S. Goudie, Eds. Cambridge: Cambridge University Press, 2010, pp. 269–278.

[13] M. Bründl, H. Romang, N. Bischof, and C. Rheinberger, “The risk concept and its application in natural hazard risk management in Switzerland,” Nat. Hazards Earth Syst. Sci. J., vol. 9, no. 3, pp. 801–813, 2009.

[14] R. Hemingway and O. Gunawan, “The Natural Hazards Partnership: A public-sector collaboration across the UK for natural hazard disaster risk reduction,” Int. J. Disaster Risk Reduct., vol. 27, no. May 2017, pp. 499–511, 2018.

[15] A. M. Youssef, B. Pradhan, A. F. D. Gaber, and M. F. Buchroithner, “Geomorphological hazard analysis along the Egyptian Red Sea coast between Safaga and Quseir,” Nat. Hazards Earth Syst. Sci., vol. 9, pp. 751–766, 2009.

[16] R. Djalante, “Research Trends on Natural Hazards, Disasters, Risk Reduction and Climate Change in Indonesia: A Systematic Literature Review,” Nat. Hazards Earth Syst. Sci. Discuss., no. November, pp. 1–39, 2016.

[17] M. Panizza, “3. Geomorphological Hazard,” Dev. Earth Surf. Process., vol. 4, no. Environmental Geomorphology, pp. 35–196, 1996.

[18] P. Brandolini, F. Facini, and M. Piccazzo, “Geomorphological hazard and tourist vulnerability along Portofino Park trails (Italy),” Nat. Hazards Earth Syst. Sci., vol. 6, pp. 563–571, 2006.

[19] J. Remondo, J. Soto, A. Gonzalez-Diez, J. R. D. de Teran, and A. Cendrero, “Human impact on geomorphic processes and hazards in mountain areas in northern Spain,” Geomorphology, vol. 66, pp. 69–84, 2005.

[20] M. Lazzari, E. Geraldi, V. Lapenna, and A. Loprete, “Natural hazards vs human impact: An integrated methodological approach in geomorphological risk assessment on the Tursi historical site, Southern Italy,” Landslides, vol. 3, pp. 275–287, 2006.

[21] E. Kurniati, N. Vikriyah, and N. Ardana, Nice Tutorial SIG Lanjut: Sistem Informasi Geografis Tingkat Lanjut. Yogyakarta: Bilion Technology, 2016.

[22] R. P. Aurita and S. Purwananta, “Karacteristik Mataair Kaki Lereng Gunung Merapi dan Pemanfaatannya di Kecamatan Dukun Kabupaten Magelang,” Geomedia, vol. 15, no. 1, pp. 75–85, 2017.

[23] H. T. Verstappen, Applied geomorphology: geomorphological surveys for environmental development. Amsterdam: Elsevier, 1983.

[24] H. T. Verstappen, Geomorfologi Terapan: Survei Geomorfologikal untuk Pengembangan Lingkungan. Yogyakarta: Penerbit Ombak, 2014.

[25] R. A. van Zuidam and F. I. van Zuidam-Cancelado, Terrain analysis and classification using aerial photographs, a geomorphological approach. Enschede: International Institute for
Aerospace Survey and Earth Sciences, 1979.

[26] H. T. Verstappen, “Old and New Trends in Geomorphological and Landform Mapping,” in Geomorphological Mapping, Methods and Application, 1st ed., M. J. Smith, P. Paron, and J. S. Griffiths, Eds. Amsterdam: Elsevier, 2011, pp. 13–35.

[27] L. W. S. de Graaff, M. G. G. Dejong, J. Rupke, and J. Verhooft, “A Geomorphological Mapping System At Scale 1:10,000 for Mountainous Areas,” in Zeitschrift fur Geomorphologie, vol. 31, no. 2, 1987, pp. 229–242.

[28] F. Dramis, D. Guida, and A. Cestari, “Nature and Aims of Geomorphological Mapping,” in Geomorphological Mapping, Methods and Application, 1st ed., M. J. Smith, P. Paron, and J. S. Griffiths, Eds. Amsterdam: Elsevier, 2011, pp. 39–64.

[29] R. A. MacMillan, D. H. MacNabb, and R. K. Jones, “Automated landform classification using DEMs: a conceptual framework for a multi-level, hierarchy of hydrologically and geomorphologically oriented physiographic mapping units,” in 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada, September 2-8, 2000, pp. 1–16.

[30] J. Knight, W. A. Mitchell, and J. Rose, “Geomorphological Field Mapping,” in Geomorphological Mapping, Methods and Application, 1st ed., M. J. Smith, P. Paron, and J. S. Griffiths, Eds. Amsterdam: Elsevier, 2011, pp. 151–181.

[31] J.-C. Otto, M. Gustavsson, and M. Geilhausen, “Cartography: Design, Symbolisation and Visualisation of Geomorphological Maps,” in Geomorphological Mapping, Methods and Application, 1st ed., M. J. Smith, P. Paron, and J. S. Griffiths, Eds. Amsterdam: Elsevier, 2011, pp. 254–293.

[32] Badan Standardisasi Nasional-BSN, “Standar Nasional Indonesia Penyusunan Peta Geomorfologi,” SNI 13-6185-1999, 1999.

[33] W. D. Thornbury, Principles of geomorphology, 2nd ed. New York: John Wiley and Sons, 1969.

[34] H. Pramono and A. Ashari, Geomorologi Dasar. Yogyakarta: UNY Press, 2014.

[35] R. J. Huggett, Fundamentals of Geomorphology, 2nd ed. New York: Routledge, 2007.

[36] H. T. Verstappen, Garis Besar Geomorfologi Indonesia, 1st ed. Yogyakarta: Gadjah Mada University Press, 2013.

[37] H. T. Verstappen, “The volcanoes of Indonesia and natural disaster reduction (with some examples),” Indonesia, vol. 26, no. 68, pp. 27–35, 1994.

[38] A. J. Pannekoek, Outline of the geomorphology of Java. Leiden: E.J. Brill, 1949.

[39] H. T. Verstappen, Outline of the geomorphology of Indonesia, a case study on tropical geomorphology of a tectogene region (with a geomorphological map 1:5.000.000). Enschede: International Institute for Aerospace Survey and Earth Sciences, 2000.

[40] A. F. Arbogast, Discovering Physical Geography, 2nd ed. New Jersey: John Wiley and Sons, 2011.

[41] Sutikno, L. W. Santosa, Widiyanto, A. Kurniawan, and T. H. Purwanto, “Kerajaan Merapi”, Sumberdaya Alam dan Daya Dukungnya. Yogyakarta: BPFG UGM, 2007.

[42] D. S. Hadmoko, F. Lavigne, J. Sartohadi, and C. Gomez, “Spatio-Temporal Distribution of Landslides in Java and The Trigerring Factors,” Forum Geogr., vol. 31, no. 1, pp. 1–15, 2017.

[43] K. D. Priyono and Priyono, “Analisis morfometri dan morfostruktur lereng kejadian longsor di Kecamatan Banjarmangku Kabupaten Banjarnegara,” Forum Geogr., vol. 22, no. 1, pp. 72–84, 2008.

[44] BPS Kabupaten Wonosobo, Kabupaten wonosobo dalam angka 2017. Wonosobo: BPS Kabupaten Wonosobo, 2017.

[45] T. Glade, “Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand,” Environ. Geol., vol. 35, no. 2–3, 1998.

[46] F. Guzzetti, A. Carrara, M. Cardinali, and P. Reichenbach, “Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy,”
Geomorphology, vol. 31, pp. 181–216, 1999.

[47] T. Glade, “Landslide occurrence as a response to land use change: a review of evidence from New Zealand,” *Catena*, vol. 51, pp. 297–314, 2003.

[48] E. De Bélizal *et al.*, “Rain-triggered lahars following the 2010 eruption of Merapi volcano, Indonesia: A major risk,” *J. Volcanol. Geotherm. Res.*, vol. 261, pp. 330–347, 2013.

[49] S. Arsyad, *Konservasi Tanah dan Air*, 2nd ed. Bogor: Penerbit IPB Press, 2012.

[50] A. J. T. Guerra, M. A. Fullen, M. do C. O. Jorge, J. F. R. Bezzera, and M. S. Shokr, “Slope Processes, Mass Movement and Soil Erosion: A Review,” *Pedosphere*, vol. 27, no. 1, pp. 27–41, 2017.

[51] H. Chen *et al.*, “Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on the Loess Plateau, China,” *Catena*, vol. 170, pp. 141–149, 2018.

[52] E. R. Engdahl and A. Villasenor, “Global Seismicity: 1900-1999,” in *International Handbook of Earthquake and Engineering Seismology Part A*, W. H. K. Lee, H. Kanamori, P. C. Jeenings, and C. Kisslinger, Eds. London, 2002.

[53] U. Hartono, “Di Wonosobo, 3 rumah warga rusak akibat gempa,” *Detik News*, 2017. [Online]. Available: https://news.detik.com/berita-jawa-tengah/d-3772478/di-wonosobo-3-rumah-warga-rusak-akibat-gempa. [Accessed: 02-Jul-2018].