Application of Landform Arrangement and Slope Classes on Detailed Soil Resources Mapping in Transitional Volcanic Landscape. Case Study: Bompon Watershed, Magelang Regency, Central Java

Ahmad Priyo Sambodo

A Thesis Submitted in Fulfillment of the Requirements for the
Degree of Master of Science in Earth System Science
(International Program)
Prince of Songkla University
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I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

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ABSTRACT

Detailed soil resources data is very importance for a development. In many sectors, information regarding the soil conditions is important, whether for civil engineering, mining, and especially agriculture. Unfortunately, despite the long history of soil studies, the cost to obtain a good soil data through soil mapping is still considerably expensive. Use of grid method for soil mapping is the reason behind the expensive cost of detailed soil mapping. In order to reduce the cost while increasing the efficiency of soil mapping, this study tries to use geomorphometry approach to simplify the soil mapping process. For this study, the geomorphology complex area, transitional volcanic landform was chosen. Transitional volcanic landform has unique soil characteristic, which are rich in clay, high erodibility, and have a depth for more than two meters. The result of this study shows that the slope has a statistical significance to the soil pH level, but the R^2 value is still low due to many human activities that potentially alter the soil conditions beyond the natural rate. Despite the low R^2 value, the time and cost needed to finish the soil survey is 70% lower than using a grid method. Those results shows that the geomorphometry approach still have a challenge to be implemented widely as a standard approach for soil mapping but have a great potency.

Keywords: Geomorphometry, Soil Mapping, Landform Study, Soil Resources, Geographic Information System

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LIST OF ABBREVIATION

BIG	Badan Informasi Geospasial (Indonesian Geospatial Agency)
DEM	Digital Elevation Model
DEMNAS	DEM Nasional (National DEM)
FAO	Food and Agriculture Organization
GIS	Geographic Information System
IFSAR	Inter-Ferometric Synthetic Aperture Radar
MLA	Minimum Legible Area
MLD	Minimum Legible Delineation
SRTM	Shuttle Radar Topography Mission
UAV	Unmanned Aerial Vehicle
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

A soil map is the important information of resources as the importance of the soil for the ecosystem especially human life development (Hartemink et al., 2008; Soil Survey Staff, 2014). Soil map contains information about soil such as physical, chemic, and biological characteristic. Primarily and basically, the development of soil mapping technique and process is for agriculture purposes. Many scientists in the United States developed the concept of soil and soil mapping from early 1800 until recently (Soil Science Division Staff, 2017). The growth of the US economy and population should be supported by food production, and the early soil map was made for agricultural planning purposes. In modern days, soil map applications have become wider than before. Soil maps can be used for land evaluation, land degradation prevention, soil-related disaster mapping, regional development, and also infrastructure project (Hartemink et al., 2008). It can be achieved because of the development of advanced soil surveys and the availability of data.

In the early development of soil mapping, the grid method is commonly used (Ge et al., 2011; Zinck et al., 2016). Soil scientists divided the mapping area into a small grid, based on the scale they wanted to make. When the remote sensing data became more available, it leads to some research about geomorphology and soil correlations (Hartemink et al., 2008). The use of geomorphology, especially the morphological aspect, as an approach for global scale soil mapping units became more common. But the use of the morphology aspect does not eliminate the use of the grid, because morphology is considered as qualitative and subjective. The grid was then made as the main guide to collect soil samples. The result then interpolated the base of each grid to make the soil map. Until recent years, the grid-based method is still used as a standard method for soil mapping, besides it needs a large number of samples, an extensive amount of laboratory process, and a long time to finish, it all leads to the high price of soil mapping process (McBratney et al., 2003; Szatmári et al., 2018; Zinck et al., 2016). Many developing countries cannot afford the high cost, which resulted in unsustainable development and land degradation.

Although many studies show that there is a strong correlation between soil and geomorphology, the use of geomorphological aspects for the main soil mapping unit is still limited. The reason, as already been stated, geomorphology is considered qualitative, subjective, and too dependent on the interpreter's experience. The geomorphological aspect of the soil mapping process is used for initial delineation on a global scale. Its functions provide an initial understanding of the mapping area, especially for genesis and parent materials. Geomorphology cannot give any precise location for a soil sampling site, that is the main reason the grid still in use today.

The latest development of the Digital Elevation Model (DEM) provides us a high-resolution and better accuracy, not like in the early developing process of soil mapping and its method (Nair et al., 2018). Many high-resolution and good accuracy DEM, such as Shuttle Radar Topography Mission 30/SRTM 30 (30 m resolution), Inter-Ferometric Synthetic Aperture Radar/IFSAR (5 m), Terra-SAR X (5 m resolution), and ALOS PALSAR (11 m resolution) help to improve the interpretation of geomorphological aspect, especially the geomorphometry aspect (Boulton & Stokes, 2018; Florinsky, 1998; Newman et al., 2018). The geomorphometry is a quantitative aspect of geomorphology features can bridge the gap between soil and geomorphology science in term to improve the accuracy of interpretation and reduce the subjectivity (Hengl et al., 2009; Pike, 2000; Smith & Pain, 2009). A high-resolution DEM can detect a more detailed geomorphometric aspect either directly such as elevation, local relief, and slope length or advance processing such as slope gradient, curvature, aspect, or drainage pattern (Hengl et al., 2009; Nair et al., 2018; Smith & Pain, 2009).

The availability of high-resolution DEM and geomorphometry aspect will help the development of modern or specific soil characteristic mapping (Ge, Thomasson, & Sui, 2011; Smith & Pain, 2009). A developing country such as Indonesia also has its own high-resolution DEM called DEMNAS (Badan Informasi Geospasial, 2018). Experimenting and research about mapping soil characteristics using the geomorphometry aspect with help from high-resolution DEM will create useful results for scientific and national development. Many soil or geomorphology scientist argues that the geomorphometry aspect will reduce cost and improve the efficiency of soil mapping process rapidly (Nair et al., 2018).

1.2 Problem Statement

A soil map is an important instrument for development, especially in the planning stage. Soil map gives detailed information about soil characteristics and could prevent incompatibility between soil use and its natural potency and limitations. Destructive processes on soil such as landslides, erosion, and loss of productivity. But, in a developing country such as Indonesia, soil maps or even soil data are not available yet on a detailed scale. Cause of the unavailability of the soil data and map is the method to build soil map is using the grid method, and it considerably labor-intensive, and expensive.

The more cost-efficient and less labor-intensive soil mapping methods in Indonesia are needed. Rapid economic growth since the early 2000s requires more land for new development, on the other hand, there is also a need for an agricultural area to supply the entire population which already reaches 270 million. In April 2019, after the election, the government release a plan to move the capital city from Jakarta, Java Island to somewhere between Panajam Paser Utara Regency and Kutai Kertanegara Regency in Kalimantan Island. Expert worry if the moving of the new capital carried out without a perfect planning or clear instrumentation such as detailed soil map it will just create a new problem in Kalimantan Island, home of dense tropical rainforest known as the lung of the world and its biodiversities.

The concept of soil mapping using geomorphometric parameters has been initiated. Previous research tends to utilize large amounts of geomorphometric parameters, as well as combining with other factors such as climate and lithology. This can be a weakness because in practice climate and geological data of good quality are very difficult to find. In addition, it is necessary to consider hierarchies in parameters used as boundary mapping units, to accommodate multi-scale studies.

The use of geomorphometric parameters as a basis for delineation units in soil mapping needs to be developed more deeply, especially to find simple and hierarchical parameters. Geomorphometric parameters also need to be used as a single parameter, to reduce errors caused by differences in data quality if using other parameters such as lithology, and climate. The latest national seamless DEM, called DEMNAS, which has just been released by Indonesia is high-resolution data that can be utilized to obtain good delineation results and is suitable for detailed scales.

1.3 Research Objective and Scope

1.3.1 Research Objective

There are still many problems that have not been answered by previous soil research. Various gaps in the study still need to fill either in theory or practice. To be able to fill the gap that has not yet been filled, the purposes of this research are:

1. Landform arrangement and slope application for a soil mapping unit on detailed soil mapping in a transitional volcanic zone,
2. Assess the effects of slope configuration in relation to the soil pH level,
3. Calculate the number of samples and cost needed and compare with the previous survey in 2018 in a Bompon watershed.

1.3.2 Research Scope

Area:

- Research conduct on Bompon Watershed in Magelang Regency, Central Java, on the southern slope of Sumbing volcano,
- Geomorphologically, the research area sits on the transition zone between Tertiary and Quaternary volcanic landforms.

Scale:

- This study was carried out with the assumption to make a 1:10.000 scale soil map

Methods:

- The delineation unit of the map produced by using the national seamless Digital Elevation Model (DEM) called DEMNAS, officially published by the Indonesian Geospatial Agency in 2018,
- The soil mapping unit derived from landform arrangement data and detailed to suitable for a detail map by using slope data,
- The soil parameter measured are soil depth, number of layers, and pH level,
- Method for fieldwork, including soil measurement was follow the guidelines from United States Department of Agriculture (USDA),
- The previous survey activity for comparison was conducted by Transbulent research group and Faculty of Agriculture in 2018 with the similar period and season conditions.

Time:

- Fieldwork conducted in July and August 2019 during the transition between rain and dry seasons to keep the ideal soil moisture for measurement.

CHAPTER 2
LITERATURE REVIEW

2.1 Geomorphometry of a Landform

Geomorphometry is a study about quantitative aspect of a landform (Hengl et al., 2009; Pike, 2000). By using a geomorphometry, landform described based on its quantitative element (Newman et al., 2018). The quantitative analysis of a landform mainly derived from the elevation data (Hengl et al., 2009; Pike, 2000; Smith & Pain, 2009). In a modern era, the elevation data was extracted from the digital elevation model (DEM).

Since the development of a landform study, many quantitative aspects of a landform have been analyzed and use for different purposes. Elevation is a basic geomorphometry parameters that could be derived directly from the DEM (Pike, 2000). The basic geomorphometry parameters from the elevation is a slope gradient, slope length, and curvature (Burian & Minár, 2013; Hengl et al., 2009; Louw & van Niekerk, 2019; Migoń et al., 2017; Mokarram et al., 2015; Pedersen, 2016; Zinck et al., 2016). Those parameters commonly used for a soil studies like landslide, erosion, and soil development studies. The development of computer science, software as well as the availability of higher resolution data lead to more advanced and complex geomorphometry aspect analysis. Other parameters such as stream gradient index, rotor curvature, relative roughness, and topographic wetness index is an example of more advance and complex geomorphometry aspect of the landform (Borujeni et al., 2010; Burian & Minár, 2013; Gopp et al., 2017; Richardson et al., 2016).

Geomorphometry could be useful in soil studies, especially soil mapping (Hengl et al., 2009; Zinck et al., 2016). To obtain a good and detailed soil data, soil scientist needs to use many samples due to the use of conventional grid methods. Soil scientist already use the landform approach to reduce the samples needed for soil mapping, but still limited on a general scale due to subjectivity of the landform approach. By using the quantitative approach, in a form of geomorphometry, the subjectivity of landform description could be reduced (Gruber & Peckham, 2009; Silveira et al., 2013; Zinck et al., 2016). The application of geomorphometry is not limited to soil science, this could be applied to disaster management, agriculture development, and civil engineering as well.

2.2 Soil-Landscape Relationship

Geomorphology is a study about landform that concerns the forming factors until a detailed dynamics system (Smith & Pain, 2009). Another study that studies landform is geomorphometry. Those studies are similar, the difference is geomorphology described the landscape qualitatively, and geomorphometry using quantitative to describe the landform. The use of geomorphometry on landform studies, as described by Pike (2000), will give a reliable method to compute basin hydrographs, estimate soil erosion, map landslide susceptibility, predict the movement of groundwater, visualize topography and address innumerable other problems in the earth sciences and several engineering fields.

Topography is consistently recognized as the key determinant in the development and functioning of soils at a local or landscape level through reference to the soil-landscape paradigm, and if climate, vegetation, and parent material are held constant, information on relief is often sufficient to produce reliable maps of soil, vegetation or ecological units (Hengl et al., 2009). A good soil surveyor can understand the landscape based on its characteristics and can identify the relationships between the soils and the general or specific features of the landscape (Hengl et al., 2009). Because topography so strongly affects pedogenic processes, either directly or indirectly, and is relatively easy to measure, there is considerable interest in using it as the basis for modeling the spatial distribution and behavior of soils.

Effects of topographic parameters on soil development can be understood by understanding the basic soil-forming factors equation by Jenny (1941) (Jenny, 1994),

$$S = f(C, O, P, R, T)$$

and also, the digital soil mapping (DSM) approach or *SCORPAN* equation

$$S = f(S, C, O, R, P, A, N)$$

Based on both equations, the geomorphology parameters are very important to soil research and mapping. On Jenny's equation, both topographic (*R*) and time (*T*) are a part of geomorphology study, while on *SCORPAN* factors there are topographic (*R*), time (*A*), and geographic position (*N*). Configuration of landscape or arrangement affects and explains the soil development and distribution (Duan et al., 2011; Nie et al., 2019; Tsozué et al., 2019; Yuan et al., 2019).

Soil-related studies know a basic principle that explains the soil distribution materials and development throughout the geographic position or landscape, called Catena (Teka et al., 2015; Urusevskaya, 2017). The Catena principle was first explained by Milne (1935) as a mapping unit of soil, where a repetition of soil characteristics will occur on the same topographical configuration (Richter & Burras, 2017; Teka et al., 2015). This approach is based on the soil erosion process from the detachment of material on the higher elevation by erosion agent (majority water), sediment transport, and material redeposition in the lower elevation area (Figure 2.1) (Dixon, 2015; Li et al., 2018).

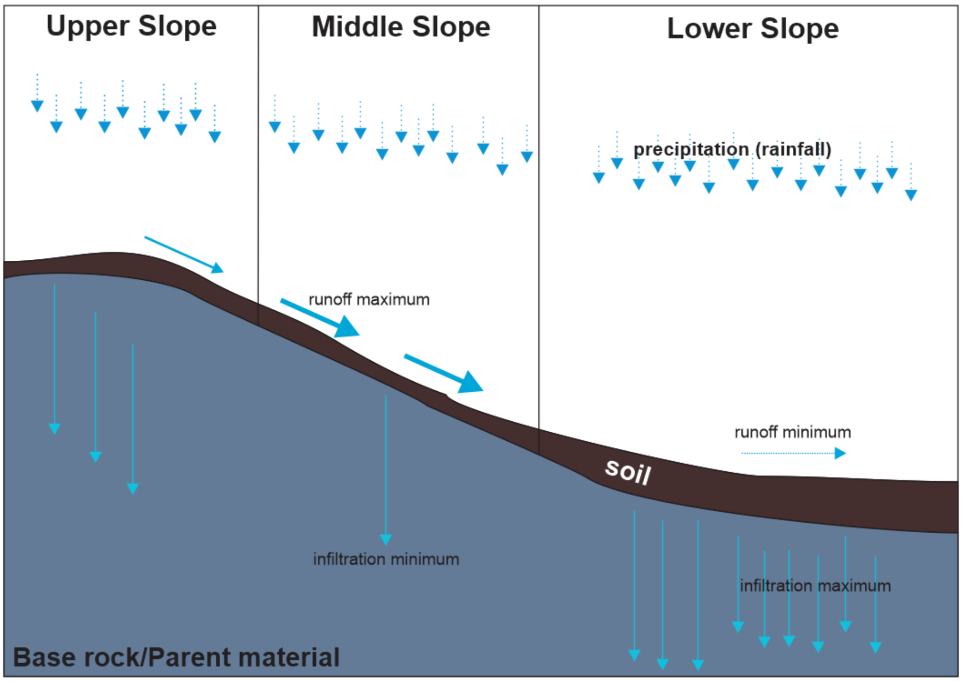


Figure 2.1 Relation between landform and soil distribution. The differences in landform, in general, could explain the differences in soil characteristics.

King et al (1983) recommend the use of landform and slope classes to describe a relation between soil and geomorphology, also as a main delineation unit for mapping and survey studies (Richter & Burras, 2017). United States Department of Agriculture also said that topographical arrangement could describe the soil pattern among the landscape (Figure 2.2) (Soil Science Division Staff, 2017).

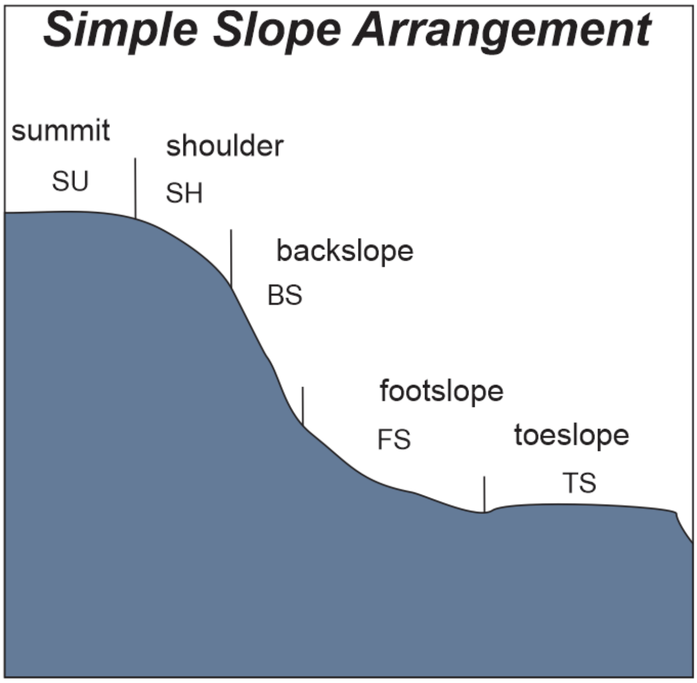


Figure 2.2 Simple landform arrangement by the United States Department of Agriculture (USDA)

The latest concept of the use of landform in the soil is Geopedology by Alfed Zinck (1988). Even though this concept already gave more detail and a clear explanation about the landscape use in soil mapping, it still lacks quantitative parameters (Zinck et al., 2016). Studies by Borujeni *et al* (2010) show that the Geopedology concept was not satisfying enough for a scale larger than 1:25.000, they suggest that more quantitative parameters of landform phases can increase the accuracy of mapping. One of the landform phases is slope conditions.

The geopedology approach uses the arrangement approach as one of the considerations to identify, analyze, and determine soil-landscape relation (Borujeni et al., 2010; Zinck et al., 2016). The use of arrangement on soil mapping is important because some of the soil characteristics are strongly influenced by the topographic position or arrangement, such as soil depth. Sauliner et al (1997) explained the strong correlation between soil depth distribution and the landform arrangement (Chan et al., 2019; Liu et al., 2019). The logic of the process behind the arrangement approach is soil erosion, on the tropical soil case is erosion by water. The soil in the upper slope tends to be thinner and less developed rather than in the downslope because the water erosion process in the upper slope is more destructive so the soil eroded before developed properly (Deressa et al., 2018; Richter & Burras, 2017; Urusevskaya, 2017).

2.3 Linear Regression Analysis

Linear regression is one of the most widely and intensively uses in the quantitative research in many fields such as economics, social, politic, demographic, agriculture, medicine, and biology. This technique is used in any research area where one is interested in studying the relationship between a variable of interest, called the response variable, and a set of predictor variables (Gujarati, 2021). For instances, linear regression has been used in analyzing the flood waste estimation (Park et al., 2021), analyzing disaster loss database in Vietnam (Luu et al., 2019); analyzing the demand for transportation mode (Konečný et al., 2021); and analyzing the environmental Impact Assessment (EIA) to predict the cost of wastewater treatment plant in Indonesia (Razif et al., 2015). Since the linear regression method has been used in almost all scientific disciplines it has been developed and improved in many ways (Gujarati, 2021).

In analyzing data that emerges from several existing populations, a method is needed to provide an overview of the results and predictions of future data from the various data variables used. Therefore, a statistical model is needed to approach the characteristics of each population that produces data, one of which is regression. Regression examines how the variable Y changes and conditional distribution $Y|x$ of the response variable Y given the $p \times 1$ vector of predictors x (Olive, 2017). While Linear regression is linear in the parameters although it may or may not be linear in the explanatory variables (Gurajati, 2019). In a linear regression model, $Y = \beta^T x + e$, and Y is conditionally independent of x given a single linear combination β^T x of the predictors, written **Y x|βT x** (Olive, 2017).

Statistical data analysis with linear regression aims to test statistical hypotheses which will later include null hypotheses or alternative hypotheses by looking for the P value. This P value describes how strong the null hypothesis is from the statistical tests carried out. A large P value means that the sample data supports the null hypothesis, while a small P value means the opposite (Sedgwick, 2014). The limit of large and small P values is conventionally set at 0.05 (5%), which is called the critical significance level. Therefore, if the P value is 0.05 or more, the sample data has presented inadequate proof to reject the null hypothesis, while if P value less than 0.05 (5%), the evidence is good enough to decline the null hypothesis. It is recommended that P values should always be displayed when reporting the results of statistical hypothesis testing, rather than simply stating "not significant (NS)" or "significant (S)," as they provide strong evidence to support the hypothesis (Sedgwick, 2014).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Methodology Overview

In order to answer the research objectives, three input data was used for this research. First is Digital Elevation Model data from Indonesian Geospatial Agency with the resolution of 8,5 meters, second is landform arrangement data from Transbulent research group, and the last is 2018 survey data from Transbulent research group. There were two main activities to obtain the results, which were laboratory processing and fieldwork. The fieldwork activity was carried out to obtain the soil samples. The three main objectives, answered by the result of the research. The flowchart of the method shown on *Figure 3.1*

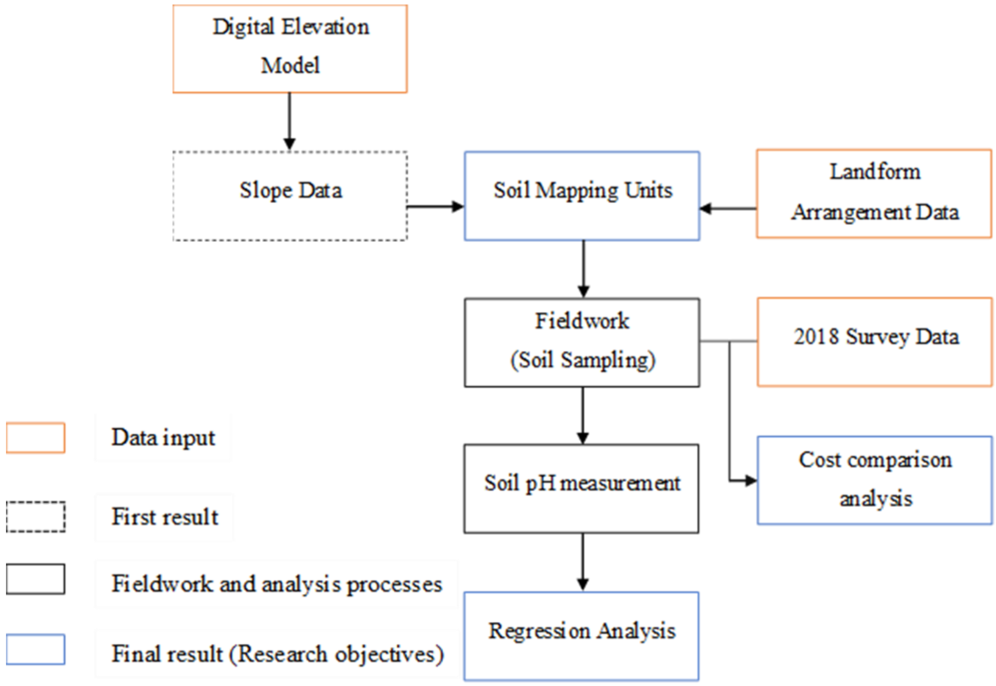


Figure 3.1 Flow Chart of Research Methodology.

3.2 Research Area

Bompon watershed is located in the southern part of Magelang District, Central Java, Indonesia. Its location span between 7^{o} 32’ 25” – 7^{o} 34’ 9” South and 110^{o} 4’ 39” – 110^{o} 4’ 24” East. Bompon watershed co Administratively, Bompon watershed separated into three villages on a two sub-district, Kwaderan and Wonogiri villages is a part of Kajoran sub-district, and Kalisari village is a part of Salaman sub-district (Figure 3.2). In total, the Bompon watershed covers an area of around 294,69 hectares. The Bompon watershed is a part of the larger Bogowonto watershed, a river system that flows to the Indian Ocean.

The area of the Bompon watershed has various land use (Table 3.1). Most of the landuse are used for agricultural purpose. There are a lot of commodities that could be harvested in Bompon, such as rice, cassava, corn, coconut, hardwood, and spices. All of them were harvested from different land use and land utilization in Bompon. The largest landuse area in the Bompon watershed is the mixed-vegetation area. This area consisted of various and multi-layered vegetation (Figure 3.3). The crop that common in the mixed-vegetation area are bamboo, coconut, sengon, coffee, ginger, and turmeric. Among other agricultural lands in Bompon, the mixed-vegetation area has the least utilization because, besides coconut or coconut sap, the crops in this area are only harvested once in a 3-5 year.

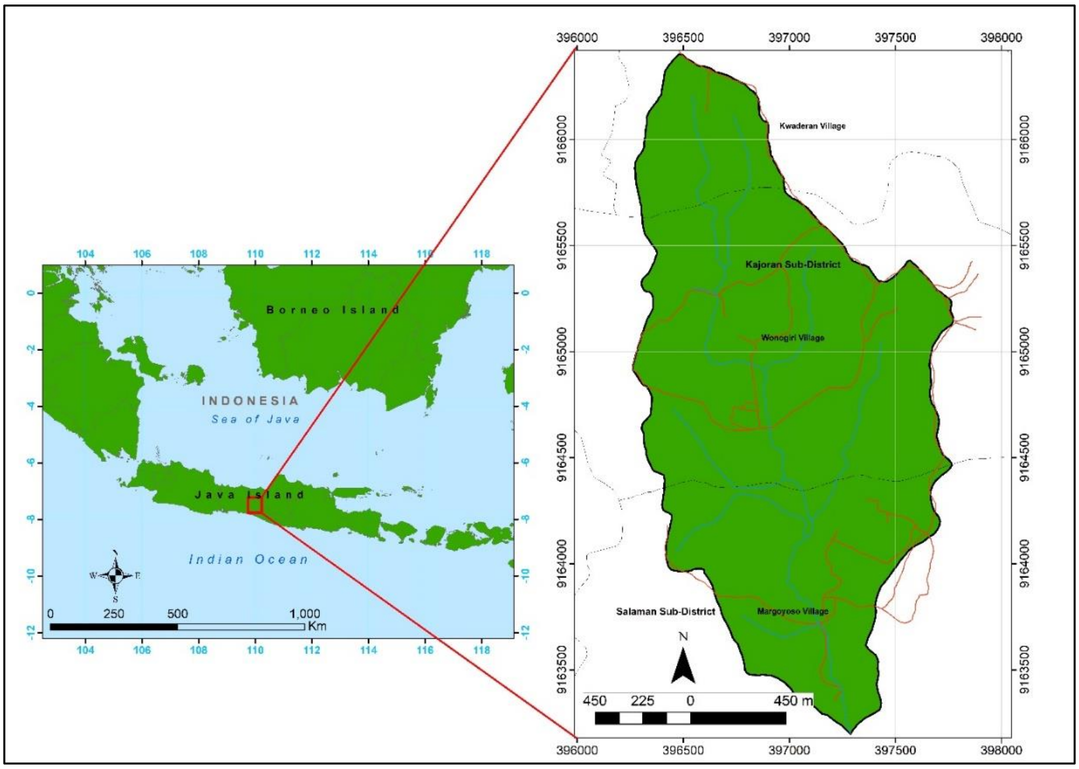


Figure 3.2 Situational map of Bompon watershed. It located on Java Island, Indonesia

Figure 3.3 The vegetation cover of mixed vegetation landuse area. The surface of the soil almost entirely covered by the multi-layered vegetation

The second-largest area is the paddy fields. It's a common crop in Indonesia, which the people's staple food is rice. It covers around 36 hectares. The paddy field in Bompon is still considered as a traditional type with mainly rely on the rain with no irrigation system from outside of the watershed. It made the paddy fields in Bompon only can be cultivated during the rainy season, while the dry season is left as a barren empty field.

Table 3.1 Percentage of landuse in Bompon watershed

Landuse	**Area**	
	Hectares	%
Mix vegetation	210,68	71,49
Paddy fields	36,61	12,42
Settlement	28,76	9,76
Moor	15,38	5,22
Empty fields	3,28	1,11

The smallest agricultural landuse type in Bompon is the moor. Similar to paddy fields, this landuse mostly consists of a single crop, but in a dry area. The crop that common in this area is cassava (Figure 3.4). This area has a more intensive utilization than the mixed vegetation area. The reason is cassava harvested once a year and needs better care to make it productive. An example of the care is by using fertilizer and keep the other vegetation away, which caused the area to have only single-layered vegetation cover.

Figure 3.4 Cassava field in Bompon watershed. The surface of the soil is exposed and not covered by vegetation.

The most unique feature of the Bompon watershed is the geomorphological setting. Bompon watershed sits in an area called transitional volcanic landform. This area is a border between quarternary and tertiary volcanic systems. In the Bompon case, it is located between quarternary Mount Sumbing and the tertiary Kulon Progo mountain range (Figure 3.5). The two systems formed in two different eras, the older is tertiary and the younger is quarternary. The differences in volcanism between the two eras also shaped a different landform. The major volcanism process in the tertiary era is a magma intrusion while explosive eruption shapes the quarter landforms. Those differences shaped the unique geomorphology setting of transitional volcanic landforms, especially the Bompon watershed.

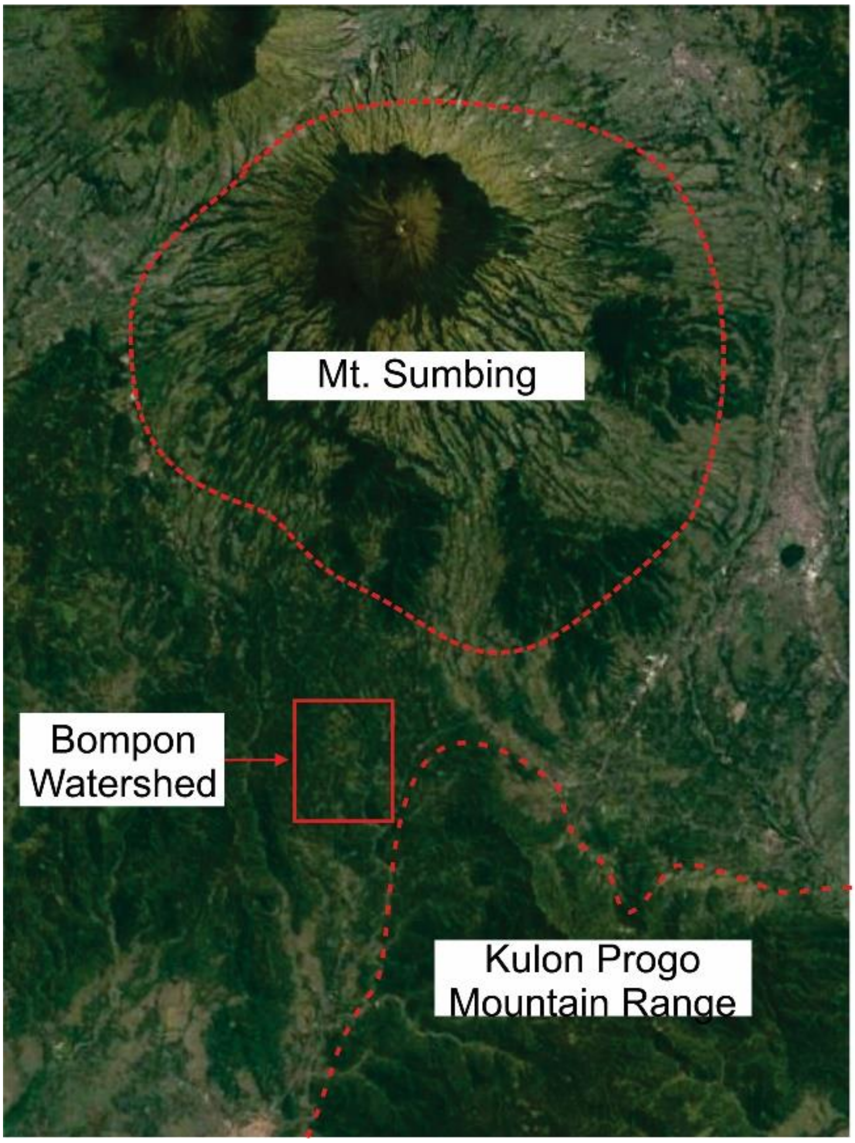


Figure 3.5 Geomorphological situation of Bompon watershed, is located between the Mount Sumbing and Kulon Progo Mountain Range

The geomorphological conditions of the Bompon watershed marked by superdeep soil that covers almost entirely of its area. The soil in the Bompon watershed in a certain area reaches more than two meters deep, while in USDA classifications soil normally reaches two meters deep at most. The superdeep soil in the Bompon watershed sits on the altered breccia materials. The soil is formed by the weathering process of Mount Sumbing volcanic ashes, while the weathered material below is a result of the hydrothermal alteration process of magma intrusion on the tertiary era. The unique combinations of material in the Bompon watershed resulted in the process of Bompon watershed to both soil erosion and landslide (Figure 3.6 and Figure 3.7).

Figure 3.6 Small trench or rill formed due to intensive soil erosion process in Bompon watershed.

Figure 3.7 Aerial photograph of the largest landslide site in Bompon, located in Kalisari Village. The landslide process starts more than 10 years ago and still expanding, threatening the paddy field and road infrastructures.

3.3 Materials and Methods

3.3.1 Soil Mapping Unit

This research divides the geomorphometry aspect into two-part, (1) main delineator, and (2) supporting information. There is a lot of morphometrical aspects that can affect soil development and distribution. Considering the scale, if the main delineator uses all of the geomorphometry aspects, the final result map will too abstract, unaesthetic at all, and contrary to the cartographic and mapping principles.

Considering the scale, which is a detail or 1:10.000, the geomorphometry aspect used as the main delineator is the slope gradient. The value of the slope gradient or just slope can be extracted or processed from the Digital Elevation Model (DEM). Using the "slope" function from ArcGIS the slope value can easily be generated. The results of slope processing are raster data that need to be converted into vector data or shapefile

Building the vector or shapefile data from the raster needs a manual delineation. There are some tools on ArcGIS to automatically convert the raster data into a shapefile, but it will just follow the raster boundary. As the raster data is pixel-shaped, the shapefile will get a square and irrational shape if compared to the true relief on the field. That is the main reason converting data needs manual interpretation and delineation. Other data such as *hillshade*, orthophoto from UAV, and contour have also been used to make delineation more realistic.

The soil mapping units for this research was derived from two morphometry parameters, landform arrangement and slope. Both parameters were not equally positioned, instead the slope was used to detail the landform arrangements. It was because the landform arrangement data was only suitable for 1:12.500 scale at maximum. To make a soil mapping unit for 1:10.000 scale, the landform arrangement data need to be detail with another parameter, which is slope that derived from 8,5-meter resolution DEM. The 8,5-meter resolution is fine enough to create a slope data that suitable for 1:10.000 scale mapping (Hengl, 2006)

3.3.1.1 Landform Arrangement

The landform arrangement data for this research using data from the Transbulent research group on Bompon Watershed. Landform arrangement data in Bompon Watershed comes from geomorphology research and mapping by the Transbulent research group from 2015 until 2016. This arrangement data derived from a modeling process using some terrain parameters such as Topographic Position Index, Slope, Curvature, and some other parameters. Those terrain parameters derived from Terra-SAR Digital Elevation Model with 12 meters resolution as the main data, and the aerial photographs to complement and improve the accuracy. The arrangement data was validated using the ground check method on the field survey activities on the Bompon watershed in mid-2016.

The study area, the Bompon watershed, have 6 landform arrangement units which are (1) interfluve, (2) Upper slope, (3) middle slope, (4) lower slope, (5) colluvial foot slope, and (6) colluvial plain (Figure 3.8). Each of the landform arrangement units has its geomorphological characteristics and uniqueness that will affect the soil condition, characters, and development.

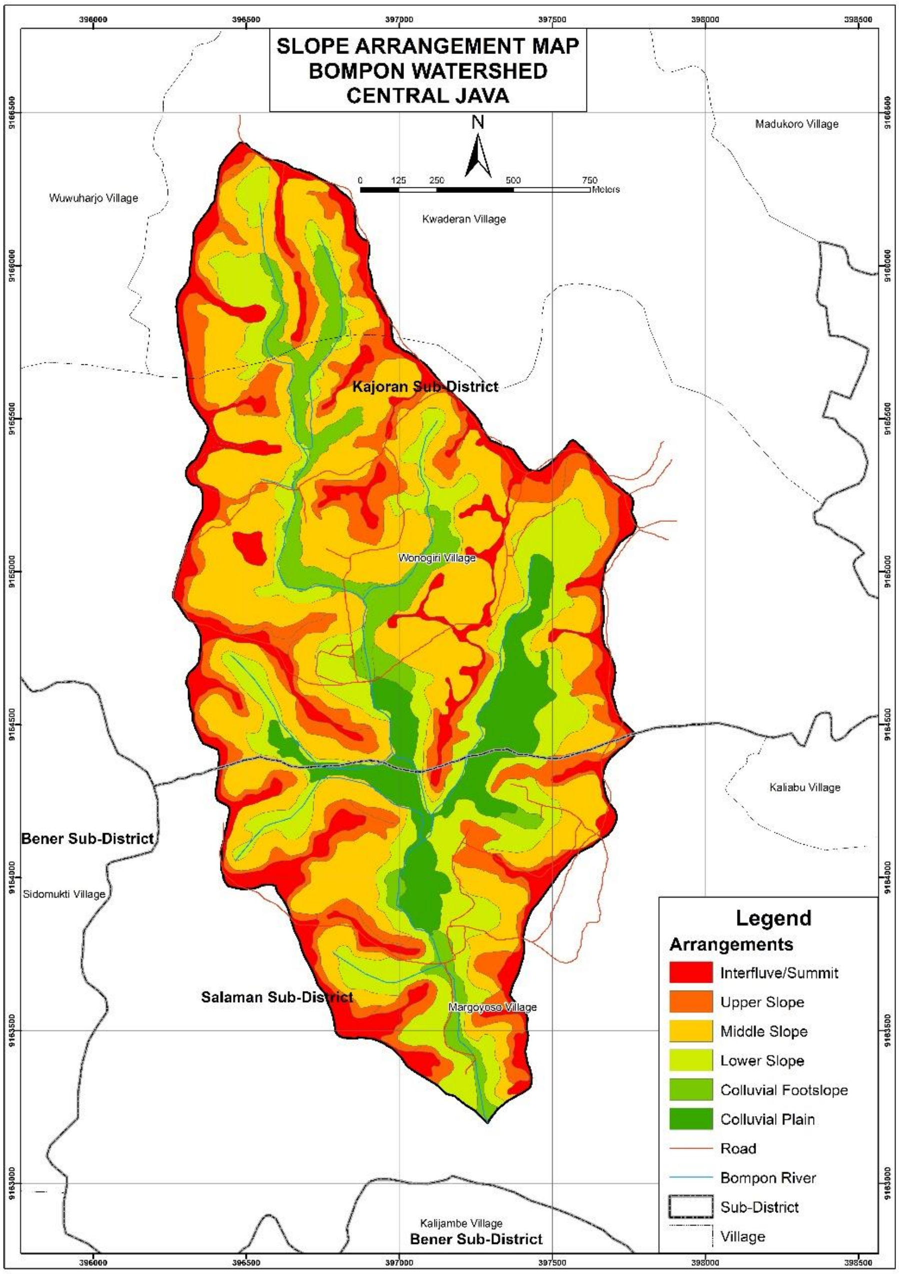
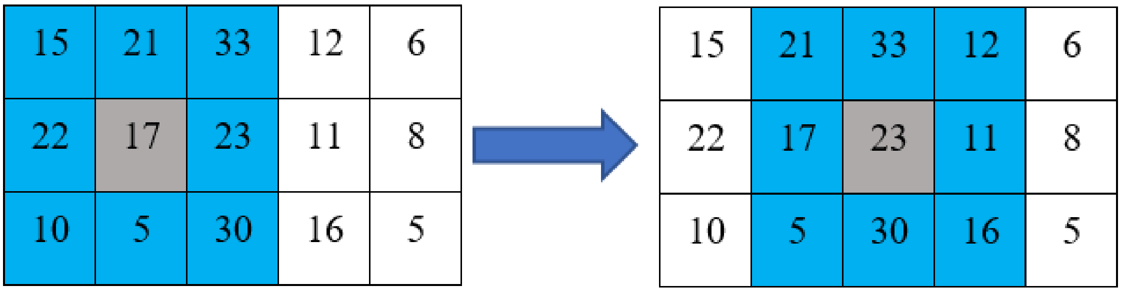


Figure 3.8 Landform arrangement map of the Bompon watershed

3.3.1.2 Slope

Slope data is generated by using the Indonesian national seamless Digital Elevation Model (DEM), named DEMNAS, released officially by the Indonesian government through Indonesia Geospatial Agency (BIG). DEMNAS is a national seamless DEM derived from multiple types and resolution DEM data such as IFSAR (5 m resolution), TERRASAR-X (5 m resolution), ALOS PALSAR (11,25 m resolution), and verified national point elevation data. The result is DEMNAS data have an 8,5 m resolution (Badan Informasi Geospasial, 2018).

Slope data is the first derivative of DEM (McBratney et al., 2003; Olaya, 2009). The method to crate slope is using the automatic calculation method on *slope* tools in Geographic Information System (GIS) software, ArcGIS 10.2. *Slope* tools in ArcGIS calculate the slope based on the moving windows system, meaning that the value of the slope on each pixel is calculated by utilizing the surrounding pixel value. As stated by ESRI, the ArcGIS developer, moving windows system have the default value by 3 x 3 pixel to calculate the slope, which means that each pixel's slope value is done by calculating 8 surrounding pixels or in total 9 pixels for each calculation steps (Figure 3.9).



15	21	33	12	6
22	17	23	11	8
10	5	30	16	5

15	21	33	12	6
22	17	23	11	8
10	5	30	16	5

Figure 3.9 Illustration of how the moving windows system works on ArcGIS

The size of the moving windows depends on many considerations, different on each research. In this research, there are 3 main factors to be considered to choose the size of the moving window, which are the total study area, local topography, and also the mapping scale. mapping scale, especially, holds an important key to determine the value of minimum legible delineation (MLD). The definition of MLD is the minimum delineation size that appears on the map (Rossiter, 2000). On a 1:10.000 mapping scale, as will be used in this study, the MLD value is 0.4 hectares or each measurement of 60 meters long. Considering the MLD value, also the local topographic conditions, the moving window size will be 3 x 3. Using that size will calculate the slope based on at least 25 meters long measurement, far more detail than the MLD.

Using slope as a delineator and soil mapping unit has advantages and a disadvantage. The slope is easy to understand and measure. To calculate the slope, the data needed is the only elevation (McBratney et al., 2003). For automatic processing on the computer, the process is also simple, there are no complex methods or pre-processing requires. To measure directly on the field, slope measurement just only needs simple tools like the Abney level (Figure 3.10).

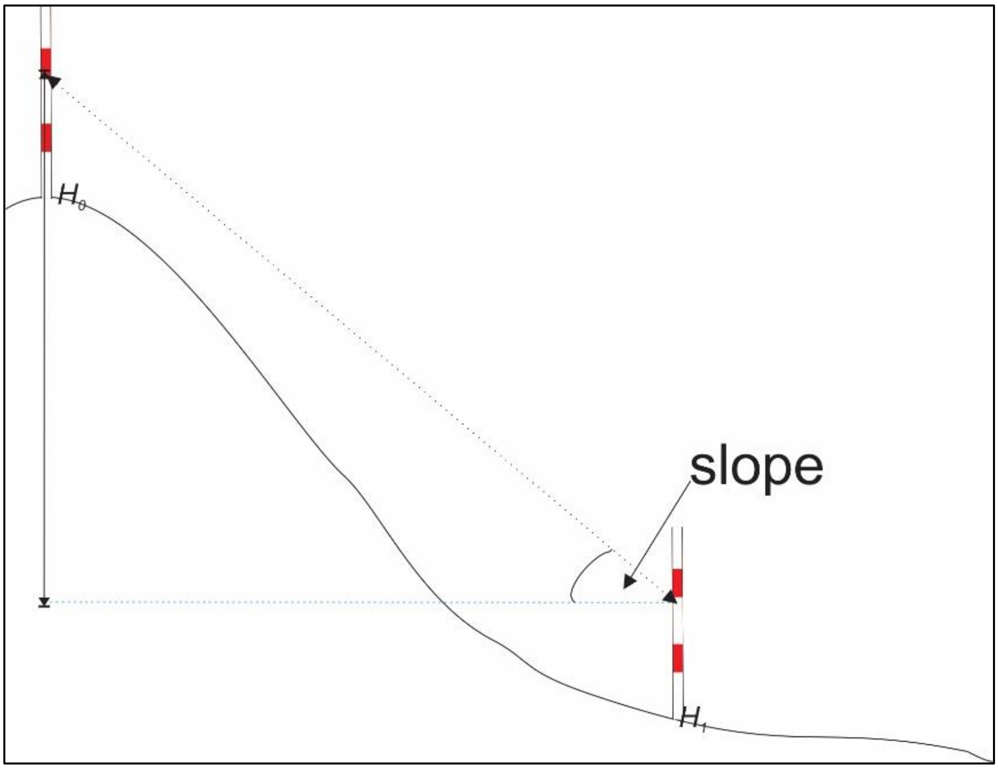


Figure 3.10 Slope measurement on the field

Other advantages are slope also easy to be recognized in the field, this factor is important to mapping studies because the delineation or border should be visible to produce an understandable map (Rossiter, 2000). The disadvantage of using slope data is this parameter is so sensitive to the grid resolution of the DEM.

3.3.2 Soil Sampling and Measurement

3.3.2.1 Soil Depth

The soil profile is the method to measure depth and differentiate layers or horizons between the body of soil (FAO, 2006; National Soil Survey Center, 2012). The purpose of using soil profile is to understand the vertical differences in the soil to see the whole pedon, the basic unit of soil measurement (Zinck et al., 2016). Another purpose is to uncover the "fresh" soil, to reduce the bias possibility during the soil analysis.

Soil depth is one of the fundamental properties of soil (Willgoose, 2018). Defining soil depth is important for the soil studies, since a lot of things could derive from it. Based on FAO (2006), National Soil Survey Center (2012). and Soil Survey Staff (2014), soil depth is also important for soil classification purpose. For example, hillslope stability and proneness to erosion and landslide is need a soil depth as a main parameter.

Soil profiles created are approximately 2 meters deep, according to the United States Department of Agriculture (USDA) standard soil sampling (National Soil Survey Center, 2012; Soil Science Division Staff, 2017). There are two approaches or methods to create or reveal the soil profile. The first is to create a 'pit' hole maximum of 2 meters in depth (Figure 3.11).

Figure 3.11 Soil profile identification using the pit method

Another method is using a terrace or slope create by human or natural processes as a soil profile (Figure 3.12). Both methods are acceptable to gather the soil data, the differences are the pit method will give more valid data, while the terrace method is faster and more time and cost-efficient. Considering the explanations in the paragraph above, both methods are acceptable and have their benefits. For this research, both methods will be used to gather soil data. The purpose is to make time and cost-efficient research without reducing the data quality.

Figure 3.12 Soil identification also could utilize the cutting slope method

3.3.2.2 Soil Layers

Similar with soil depth, soil layer also one of the basic parameters of soil, specifically for a basic units of soil data collection (FAO, 2006; Zinck et al., 2016). Method to differentiate layer of the soil is varies, depend on the purpose of the research and the soil conditions on the research area. The common methods are fix depth method and natural boundaries (FAO, 2006; Soil Science Division Staff, 2017). As stated on the name, fixed depth soil layering is defining layer of the soil with a fix interval and number of layers. This method widely uses for agricultural studies. The second method, the natural boundary using a soil characteristic to determine the different layers within the body of soil. The depth between each layer is flexible, and the border sometimes unclear.

This research used the natural boundary to differentiate each layer within the soil profile. The natural boundary method is suitable for both the research objectives and also the natural conditions of research area. This research meant to assess the effects of geomorphometry aspect as a quantitative parameter to the soil conditions, in this case is soil ph. By using the natural boundary to differentiate the soil layers, the data that obtained will reflects its natural state as it is in the body of soil. Second is related to the heterogeneity of topographic configuration of the Bompon watershed. The slope and elevation are varying between the 1 to 60% for the slope and the elevation difference could reach as high as 100 meters. If the layer of soil is predetermined by a constant interval, it will not reflect the natural conditions and effect of topographic differences would be bias.

3.3.2.3 Soil pH Level

There are two types of soil pH measurement, using electrometric or colorimetric methods (Chesworth, 2008). Both methods can be done in the field and relatively fast. The advantages of using a colorimetric are fast, while electrometric is slower both in sample preparation and the measurement tools. Cost-efficient also a part of the benefit of using on colorimetric method rather than laboratory testing. The advantage of using electrometric is to obtain more accurate results, even though the colorimetric results already enough and the error still in the accepted range (Chesworth, 2008).

The simplest tool to measure the soil pH is using the pH test Strips (FAO, 2006; National Soil Survey Center, 2012). The strips have multi-color paper that changes the color depending on the pH it interacts with. The pH value is known by comparing the color of the strips with the standard color in the box. pH measurement using pH strips is relatively cheaper rather than other tools such as pH meter or laboratory test, it also simple, fast with reliable accuracy (Chesworth, 2008).

There are certain procedures and steps to measure soil pH using pH test strips. For this research, there are two types of pH used which are actual and potential pH. The amount of sample needed is around 1 gram each. Soil sample then diluted on the reaction tube using two kinds of solution, H_2O or pure water for actual pH, and KCl for potential pH with a 1:1 ratio (Chesworth, 2008). The pH test strip is then dipped into the solution after the soil particle settles at the bottom of the tube. After the result came, the pH value will be classified based on USDA pH classifications (Table 3.2) (Hazelton & Murphy, 2007; National Soil Survey Center, 2012; Soil Science Division Staff, 2017)

Table 3.2 The pH classifications by the USDA

pH Value	Classification
3,50 – 4,40	Extremely acid
4,50 – 5,00	Very strongly acid
5,10 – 5,50	Strongly acid
5,60 – 6,00	Moderately acid
6,10 – 6,50	Slightly acid
6,60 – 7,30	Neutral
7,40 – 7,80	Slightly alkaline
7,90 – 8,40	Moderately alkaline
8,50 – 9,00	Strongly alkaline

3.3.3 Linear Regression

Linear models have the advantage of being easy to do and to be interpreted, provided the data used is continuous and has linear distribution (Lane, 2002). In some cases, when there is an irregularity in modeling, scientists tend to transform the model and variables so that they can match and give relatively good results. Although the results obtained are better, some weaknesses of the process are biases, and results that are difficult to interpret. The solution to solve this problem is to modify the model used, or better known as Generalized Linear Models (GLMs) (Faraway, 2010; Lane, 2002).

GLMs are a development of ordinary linear models. This method was developed by Nedler and Wedderburn in 1972 and further popularized by McCullagh and Nedler in 1989 (Faraway, 2010; Lane, 2002). The development of GLMs is based on the limitations possessed by the ordinary linear model method for processing with binary or discrete data characteristics. Some methods included in GLMs are (1) linear regression, (2) ANNOVA, (3) ANCOVA, (4) logistic regression, (5) Poisson regression,

(6) logistic regression, and (7) dilution assay (Lane, 2002; The Pennsylvania State University, 2018).

There are several advantages of GLM compared to ordinary linear models (Lane, 2002; The Pennsylvania State University, 2018). The first is flexibility, because of the ability to change the model without refracting the results of processing. Second, making changes to the model used is a better solution, compared to making changes to the data used. Another benefit is that there is no problem if the data used has a value of '0'. The last advantage that is quite important and becomes the main consideration is related to the research data used, both continuous, and discrete or categorical so that the use of GLMs compared to ordinary linear models is better and potentially gives more explainable results.

In this research, to understand the correlation between the soil characteristic and morphometry, soil ph. level and slope was used as an input for statistical regression test. On the test, slope parameters act as independent variable, while soil ph. level is dependent variable. The analyze focused on the two factors, the significance (p-value) and coefficient of correlation (R^2).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Geomorphometry of Bompon Watershed

The landform arrangement of the Bompon watershed could be divided into six classes, which are (1) Interfluve, (2) Upper slope, (3) Middle slope, (4) Lower slope, (5) Colluvial footslope, and (6) Colluvial plain (Figure *4.1*). Each of the arrangements has a different characteristic. The interfluve is the highest elevation of the arrangements, this is where the boundary of the watershed is drawn. On a Bompon watershed, the Interfluve arrangement makes up almost 14% of the total area. The upper slope is the arrangement below the interfluve, it makes up 15% of the total area of the Bompon watershed. The upper slope area is located below the interfluve. On a transport sediment system, both interfluve and upper slope are the areas in which the dominant process is erosion. The largest arrangement, by area, in the middle slope. The middle slope covers 37% of the Bompon watershed (Table *4.1*). This area is a transition between the upper slope and lower slope. The lower slope in the Bompon watershed cover around 19% of the total area. Both middle and lower slope is the transport area, where the erosion and sedimentation rate are almost equal. The smallest arrangement, by area, is the colluvial footslope, which covers 7.11% of the total area. The second smallest is the colluvial plain, it covers around 7.34% of the total area in the Bompon watershed. Both colluvial footslope and colluvial plain are the deposit area of the sediment from erosion or landslide process.

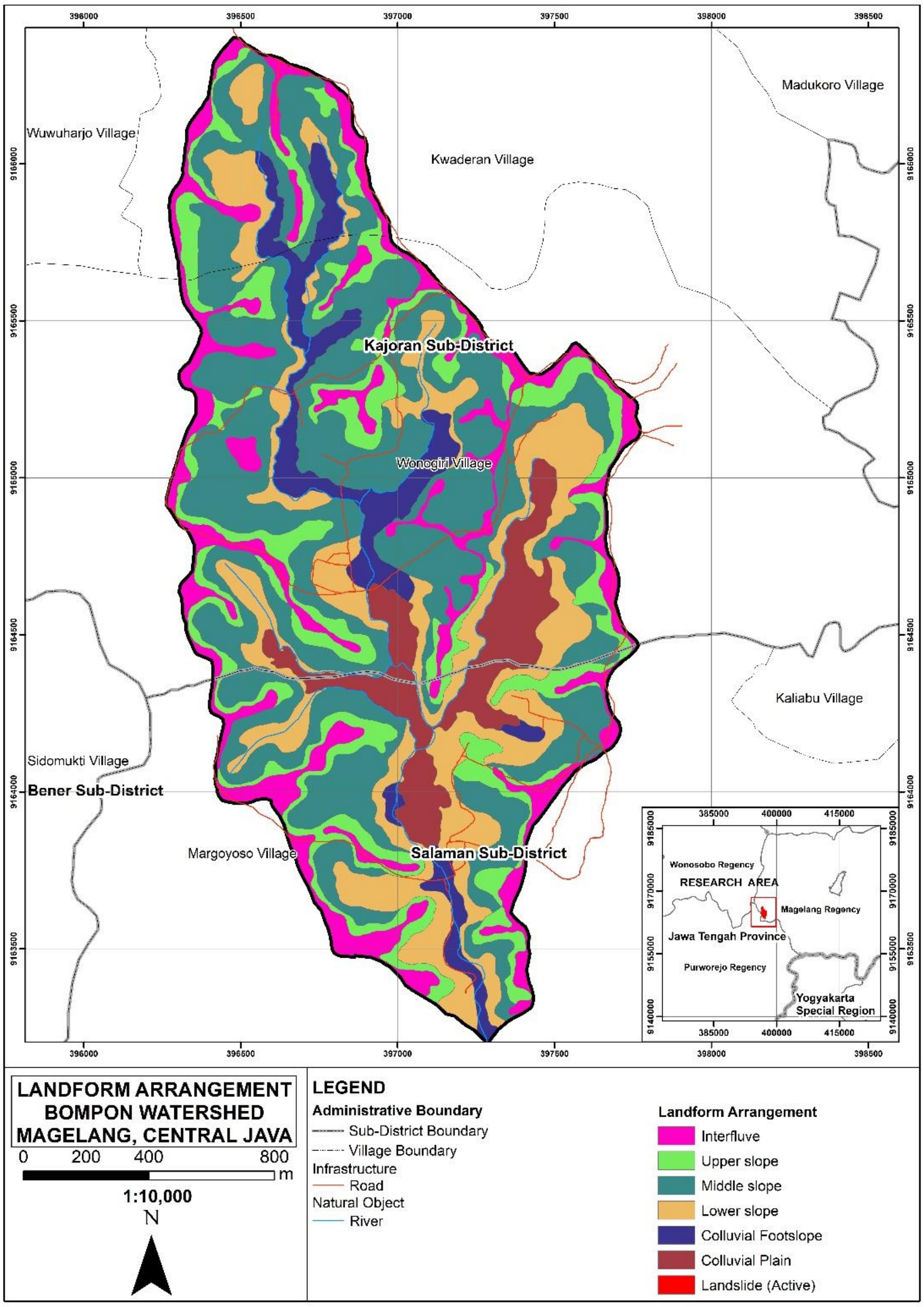


Figure 4.1. Landform Arrangement Map of the Bompon Watershed

Table 4.1. Proportion of Landform Arangement Coverage in Bompon Watershed

Landform Arrangements	**Area (Hectares)**	**Area (Percent)**
Interfluve	41,20	13,98
Upper slope	44,44	15,08
Middle slope	110,30	37,43
Lower slope	56,12	19,04
Colluvial Footslope	20,97	7,11
Colluvial Plain	21,69	7,36
Total	**294,71**	**100,00**

The slope condition in the Bompon watershed is varied between 1% for the flattest up until 60% steep (

Figure 4.2 and

Table 4.2). The dominant slope in the Bompon watershed is between 15% until 30% or under "hilly" classifications. This slope class covers 67% of the Bompon watershed total area. Climate, position, elevation, soil characteristics is a factor that affects the slope conditions. The slope steeper than 30% is more prone to gravitational processes like a landslide. That is the reason the steeper slope is rarely grouped in a large area in Bompon. Besides the dominance and distribution of "hilly" class slope, and the absence of slope steeper than 60% the flat slope is also distributed evenly. On a fieldwork observation, there are a lot of flat slopes throughout Bompon, even in the interfluve area. The flat slope spot appears in a processing result of DEMNAS data processing. But the flat slope area is not clustered to form an area huge enough for the minimum legible delineation (MLD) for a 1:10.000 scale map. The minimum legible delineation (MLD) for 1:10.000 scale mapping is around 3600 m^2 or 0,36 hectares (Rossiter, 2000).

Table 4.2 Distribution of Slope Classes in Bompon Area

Slope Classes	Area (hectares)	Area (Percent)
Flat 0 - 3	0,00	0,00
Undulating 3,01 - 8,00	8,26	2,80
Moderately Sloping (8,01 - 15,00)	61,14	20,75
Hilly (15,01 - 30,00)	196,41	66,65
Moderately Steep (30,01 - 45,00)	28,65	9,72
Steep (45,01 - 45,01 - 60,00)	0,24	0,08
Very Steep (> 60,01)	0,00	0,00
Total	**294,71**	**100,00**

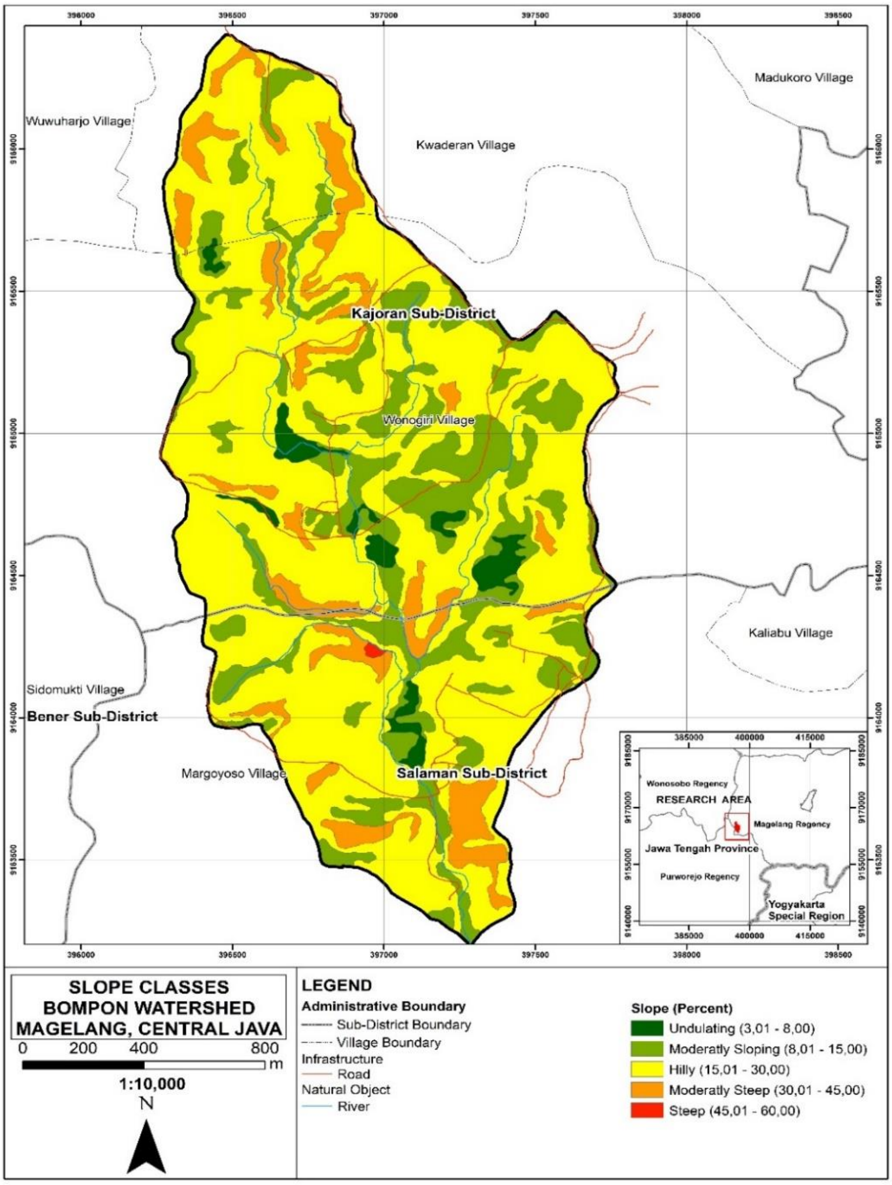


Figure 4.2. Slope Classes Map of Bompon Watershed

Complexity of Bompon watershed geomorphometry configuration as shown on the Figure *4.3***Error! Reference source not found.** commonly caused by the exogen processes. Under a wet tropical climate, the main exogenic force that caused a geomorphologic process is water, in a form of rainfall (Morgan, 2005). The rainfall with its kinetic energy could break the soil aggregate and carry the materials away to the other area to be deposited (Montgomery, 2007; Morgan, 2005; Pierce et al., 1983). One process is soil erosion. Besides the kinetic energy, the water also seeps into the soil, whether it accumulates and moves through the soil. The accumulation and movement of water on the soil, with the additional help of gravity, could cause a landslide (National Research Council (U.S.) et al., 1978; Varnes, 1984). The two geomorphologic processes, soil erosion, and landslide are the two major processes that shaped the geomorphometry of the Bompon watershed.

The geomorphometry conditions of the Bompon watershed affect the movement of water, both on and below the surface. The importance of geomorphometry conditions on the soil has been studied for many years. The arrangement of landform could explain the soil distributions on a general scale, explained by Soil Catena theory (Deressa et al., 2018; Teka et al., 2015; Urusevskaya, 2017). Slope, the basic parameter of landform is very important on landform and its process studies (Hengl et al., 2009; Kim & Zheng, 2011; Zinck et al., 2016).

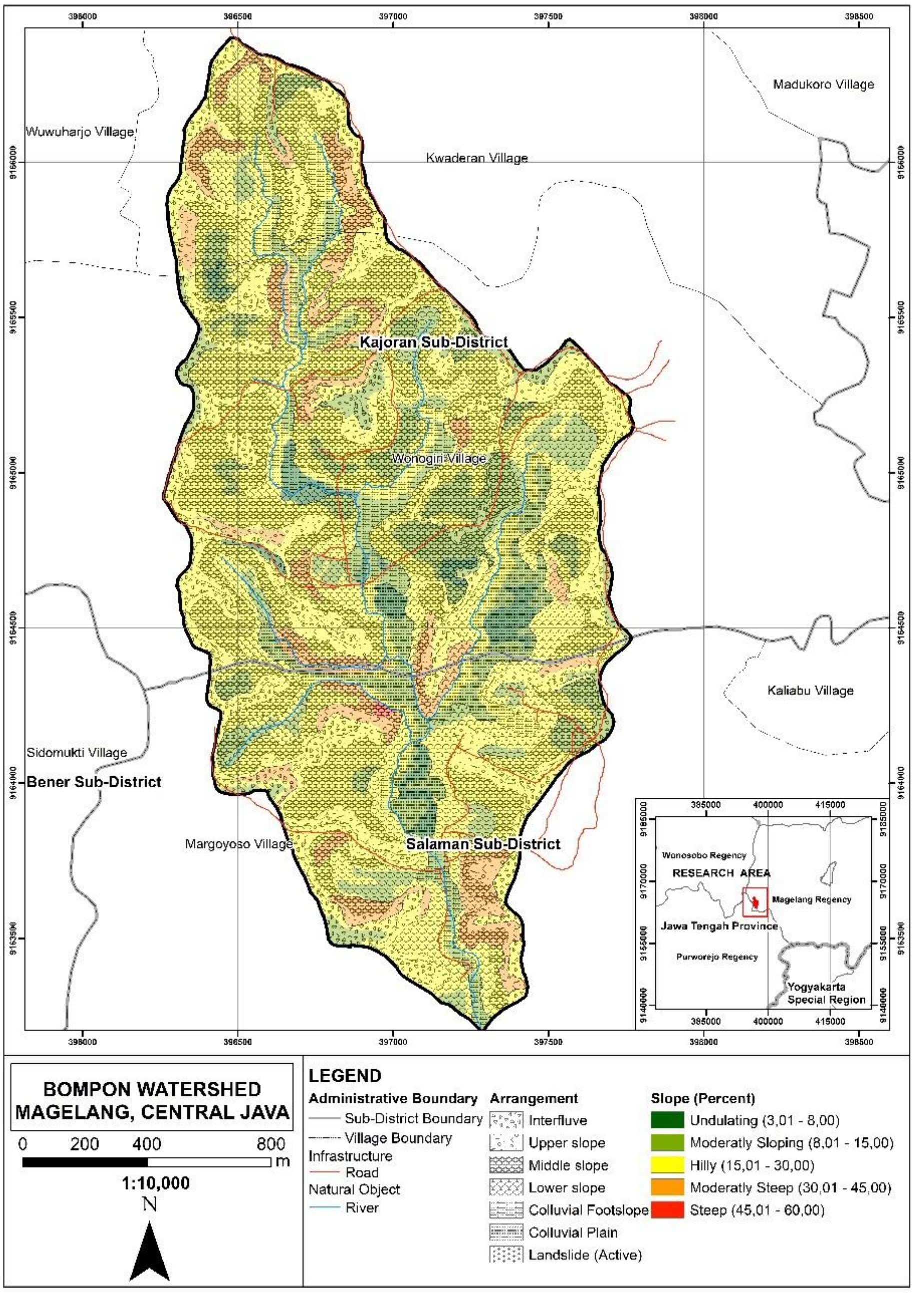


Figure 4.3. Geomorphometry Map of Bompon Watershed

The relation of geomorphometry configuration and soil erosion is interrelated. The erosion process could change the geomorphometry, and the rate of erosion also caused by the geomorphometry configurations. Besides the physical conditions, landuse also plays a significant role in the soil erosion process. Throughout the Bompon watershed, an erosion-caused formation are often found such as pedestal, rill, gully, or root exposure (Figure 4.4).

Figure 4.4 Pedestal, one of the phenomena caused by the soil erosion process

Besides the soil erosion, the Bompon watershed also prone to landslide process. The landslide itself is a process that driven by gravitational force. It usually occurs in an area that has a steep slope. In almost all the Bompon area, there has been a landslide. The landslide area could be identified by the spoon-like shape morphological features (Gutiérrez Elorza, 2013). Currently, the process is still happening in Bompon, with a different scale and speed. A notable landslide area in the Bompon watershed is in Kalisari village (Figure 4.6). Fortunately, the landslide process in Bompon usually relatively slow, and not a life-threatening one, but still concerning due to its effects of changing the land configurations and also destroying the infrastructure such as road (Figure 4.5).

Figure 4.5 Small landslide in Bompon watershed threatening the road infrastructure. Despite the thick vegetation on the surface, the landslide still occurs in several areas in the Bompon watershed.

Another factor that causing landslide is the soil condition in Bompon. The soil in Bompon has a depth of more than two meters in a certain area (Figure 4.6), but mostly still reaches the depth of two meters (Pratiwi et al., 2019). Under the deep soil, lies an altered breccia material, which is soft and slippery during the rainy season. This combination makes the root of vegetation in the Bompon watershed doesn't have a solid base to hold the slope stability. Besides the depth, the clay content in Bompon soil also plays a role. Clay tends to expand or contract depending on the water content within the soil (Sartohadi et al., 2018; Wida et al., 2019). This process caused a crack on the surface during the dry season. When it comes to the rainy season, the water from rainfall quickly filled the crack and reaches the altered material and makes it slippery, thus caused the landslide.

Figure 4.6 The thick soil layers in the Bompon watershed. The picture was taken on the Kalisari landslide site.

4.2 Distribution of Soil pH and Soil Depth

Soil pH condition in the Bompon watershed varies from 4.30 up to 7.49. Based on the USDA Classifications (National Soil Survey Center, 2012; Soil Science Division Staff, 2017), soil pH in the Bompon watershed is distributed from extremely acid to slightly alkaline. The dominant soil pH level in the Bompon watershed is moderately acid, or between 5,60 – 6,00. Besides the moderately acid, a lot of samples in the Bompon watershed also shown a significant number of soils with pH levels strongly acid, ranged between 5,10 – 5,50. On a detailed observation between the layer, most of the layers still in the moderately acidic class, except the first layer that dominantly strongly acidic. The third most frequent pH classes are slightly acidic, even though the big differences. Figure 4.7 shows the distribution of the sampling site in the Bompon watershed.

In general, most of the soil samples in Bompon could be categorized as acidic soil (Figure 4.8). This phenomenon is normal since the soil in Bompon is formed from a volcanic material (Sambodo et al., 2018). Under a wet tropical climate, volcanic material could form an acidic soil with pH levels ranged between 5,10 to 6,50 (Navia et al., 2005). The acidity of volcanic soil is caused by the oxidation process of the iron (Fe) mineral. Oxidation processes release the Fe^{3+} ion and dropping the pH level. Besides the oxidation process, the heavy rainfall and water movement also wash away some alkaline minerals such as Magnesium (Mg) (Azouzi et al., 2016; Lichty et al., 2011). Another factor that causing soil in Bompon become acidic is the absence of carbonate minerals (Sambodo et al., 2018).

Soil pH conditions also could be affected by agricultural activity (Azouzi et al., 2016; Bakhshandeh et al., 2019; Ferreira et al., 2015). The agricultural activity in Bompon includes land preparation, fertilizer, irrigation, and harvesting. All processes of agriculture could affect the soil's chemical conditions, including pH level. The irrigation process affects the water flow on the surface as well as modifying the water availability on the soil body. Land clearance and preparation affect the rate of soil erosion and physical structures of the soil (Borrelli et al., 2017; Haghighi et al., 2010; Zajícová & Chuman, 2019). Lastly, the use of fertilizer, both natural and chemical is changing the soil properties (Nanganoa et al., 2019; Paz González et al., 2014). But, despite the intensity of agriculture activity, it mostly modifies the top-soil layer (depth 0 – 50 cm) of soil. It has fewer impacts, in the short and direct term, on the deeper layer. The agriculture activity could be the reason behind the topsoil in the Bompon watershed dominated by strongly acidic pH class.

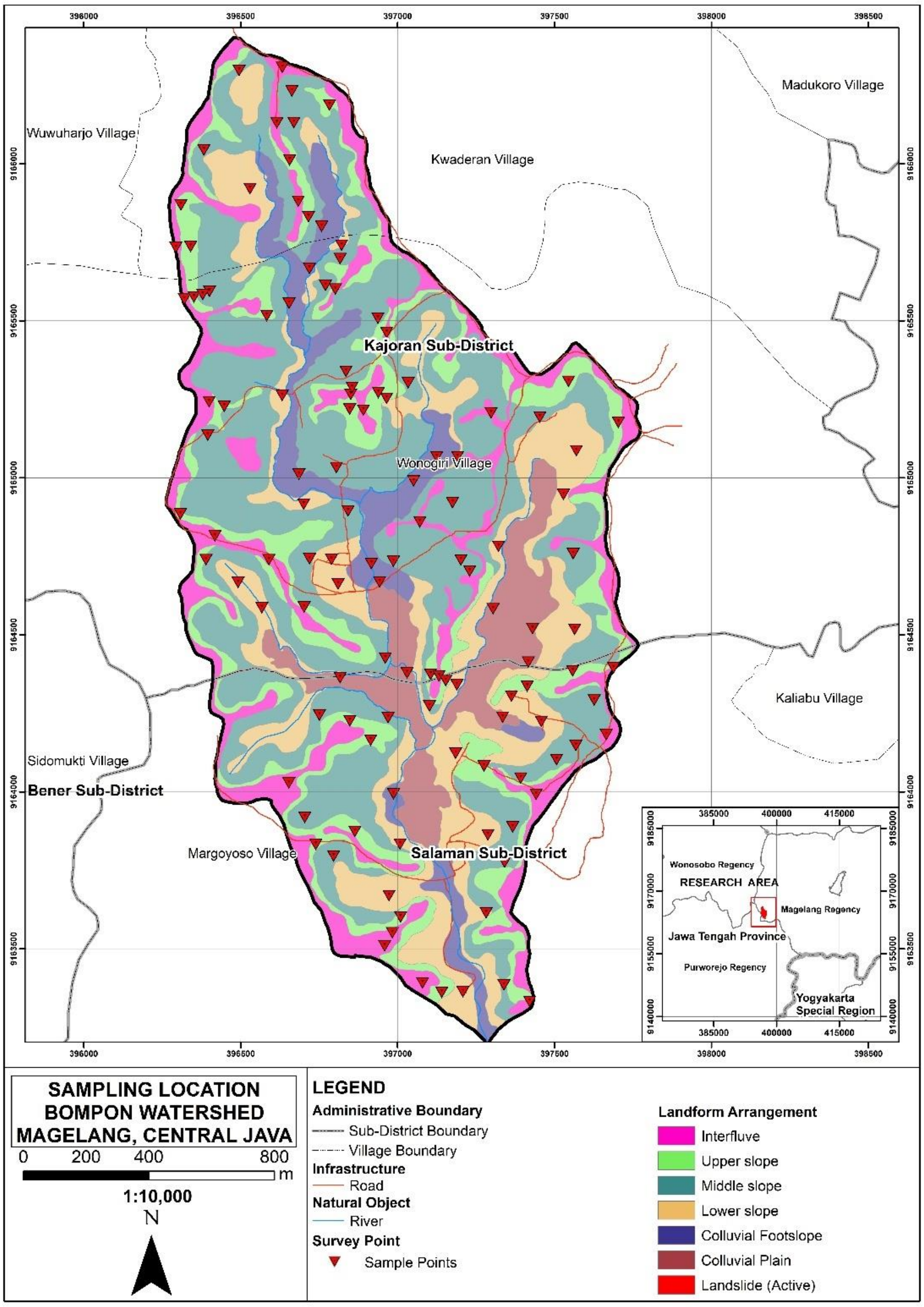


Figure 4.7 The distribution of soil samples on the Bompon watershed

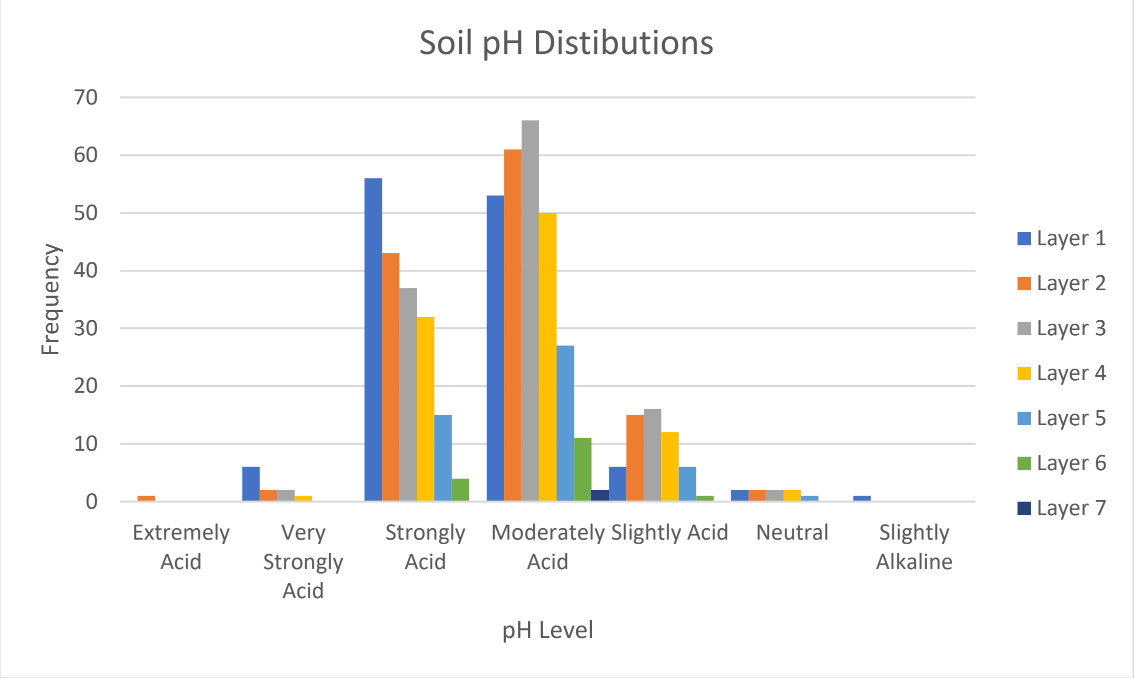


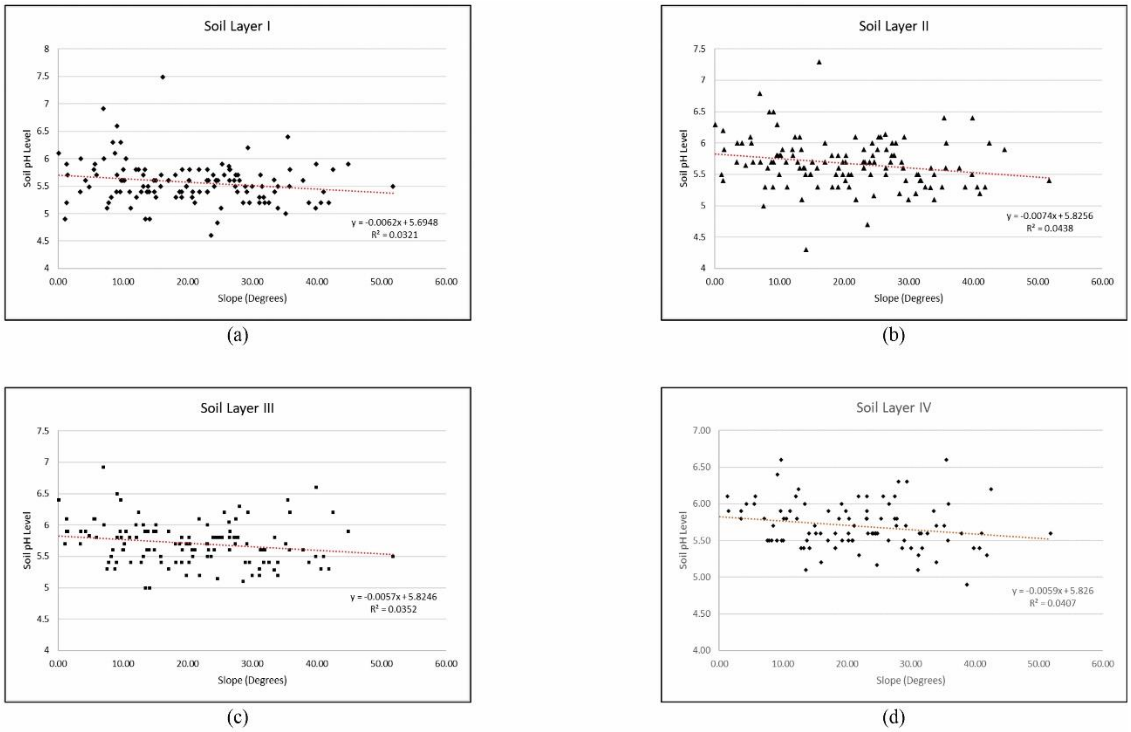
Figure 4.8 Distribution of the soil pH value in the Bompon watershed

4.3 Linear Regression Analysis

Based on the observation and sampling process, the statistical regression test only could be available for four soil layers. The reason is the sufficiency of the samples. The sampling locations show a different number of layers. Some locations have seven layers, but most of them have no more than four layers. After the data recapitulations, it shows that only 49 locations have soil more than four layers.

Based on the statistical regression analysis, the p-value shows that the geomorphometry aspect has significance on the soil pH value on all four layers. The geomorphometry aspect of a landform is affecting the soil conditions, in this case, is soil pH. The geomorphic process such as soil erosion and landslide strongly influenced by the geomorphometry conditions. The soil catena theory explains the distributions of soil, along with the unique characteristics throughout the landform (Borden et al., 2020; Richter & Burras, 2017; Teka et al., 2015; Urusevskaya, 2017). The more modern approach such as geopedology also states the strong relations between topography conditions and soil characteristics (Borujeni et al., 2010; Saldaña et al., 2011; Zinck et al., 2016).

The coefficient determination (R^2) shows a low-value result. All the soil layer in the Bompon watershed shows an R^2 value under 0,10. The results are 0,0321; 0,0438; 0,0352; and 0,0407 respectively (Figure 4.9). From the regression test, it can be said that the R^2 between slope and soil ph. level is quite low. The low value in R^2 not something bad or unexplainable. Low in R2 is common due to a lot of indescribable variations on the dependable parameters (Bartels, 2015; Frost, 2020). Especially on the detailed soil mapping, a lot of conditions could disturb the relation between independent and dependent variables. Despite the low R^2, the p-value shows a statistical significance result. The significance on the regression means that the independent variable, in this case is slope, still have a strong relation with the dependent variable, in this case is soil ph.



(a) (b) (c) (d)

Figure 4.9 Statistical regression result of all soil layers in the Bompon watershed. The result shows that on each layer the value of R2 is lower than 0,1.

Clay content in the soil has a significant role that caused the low R^2 value in statistic regression results. The soil in the Bompon watershed has clay content higher than 30% (Budianto, 2016; Rokhmaningtyas, 2017; Sambodo et al., 2018). This percentage is considered high enough to make the soil in Bompon classified as a loam – clayey soil. Clay has the smallest particle size on the soil (FAO, 2006; Sartohadi et al., 2012; Soil Survey Staff, 2014). The small particle of clay also makes the pores within the soil to be small. This could affect the movement of water and air throughout the soil (Ludovici, 2004; Ramesh et al., 2019; Singh et al., 2014). High clay content in soil could slow the leaching process within the soil layer because clayey soil has a slow water movement. Clay content helps the soil to maintain the original state characteristics, despite the heavy rainfall intensity under a wet tropical climate.

Another natural factor affecting the low R^2 value in the Bompon watershed's soil is the size *of research area* and parent materials. Due to its small size, soil in the Bompon watershed has the same parent material and lithologic conditions, Volcanic ashes, and altered breccia materials. This homogeneity of parent materials also reduces the influence of geomorphometry on soil pH conditions.

Besides the natural factor, human activities throughout the Bompon watershed also affect the soil conditions. Agricultural, transportation, and also settlement, all of that could affect the soil characteristic (Azouzi et al., 2016; Bakhshandeh et al., 2019; Bizuhoraho et al., 2018). Land use in the Bompon watershed is not affected by the control of landform or specific geomorphometry conditions (Sambodo et al., 2018). Each of the landuse could be described as randomly scattered around the watershed. For example, mixed vegetation landuse could be found in many different locations with different landform arrangements and slope conditions. Similar conditions also happened in cassava plantation it stretches across interfluve right until colluvial foot plain. Land management in Bompon is also not affected by the arrangement of slope conditions, but land ownership. The combinations of the relatively random landuse and management conditions reduce the geomorphometry influenced on soil conditions, in this case, is pH level.

4.4 Cost Comparison

The geomorphometry approach for soil mapping in the Bompon watershed shows a statistically significant result. This proofs that the geomorphometry approach could be compared with the standard conventional grid method to explain the general trend of soil pH conditions on the transitional volcanic landform. The use of the geomorphometry approach also reduces the sample needed for soil research. On the 300 hectares area of the Bompon watershed, using the geomorphometry approach only needs 124 samples locations, compared to 811 samples with the conventional grid method. Sampling density by using geomorphometry is 42 samples/km^2 (Table 4.3). The sampling density is sufficient for detailed (1:10.000) soil mapping (Hazelton & Murphy, 2007).

Table 4.3 The number of samples collected on the Bompon watershed and the density of samples per hectares and square kilometers.

Landform Arrangement	Soil Sample	Area (Hectares)	Sample/ha	Sample/Km^2
Interfluve	25	41,203	0,607	61
Upperslope	26	44,439	0,585	59
Middle Slope	37	110,295	0,335	34
Lower Slope	22	56,116	0,392	39
Colluvial Footslope	9	20,967	0,429	43
Colluvial Plain	5	21,687	0,231	23
Total	**124**	**294,708**	**0,421**	**42**

Reduction in the number of samples also affects the cost needed to survey the Bompon watershed. Between 2018 and 2019, there were two soil survey activities in Bompon (Table 4.4). The 2018 surveys used the conventional grid method and the 2019 survey used the geomorphometry approach. The survey in 2019 involved three teams with three members on each team. On an efficient condition, each team could survey 5 sample locations daily. Assume both surveys had the same survey teams involved, the 2018 survey needs almost 54 days to complete, while the 2019 survey only needs 8 days. Each day, the logistics cost around USD 31. The differences in cost needed between the two survey methods are staggering. By using the geomorphometry approach, the survey could finish seven times faster than using conventional grid methods. The significant reduction in time needed also saves the cost needed up to 80%.

Table 4.4 Comparison of the cost required between geomorphometry approach and conventional grid method.

	Geomorphometry Mapping Units	**Grid Method (60 m x 60 m)**
Number of Samples	124	811
Number of teams	3	3
Time for survey	8	54
Cost (1 USD = 14.500 IDR)	\$ 256,27	\$ 1.676,07
Cost/Km^2	\$ 85,42	\$ 558,69

The geomorphometry approach has a potency of benefits in the detailed soil mapping, specifically from an economical perspective, but it still far from perfect. Despite the reduction of labor, logistic, time, and cost needed, a lot of things should be researched to improve this approach. The Table 4.3 shows not each area has the same amount of sampling/km^2. In almost heterogeny areas, in this case, flat areas such as colluvial plain, it still has a difficulty to justify the sampling locations. On the other hand, in a heterogeny area such as Interfluve and upper slope, the amount of sample is dense enough to create a confident result. It's because the geomorphometry parameters used in this research are the landform arrangement and detailed by the slope.

CHAPTER 5

CONCLUSIONS

The geomorphometry aspect of the landform, which are arrangement and slope is applicable to create a soil mapping unit. The mapping units created by using geomorphometry approach is simpler and more practical than a grid method. Each of mapping units is visible and could be differentiate easily in the field without complicated measurement and advanced tools. The simple yet practical mapping units is useful for the surveyor and the end user to easing the survey process, reducing the cost but still provide the understandable and readable map as a result. After the small generalization to meet the minimum legible delineation (MLD), the geomorphometry map of Bompon watershed only contain 252 polygons.

In general, slope parameters of the landform could describe the soil pH trends, it shows on the p-value of the regression test that shows the significancy. Slope, as one of the basic features of the landform, naturally control a flow of the water on the soil. The slope conditions affect how the water move and its speed. The flow of the water alters and distribute both physical, chemical, and biological composition of the soil, both vertically and horizontally, through geomorphic process such as water absorption, landslide, and erosion. Those process affected the soil pH conditions. However, the statistical regression test between pH and slope shows low value of R^2. It indicates that besides of the significance, there are still a lot of noise which affects the soil pH conditions besides the slope. Agricultural activities such as chemical fertilizer use, plowing, cutting slope, settlement growth, and irrigation process is a possible disturbance of the natural soil pH and slope conditions relations. Considering the long period of human settlement and intensity of their activities in Bompon watershed, that factor is very possible to alter the natural state of soil in Bompon watershed.

Use of geomorphometry approach for the detailed soil resources mapping is prove simpler and cheaper than the conventional grid method. Compared to previous survey by using grid method in 2018, the geomorphometry approach could provide a simpler method for soil mapping. The reason behind large of samples needed for the grid method is to draw the border and mapping units. By reversing the process, determine mapping units first before the soil survey using the geomorphometry approach, the samples needed could be reduced by a significance number. Reduction of samples needed lead to reduction of time and manpower needed and affects the cost for the survey as well. The cost needed for the soil survey by using the geomorphometry approach is 70% cheaper compared to the grid method. This significance reduction of the cost is meaningful for the developing countries. The cheaper cost means the developing country could easily and cheaply conduct and provide a good quality soil data for the development plan. Besides for the general use by the state, the good soil data with a cheaper cost could be used for both large agricultural company or community farm to plan and create a better, efficient, and sustainable farming system.

CHAPTER 6

RECOMMENDATIONS

Use of geomorphometry approach in for soil resources mapping in the tropical climate transitional volcanic landscape shows a promising result. The aim of the research to study the options for a cheaper and simpler method of soil mapping is achieved. However, there are several things that still need to be considered before the geomorphometry approach is widely accepted and applied in a wider scale project. More research and study with other possibilities and improvement is still needed.

Despite the promising result, the R^2 shows a low value. It could indicate that besides the slope, there are other factors that affects the ph. The statistical value is relatively important to prove the qualitative evidence and validation of the research. For the future research, there are three recommendations to improve the statistical test result, (1) add more samples, (2) use another parameter such as curvature, or topographic position index, and (3) combine or add another parameter besides the slope. Those three options will create different result than this research, but always with a different consequence.

Based on this research, we could conclude that the pure geomorphometric parameters use is weak on the intensive human activities. The anthropogenic process such as agriculture, infrastructure, and settlement development could alter the soil characteristic beyond its natural rate. We could recommend conducting the similar research on the area with a minimum human activity and compare the result with this research. If the result is even more promising, then this approach could be used for a niche development on the untouched landscape such as in the deep of Kalimantan, Sulawesi, or Papua, Indonesia.

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APPENDIX

1. Sampling point data

Sample Number	Arrangement	Slope	Land Use (ENG)	Soil Depth Total (cm)	Depth 4th Layers (cm)	Total Layers	pH I	pH II	pH III	pH IV	pH V	pH VI	pH VII
1	Interfluve	7,03	Mix Vegetation Area	60	60	3	6,91	6,79	6,92				
2	Interfluve	14,13	Moor	160	160	4	4,90	4,30	5,00	5,40			
3	Interfluve	13,54	Mix Vegetation Area	200	149	6	4,90	5,10	5,00	5,10	5,30	5,40	
4	Interfluve	12,16	Moor	176	134	5	5,30	5,80	5,80	5,80	5,80		
5	Interfluve	19,12	Moor	150	150	3	5,40	5,30	5,40				
6	Interfluve	39,85	Mix Vegetation Area	170	170	4	5,10	5,50	5,50	5,40			
7	Interfluve	28,65	Mix Vegetation Area	170	133	5	5,20	5,20	5,10	5,40	5,60		
8	Interfluve	9,14	Moor	174	174	4	6,60	6,50	6,50	6,40			
9	Interfluve	41,89	Mix Vegetation Area	180	119	6	5,20	5,30	5,30	5,30	5,50	5,40	
10	Interfluve	29,17	Mix Vegetation Area	150	150	4	5,40	5,60	5,70	5,70			
11	Interfluve	1,49	Mix Vegetation Area	200	148	6	5,70	5,90	5,90	5,90	6,00	6,00	
12	Interfluve	4,22	Mix Vegetation Area	186	149	5	5,60	6,00	5,90	6,00	5,40		
13	Interfluve	25,34	Mix Vegetation Area	172	90	7	5,90	6,10	5,80	5,80	6,00	5,90	5,90
14	Interfluve	15,96	Mix Vegetation Area	180	180	4	5,70	5,30	5,40	5,20			
15	Upper slope	29,61	Moor	150	150	3	5,20	5,40	5,40				
16	Upper slope	10,28	Moor	150	150	3	5,60	5,80	5,70				
17	Middle slope	35,78	Mix Vegetation Area	200	180	5	5,50	5,60	5,60	5,50	5,70		
18	Upper slope	27,71	Mix Vegetation Area	166	140	5	5,40	5,80	5,80	5,70	5,70		
19	Upper slope	23,28	Mix Vegetation Area	140	73	6	5,60	5,70	5,60	5,60	5,70	5,70	
20	Upper slope	15,10	Moor	200	186	6	5,60	5,70	5,90	5,60	5,80	5,80	
21	Upper slope	23,12	Mix Vegetation Area	200	136	5	5,80	5,90	6,00	6,10	6,10		

Sample Number	**Arrangement**	**Slope**	**Land Use (ENG)**	**Soil Depth Total (cm)**	**Depth 4th Layers (cm)**	**Total Layers**	**pH I**	**pH II**	**pH III**	**pH IV**	**pH V**	**pH VI**	**pH VII**
22	Upper slope	18,21	Moor	160	160	4	5,30	5,30	5,40	5,60			
23	Interfluve	19,86	Moor	180	180	3	5,50	5,50	5,20				
24	Upper slope	20,85	Moor	200	151	5	5,40	5,30	5,50	5,50	5,60		
25	Upper slope	31,17	Mix Vegetation Area	106	89	5	5,30	5,20	5,30	5,30	5,50		
26	Upper slope	51,82	Mix Vegetation Area	105	105	4	5,50	5,40	5,50	5,60			
27	Upper slope	17,10	Mix Vegetation Area	180	180	4	5,60	6,00	5,90	5,90			
28	Upper slope	33,96	Mix Vegetation Area	185	185	4	5,50	5,50	5,40	5,70			
29	Upper slope	27,81	Bush	180	150	5	5,70	5,80	5,80	5,80	5,80		
30	Middle slope	3,42	Mix Vegetation Area	200	166	5	5,40	5,70	5,70	5,90	5,90		
31	Middle slope	10,52	Settlement	200	192	5	6,00	5,90	5,90	5,80	5,80		
32	Middle slope	9,00	Moor	150	100	5	5,40	5,30	5,40	5,50	5,50	5,80	
33	Middle slope	7,55	Mix Vegetation Area	88	88	4	5,10	5,00	5,30	5,50			
34	Middle slope	13,14	Mix Vegetation Area	180	180	3	5,70	6,10	6,00				
35	Middle slope	19,22	Mix Vegetation Area	170	131	5	5,80	5,60	5,60	5,50	5,50		
36	Middle slope	8,80	Moor	200	200	3	6,10	5,70	5,30				
37	Middle slope	30,04	Mix Vegetation Area	157	130	5	5,50	5,10	5,20	5,40	5,50		
38	Upper slope	31,11	Mix Vegetation Area	160	111	5	5,20	5,20	5,20	5,10	5,20		
39	Middle slope	40,70	Mix Vegetation Area	160	160	5	5,20	5,30	5,30	5,40	5,50		
40	Middle slope	24,65	Mix Vegetation Area	80	80	4	4,83	5,16	5,14	5,17			
41	Middle slope	31,77	Mix Vegetation Area	147	113	6	5,30	5,40	5,40	5,40	5,50	5,40	
42	Middle slope	19,85	Mix Vegetation Area	180	180	4	5,50	5,70	5,70	5,90			
43	Middle slope	27,46	Settlement	200	149	6	5,70	6,00	6,10	6,10	6,20	6,10	
44	Middle slope	21,16	Settlement	180	117	5	5,20	5,50	5,60	5,70	5,80		

Sample Number	**Arrangement**	**Slope**	**Land Use (ENG)**	**Soil Depth Total (cm)**	**Depth 4th Layers (cm)**	**Total Layers**	**pH I**	**pH II**	**pH III**	**pH IV**	**pH V**	**pH VI**	**pH VII**
45	Middle slope	25,70	Moor	200	139	6	5,70	6,10	6,20	6,10	6,10	6,00	
46	Middle slope	23,67	Moor	150	150	3	4,60	4,70	5,50				
47	Middle slope	26,49	Mix Vegetation Area	170	170	3	5,80	5,60	5,80				
48	Interfluve	21,85	Mix Vegetation Area	164	146	5	5,40	5,10	5,20	5,30	5,20		
49	Middle slope	35,21	Mix Vegetation Area	200	200	4	5,00	5,30	5,70	5,70			
50	Middle slope	33,43	Settlement	80	80	3	5,61	5,29	5,28				
51	Middle slope	37,92	Mix Vegetation Area	180	180	4	5,60	5,60	5,60	5,60			
52	Middle slope	33,96	Mix Vegetation Area	200	177	5	5,10	5,10	5,20	5,20	5,10		
53	Lower slope	1,28	Mix Vegetation Area	102	102	3	5,20	5,40	5,90				
54	Lower slope	9,64	Mix Vegetation Area	160	160	4	5,40	5,80	5,90	5,90			
55	Lower slope	3,47	Mix Vegetation Area	130	130	4	6,00	6,00	5,90	5,80			
56	Lower slope	1,32	Mix Vegetation Area	153	85	7	5,90	6,20	6,10	6,10	6,00	5,90	5,90
57	Lower slope	18,18	Mix Vegetation Area	200	200	4	5,70	5,80	5,70	5,40			
58	Lower slope	26,42	Paddy Fields	100	100	3	5,86	6,14	6,05				
59	Lower slope	15,88	Mix Vegetation Area	158	158	4	5,50	5,60	5,50	5,60			
60	Lower slope	20,34	Mix Vegetation Area	180	160	5	5,80	5,80	5,70	5,80	5,60		
61	Lower slope	24,12	Mix Vegetation Area	146	121	5	5,50	5,50	5,60	5,60	5,40		
62	Lower slope	25,18	Mix Vegetation Area	140	140	3	5,10	5,90	5,80				
63	Lower slope	26,57	Mix Vegetation Area	180	180	4	5,80	5,90	5,90	6,00			
64	Lower slope	26,51	Mix Vegetation Area	180	180	4	5,60	5,50	5,60	5,50			
65	Lower slope	35,86	Mix Vegetation Area	137	118	5	5,80	6,00	6,20	6,00	6,00		
66	Colluvial Footslope	4,83	Paddy Fields	100	100	3	5,49	5,65	5,83				

Sample Number	Arrangement	Slope	Land Use (ENG)	Soil Depth Total (cm)	Depth 4th Layers (cm)	Total Layers	pH I	pH II	pH III	pH IV	pH V	pH VI	pH VII
67	Colluvial Footslope	14,06	Mix Vegetation Area	200	131	6	5,40	5,50	5,60	5,60	5,80	5,90	
68	Colluvial Footslope	15,13	Moor	66	66	3	5,30	5,70	6,00				
69	Colluvial Footslope	21,76	Moor	130	130	4	5,80	6,10	6,10	6,10			
70	Colluvial Plain	0,11	Paddy Fields	75	75	3	6,10	6,30	6,40				
71	Colluvial Plain	9,67	Paddy Fields	160	160	4	6,30	6,30	6,40	6,60			
72	Colluvial Plain	29,33	Paddy Fields	122	122	4	6,20	6,10	6,20	6,30			
73	Interfluve	14,78	Mix Vegetation Area	183	183	3	5,60	5,50	5,90				
74	Interfluve	31,34	Mix Vegetation Area	113	60	6	5,70	5,50	5,60	5,60	5,60	5,60	
75	Upper slope	9,99	Moor	200	200	4	5,60	5,50	5,60	5,50			
76	Upper slope	8,21	Mix Vegetation Area	169	134	5	5,30	5,60	5,50	5,50	5,40		
77	Lower slope	11,21	Moor	104	104	3	5,10	5,30	5,40				
78	Colluvial Footslope	5,53	Mix Vegetation Area	130	95	5	5,80	6,10	6,10	6,00	6,00		
79	Colluvial Footslope	5,67	Paddy Fields	88	88	4	5,90	6,00	6,10	6,10			
80	Colluvial Footslope	39,90	Mix Vegetation Area	54	54	3	5,90	6,40	6,60				
81	Colluvial Plain	35,55	Moor	180	154	5	6,40	6,40	6,40	6,60	6,60		
82	Colluvial Plain	28,03	Paddy Fields	110	98	5	5,60	6,00	6,30	6,30	6,40		
83	Middle slope	14,92	Open Field	192	192	4	5,40	5,50	5,60	5,70			
84	Middle slope	44,85	Bush	250	250	3	5,90	5,90	5,90				
85	Interfluve	13,87	Mix Vegetation Area	180	180	3	5,50	5,60	5,90				

Sample Number	Arrangement	Slope	Land Use (ENG)	Soil Depth Total (cm)	Depth 4th Layers (cm)	Total Layers	pH I	pH II	pH III	pH IV	pH V	pH VI	pH VII
86	Upper slope	24,51	Moor	200	200	4	5,60	5,80	5,80	5,60			
87	Interfluve	9,80	Open Field	180	180	4	5,60	5,80	5,80	5,50			
88	Interfluve	13,20	Mix Vegetation Area	200	200	4	5,50	5,60	5,50	5,40			
89	Upper slope	7,81	Moor	130	130	4	5,20	5,30	5,40	5,50			
90	Upper slope	24,43	Mix Vegetation Area	160	160	4	5,60	6,00	5,80	5,60			
91	Middle slope	28,93	Moor	140	140	4	5,50	5,70	5,40	5,50			
92	Upper slope	20,78	Mix Vegetation Area	121	98	6	5,30	5,50	5,60	5,50	5,70	5,50	
93	Upper slope	8,48	Mix Vegetation Area	176	176	4	6,30	6,50	5,60	5,70			
94	Upper slope	41,02	Moor	200	200	4	5,40	5,20	5,50	5,60			
95	Middle slope	17,04	Mix Vegetation Area	200	200	4	5,60	5,70	5,30	5,50			
96	Middle slope	11,07	Mix Vegetation Area	160	76	5	5,40	5,70	5,80	5,90	6,00		
97	Middle slope	32,57	Mix Vegetation Area	171	171	4	5,20	5,30	5,40	5,60			
98	Middle slope	38,75	Settlement	200	164	5	5,20	5,30	5,40	4,90	5,50		
99	Middle slope	16,19	Settlement	50	50	2	7,49	7,29					
100	Middle slope	12,84	Mix Vegetation Area	176	176	4	5,40	5,70	5,40	5,40			
101	Middle slope	42,56	Settlement	140	140	4	5,80	6,00	6,20	6,20			
102	Lower slope	10,07	Settlement	180	180	4	5,80	5,80	5,60	5,80			
103	Lower slope	23,97	Mix Vegetation Area	160	103	5	5,70	5,70	5,80	5,60	5,70		
104	Lower slope	19,14	Mix Vegetation Area	200	200	4	5,30	5,80	5,80	6,00			
105	Colluvial Footslope	1,10	Paddy Fields	60	60	3	4,90	5,50	5,70				
106	Colluvial Footslope	27,26	Paddy Fields	54	54	3	5,60	5,70	5,80				

Sample Number	Arrangement	Slope	Land Use (ENG)	Soil Depth Total (cm)	Depth 4th Layers (cm)	Total Layers	pH I	pH II	pH III	pH IV	pH V	pH VI	pH VII
107	Lower slope	13,43	Paddy Fields	105	105	4	5,80	5,90	5,90	6,00			
108	Interfluve	20,23	Mix Vegetation Area	179	131	5	5,60	5,40	5,40	5,50	5,70		
109	Interfluve	9,13	Mix Vegetation Area	200	200	3	5,70	5,70	5,80				
110	Interfluve	13,74	Mix Vegetation Area	164	164	4	5,40	5,60	5,60	5,50			
111	Upper slope	33,54	Mix Vegetation Area	200	200	4	5,40	5,60	5,80	5,90			
112	Upper slope	18,75	Mix Vegetation Area	138	107	5	5,40	5,50	5,70	5,80	5,80		
113	Upper slope	23,07	Mix Vegetation Area	160	160	4	5,40	5,60	5,50	5,80			
114	Upper slope	23,07	Mix Vegetation Area	165	94	6	5,40	5,60	5,70	5,90	6,00	5,80	
115	Middle slope	12,02	Moor	190	180	5	5,80	5,90	6,00	6,10	6,10		
116	Middle slope	23,03	Mix Vegetation Area	180	92	6	5,60	5,70	5,70	5,80	5,80	5,90	
117	Middle slope	20,27	Mix Vegetation Area	200	200	4	5,60	5,70	5,80	5,60			
118	Middle slope	31,95	Mix Vegetation Area	128	128	3	5,20	5,40	5,60				
119	Middle slope	31,57	Mix Vegetation Area	180	180	4	5,50	5,50	5,60	5,60			
120	Lower slope	12,44	Settlement	166	134	5	5,80	6,10	6,20	6,20	6,10		
121	Lower slope	7,06	Mix Vegetation Area	140	140	4	6,00	5,70	6,00	5,80			
122	Lower slope	24,74	Moor	170	170	4	5,60	5,70	5,80	5,60			
123	Lower slope	27,45	Moor	156	156	4	5,50	5,80	5,70	5,80	6,00		
124	Interfluve	5,96	Moor	160	160	3	5,70	5,70	5,80				

2. List of Mapping Units

Polygon Number	**Arrangement**	**Slope Class (Number)**	**Slope Classes**
1	Middle slope	4	Hilly
2	Upper slope	5	Moderately Steep
3	Upper slope	5	Moderately Steep
4	Lower slope	4	Hilly
5	Lower slope	3	Moderately Sloping
6	Upper slope	4	Hilly
7	Middle slope	4	Hilly
8	Upper slope	4	Hilly
9	Upper slope	4	Hilly
10	Middle slope	3	Moderately Sloping
11	Middle slope	4	Hilly
12	Middle slope	4	Hilly
13	Middle slope	3	Moderately Sloping
14	Middle slope	4	Hilly
15	Middle slope	4	Hilly
16	Middle slope	5	Moderately Steep
17	Middle slope	3	Moderately Sloping
18	Middle slope	4	Hilly
19	Middle slope	4	Hilly
20	Middle slope	4	Hilly
21	Middle slope	5	Moderately Steep
22	Middle slope	4	Hilly
23	Middle slope	5	Moderately Steep
24	Middle slope	4	Hilly
25	Middle slope	3	Moderately Sloping
26	Middle slope	3	Moderately Sloping
27	Middle slope	4	Hilly
28	Middle slope	3	Moderately Sloping
29	Middle slope	4	Hilly

Polygon Number	Arrangement	Slope Class (Number)	Slope Classes
30	Middle slope	5	Moderately Steep
31	Middle slope	2	Undulating
32	Middle slope	4	Hilly
33	Middle slope	3	Moderately Sloping
34	Middle slope	4	Hilly
35	Colluvial Plain	3	Moderately Sloping
36	Colluvial Plain	3	Moderately Sloping
37	Colluvial Plain	2	Undulating
38	Colluvial Plain	4	Hilly
39	Colluvial Plain	4	Hilly
40	Colluvial Plain	5	Moderately Steep
41	Colluvial Plain	3	Moderately Sloping
42	Colluvial Plain	3	Moderately Sloping
43	Colluvial Plain	2	Undulating
44	Colluvial Plain	2	Undulating
45	Colluvial Plain	4	Hilly
46	Colluvial Plain	3	Moderately Sloping
47	Colluvial Plain	4	Hilly
48	Colluvial Plain	3	Moderately Sloping
49	Colluvial Plain	4	Hilly
50	Colluvial Footslope	3	Moderately Sloping
51	Colluvial Footslope	4	Hilly
52	Colluvial Footslope	3	Moderately Sloping
53	Middle slope	5	Moderately Steep
54	Middle slope	4	Hilly
55	Colluvial Footslope	4	Hilly
56	Lower slope	4	Hilly

Polygon Number	Arrangement	Slope Class (Number)	Slope Classes
57	Lower slope	5	Moderately Steep
58	Lower slope	3	Moderately Sloping
59	Lower slope	4	Hilly
60	Lower slope	3	Moderately Sloping
61	Lower slope	4	Hilly
62	Lower slope	3	Moderately Sloping
63	Lower slope	3	Moderately Sloping
64	Lower slope	5	Moderately Steep
65	Lower slope	4	Hilly
66	Lower slope	5	Moderately Steep
67	Lower slope	5	Moderately Steep
68	Lower slope	4	Hilly
69	Lower slope	4	Hilly
70	Lower slope	4	Hilly
71	Lower slope	3	Moderately Sloping
72	Lower slope	3	Moderately Sloping
73	Lower slope	4	Hilly
74	Lower slope	3	Moderately Sloping
75	Lower slope	4	Hilly
76	Lower slope	3	Moderately Sloping
77	Lower slope	4	Hilly
78	Lower slope	4	Hilly
79	Middle slope	5	Moderately Steep
80	Middle slope	5	Moderately Steep
81	Middle slope	4	Hilly
82	Lower slope	4	Hilly
83	Lower slope	3	Moderately Sloping
84	Lower slope	4	Hilly
85	Lower slope	5	Moderately Steep

Polygon Number	Arrangement	Slope Class (Number)	Slope Classes
86	Lower slope	3	Moderately Sloping
87	Lower slope	4	Hilly
88	Middle slope	5	Moderately Steep
89	Middle slope	3	Moderately Sloping
90	Middle slope	4	Hilly
91	Middle slope	3	Moderately Sloping
92	Middle slope	3	Moderately Sloping
93	Middle slope	4	Hilly
94	Middle slope	5	Moderately Steep
95	Middle slope	2	Undulating
96	Middle slope	3	Moderately Sloping
97	Middle slope	4	Hilly
98	Middle slope	3	Moderately Sloping
99	Middle slope	3	Moderately Sloping
100	Middle slope	5	Moderately Steep
101	Middle slope	4	Hilly
102	Middle slope	5	Moderately Steep
103	Middle slope	4	Hilly
104	Middle slope	4	Hilly
105	Middle slope	5	Moderately Steep
106	Middle slope	4	Hilly
107	Middle slope	5	Moderately Steep
108	Middle slope	4	Hilly
109	Middle slope	3	Moderately Sloping
110	Interfluve	4	Hilly
111	Interfluve	3	Moderately Sloping
112	Interfluve	4	Hilly
113	Interfluve	4	Hilly
114	Interfluve	4	Hilly

Polygon Number	**Arrangement**	**Slope Class (Number)**	**Slope Classes**
115	Interfluve	4	Hilly
116	Interfluve	3	Moderately Sloping
117	Interfluve	4	Hilly
118	Interfluve	5	Moderately Steep
119	Interfluve	4	Hilly
120	Interfluve	3	Moderately Sloping
121	Interfluve	4	Hilly
122	Interfluve	4	Hilly
123	Interfluve	4	Hilly
124	Interfluve	4	Hilly
125	Interfluve	4	Hilly
126	Interfluve	4	Hilly
127	Interfluve	4	Hilly
128	Interfluve	3	Moderately Sloping
129	Interfluve	2	Undulating
130	Interfluve	4	Hilly
131	Interfluve	4	Hilly
132	Interfluve	4	Hilly
133	Interfluve	3	Moderately Sloping
134	Interfluve	4	Hilly
135	Interfluve	4	Hilly
136	Interfluve	3	Moderately Sloping
137	Interfluve	4	Hilly
138	Interfluve	3	Moderately Sloping
139	Interfluve	4	Hilly
140	Interfluve	3	Moderately Sloping
141	Interfluve	4	Hilly
142	Interfluve	4	Hilly
143	Interfluve	4	Hilly
144	Interfluve	4	Hilly
145	Interfluve	4	Hilly

Polygon Number	Arrangement	Slope Class (Number)	Slope Classes
146	Interfluve	4	Hilly
147	Interfluve	3	Moderately Sloping
148	Interfluve	4	Hilly
149	Upper slope	4	Hilly
150	Upper slope	4	Hilly
151	Upper slope	5	Moderately Steep
152	Upper slope	4	Hilly
153	Landslide (Active)	4	Hilly
154	Upper slope	4	Hilly
155	Upper slope	4	Hilly
156	Upper slope	4	Hilly
157	Upper slope	4	Hilly
158	Upper slope	4	Hilly
159	Upper slope	5	Moderately Steep
160	Upper slope	4	Hilly
161	Upper slope	4	Hilly
162	Upper slope	4	Hilly
163	Upper slope	5	Moderately Steep
164	Upper slope	4	Hilly
165	Upper slope	4	Hilly
166	Lower slope	2	Undulating
167	Lower slope	4	Hilly
168	Lower slope	4	Hilly
169	Middle slope	4	Hilly
170	Middle slope	5	Moderately Steep
171	Middle slope	4	Hilly
172	Middle slope	5	Moderately Steep
173	Upper slope	5	Moderately Steep
174	Upper slope	4	Hilly
175	Upper slope	4	Hilly
176	Lower slope	4	Hilly
177	Lower slope	4	Hilly
178	Interfluve	4	Hilly
179	Middle slope	4	Hilly
180	Middle slope	3	Moderately Sloping

Polygon Number	Arrangement	Slope Class (Number)	Slope Classes
181	Middle slope	4	Hilly
182	Middle slope	5	Moderately Steep
183	Middle slope	4	Hilly
184	Middle slope	4	Hilly
185	Middle slope	4	Hilly
186	Middle slope	4	Hilly
187	Middle slope	3	Moderately Sloping
188	Middle slope	3	Moderately Sloping
189	Middle slope	4	Hilly
190	Lower slope	3	Moderately Sloping
191	Lower slope	4	Hilly
192	Lower slope	3	Moderately Sloping
193	Upper slope	4	Hilly
194	Upper slope	4	Hilly
195	Upper slope	4	Hilly
196	Upper slope	5	Moderately Steep
197	Upper slope	4	Hilly
198	Interfluve	4	Hilly
199	Lower slope	4	Hilly
200	Interfluve	4	Hilly
201	Colluvial Footslope	4	Hilly
202	Upper slope	4	Hilly
203	Upper slope	4	Hilly
204	Interfluve	3	Moderately Sloping
205	Interfluve	4	Hilly
206	Upper slope	3	Moderately Sloping
207	Upper slope	5	Moderately Steep
208	Upper slope	4	Hilly
209	Upper slope	3	Moderately Sloping
210	Upper slope	5	Moderately Steep

Polygon Number	**Arrangement**	**Slope Class (Number)**	**Slope Classes**
211	Upper slope	5	Moderately Steep
212	Upper slope	4	Hilly
213	Upper slope	5	Moderately Steep
214	Upper slope	5	Moderately Steep
215	Upper slope	4	Hilly
216	Upper slope	4	Hilly
217	Middle slope	4	Hilly
218	Middle slope	4	Hilly
219	Middle slope	3	Moderately Sloping
220	Middle slope	4	Hilly
221	Middle slope	3	Moderately Sloping
222	Upper slope	4	Hilly
223	Upper slope	5	Moderately Steep
224	Upper slope	4	Hilly
225	Upper slope	4	Hilly
226	Upper slope	4	Hilly
227	Upper slope	4	Hilly
228	Upper slope	4	Hilly
229	Upper slope	5	Moderately Steep
230	Interfluve	4	Hilly
231	Upper slope	4	Hilly
232	Upper slope	5	Moderately Steep
233	Lower slope	4	Hilly
234	Lower slope	3	Moderately Sloping
235	Lower slope	4	Hilly
236	Upper slope	4	Hilly
237	Colluvial Footslope	3	Moderately Sloping
238	Colluvial Footslope	2	Undulating
239	Colluvial Footslope	3	Moderately Sloping
240	Colluvial Footslope	2	Undulating

Polygon Number	**Arrangement**	**Slope Class (Number)**	**Slope Classes**
241	Colluvial Footslope	3	Moderately Sloping
242	Colluvial Footslope	4	Hilly
243	Colluvial Footslope	4	Hilly
244	Colluvial Footslope	3	Moderately Sloping
245	Colluvial Footslope	4	Hilly
246	Colluvial Footslope	5	Moderately Steep
247	Colluvial Footslope	3	Moderately Sloping
248	Colluvial Footslope	4	Hilly
249	Colluvial Footslope	4	Hilly
250	Upper slope	4	Hilly
251	Landslide (Active)	6	Steep
252	Middle slope	5	Moderately Steep

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