Soil water availability for crops on landslide deposits in Bompon Sub-Watershed, Magelang

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Abstract. One of the important factors in agricultural practices is the soil water availability for crops. This study was aimed to identify landslide deposits, assess the soil characteristics of each landslide zone, the effect of soil physical characteristics on the soil water availability for crops, and determine the availability of water for crops in landslide deposits. The soil sampling was carried out by purposive sampling method at 12 landslide points and 4 zones, i.e. crown, main-scarp, main-body, and toe-slope at two soil depths (0-100 cm and 100-200 cm). The data were analyzed with a regression test and standard deviation method. The results showed that the high soil water availability for crops occurred at the toe-slope zone, 0-100 cm depth and at the main-scarp zone, 100-200 cm depth. The soil physical properties clearly correlated with soil moisture content. Based on the soil water availability level, it might be suitable for annual crops (i.e. cassava, ginger, sweet potatoes, etc.) at the toe-slope zone and perennial crops i.e. Albizia chinensis, etc.) at the main-scarp zone. Therefore, landslides in the Bompon Sub-watershed, Magelang, is potentially utilized for agricultural development.

Keywords: agricultural development, landslide deposit, soil physical, soil water availability

1. Introduction

Bompon sub-watershed is an area with a high level of landslide vulnerability and hilly morphology. The soil in this area has a characteristic of thick pits [1]. Besides, most of the existing soil has a clay texture [2]. This kind of texture is caused by the location of the Bompon sub-watershed in a transition zone between the Tertiary and Quaternary volcanic landscapes [3]. This zone leads to a high frequency of landslides in the Bompon sub-watershed. The high frequency of landslides in the Bompon Sub-watershed has resulted in reduced agricultural cultivation land. Citizens take advantages of post-landslide land that has stabilized as an alternative to more productive agricultural land [4]. Cultivation activities are carried out scattered in each landslide zone, such as landslide crowns, scarps, heads, bodies, and toes.

The water availability for plants is primarily determined by the characteristics of the land being cultivated. The water availability level in the soil depends on the pore conditions of the soil. The presence of water in soil pores is influenced by cohesion and adhesion forces between soil and water [5]. The attractive forces between these particles can bind water to keep it between the soil fractions. This retained water can be used by plants to live. Meanwhile, water that is not retained will be carried away as drainage water by gravity [6]. Research on the availability of water for plants in landslide areas can be academically and practically beneficial. Academically, it can add new evidence about the ability of landslide deposits as agricultural cultivation land. While practically, it can provide detailed information...
about the availability of water for plants in each landslide area.

2. Materials and methods
This research was carried out through map interpretation, field survey, laboratory analysis, and secondary data processing. Map interpretation to determine the geomorphological conditions in the study area as well as to determine the points of landslide occurrence. The field survey was carried out to observe the condition of the study area, observe the landslide occurrence, take soil samples, and measure the physical properties of the soil qualitatively. Secondary data processing was to get the basic data that has been done in previous research. Purposive sampling was chosen as a research methodology in this study. The selected study area was based on landslides that have the potential to become agricultural cultivation areas.

The 12 landslide areas were identified qualitatively and quantitatively. Qualitatively, landslide deposit was identified for its morphological characteristics, meanwhile, quantitatively, landslide deposit was analyzed in the laboratory to assess the physical soil characteristics of the deposits. The soil sampling was taken based on landslide zonation, namely the crown, main-scarp, main-body, and toe at two soil depths (0-100 cm and 100-200 cm) in each.

Laboratory analyses were conducted to analyze the physical soil properties such as soil moisture, soil texture, bulk density, particle density, porosity, permeability, liquid limit, plastic limit, plasticity index, and available water. The soil moisture was measured in the gravimetric method. The textures were measured in the pipette method. Bulk density was measured in the ring method. Particle density was measured in the Picnometric method. Porosity is the ratio between the pore volume of a medium and its total volume. Permeability was measured in a permeameter. Liquid limits were measured in the Casagrande method. Plastic limits were measured in the Gravimetric method. Index plasticity is numerical difference between liquid limit and plastic limit. The available water was obtained by the pF method using pressure plate apparatus with two pressures, 0.33 atm (pF 2.54) and 15 atm (pF 4.2).

The data analysis was conducted through a regression test and standard deviation method. This is to be able to conclude the close relationship between the parameters studied and the availability of water. ArcMap was required for processing DEMNAS and overlaying some basic shapefiles such as Das boundaries, contour lines, and administrative boundaries. The maps were made in the form of slope maps, land use maps, landform maps, and sample point maps.

3. Study area
The Bompon sub-watershed is administered by two sub-districts, namely Kajoran District and Salaman District, in Magelang Regency (Fig.1). The Bompon sub-watershed is located in the 49M 0396957 mT and 916483mU zones. The Bompon sub-watershed has about 300 ha with a morphometric length of 3.1 km and a width of 1.5 km.

Topographically, Bompon sub-watershed is divided into six types, namely: hilltops, hilltop slopes, mid-hill slopes, hillside downslopes, alluvial plains, and colluvial plains. The surface material in the Bompon sub-watershed is dominated by soil resulting from deposition and weathering of volcanic material from the Menoreh Mountains and Sumbing Volcano [3]. Rock underlaid in the Bompon sub-watershed are diorite-inserted andesite breccias, altered andesite breccias, altered andesite breccias with incised sandstone, volcanic breccias, young chipped deposits and landslides, sandy tuffs, sandy tuffs with tuffaceous sand, and andesite breccias. Two processes control the formation of landforms in the Bompon sub-watershed, namely volcanic and fluvial-volcanic processes. Volcanic processes dominate almost all parts of the Bompon watershed. The slope is an internal factor that causes landslides. Most of the Bompon Sub-watershed area has a slope of 15-40%. Only a tiny part of the Bompon Sub-watershed area has a slope of more than 40%. Most of the landslide locations in this study were on 15-25% slopes (sloping slopes) and 25-40% (steep slopes). The climatic condition that plays an essential role in controlling the occurrence of landslides is rainfall. According to [7], the rainfall in the Bompon sub-watershed reaches 2000 mm/year. This condition is included in the category of moderate rainfall according to PERKA BNPB No. 2 of
2012. The Bompon sub-watershed has various land use types, including mixed gardens, dry fields, and rice fields.

![Figure 1. Bompon's sub-watershed](image1)

### 4. Result

#### 4.1 Soil characterization of landslide deposits

This research is devoted to the study of the physical characteristics of the soil. Soil physical characteristics can provide a significant description of the impact of landslide activity on soil development.

#### 4.1.1 Soil Moisture

Soil moisture in the scarp zone is the highest compared to the soil moisture in other landslide zones (Fig. 2). The standard deviation value (Std) of the moisture content is the highest compared to the Std value of other soil physical parameters. The highest value is in the toe zone, which is 25.79% (Table 1). The lowest value was in the crown zone as much as 2.39% (Table 1). The highest Std value in the toe zone means that the soil stirring process by landslides significantly affects the moisture content of the landslide deposit material in the toe zone.

| Zone       | Data range (%) | Mean  | Std  |
|------------|----------------|-------|------|
| Min.       | Max.           |       |      |
| Crown      | 7.69           | 14.16 | 12.42| 2.39 |
| Main-scarp | 8.08           | 68.86 | 51.94| 22.46|
| Main-body  | 6.82           | 60.49 | 27.12| 23.78|
| Toe-slope  | 4.50           | 75.03 | 42.06| 25.79|

![Figure 2. Average soil moisture in landslide deposits zone](image2)

#### 4.1.2 Soil texture

The landslide area showed that clay fractions are the highest among the other fractions as can be seen in the figure that among all landslide zones. Budianto's research [2] states that the soil layer in the Bompon watershed landslide has a very high clay content, and there are sensitive clay types. The crown part has the highest clay content. This crown zone is still formed by residual soil resulting from the development of weathered volcanic material rich in clay. While the scarp, body, and toe have lower clay content.
The Std of the soil texture is quite diverse. The highest Std value was found in the clay texture in the main-scarp zone, which was 16.95% (Table 2). The lowest Std value was found in the sand texture in the crown zone, as much as 0.65% (Fig. 3). However, the highest Std value for all zone was found in the toe zone, an accumulation zone of landslide material. These results reflect that the toe zone's texture variation is very high, resulting in a very heterogeneous mixture of clay, silt, and sand fractions in this zone.

### Table 2. Soil texture in landslide deposits

| Zone          | Parameter | Data range (%) | Mean | Std |
|---------------|-----------|----------------|------|-----|
| Crown         | Sand      | 5.36 - 18.20   | 9.76 | 4.60|
| Crown         | Silt      | 6.00 - 22.15   | 15.77| 5.98|
| Crown         | Clay      | 59.60 - 88.10  | 74.45| 9.99|
| Main-scarp    | Sand      | 2.99 - 19.55   | 9.27 | 5.94|
| Main-scarp    | Silt      | 8.23 - 45.68   | 28.59| 11.94|
| Main-scarp    | Clay      | 34.77 - 87.93  | 62.14| 16.95|
| Main-body     | Sand      | 13.33 - 14.63  | 13.66| 0.65|
| Main-body     | Silt      | 8.57 - 25.18   | 16.87| 8.31|
| Main-body     | Clay      | 60.39 - 78.13  | 69.26| 8.87|
| Toe-slope     | Sand      | 1.89 - 42.00   | 13.92| 14.58|
| Toe-slope     | Silt      | 11.20 - 42.11  | 26.10| 10.89|
| Toe-slope     | Clay      | 46.80 - 79.83  | 60.00| 11.90|

#### 4.1.3 Bulk density, particle density, porosity, and permeability

The highest porosity value is in the toe zone compared (Fig. 4). The higher clay content causes a high level of bulk density value. Soils with low soil density show the dominance of coarse fractions and vice versa [8].

### Table 3. The bulk density, particle density, porosity, and permeability in landslide deposits zone

| Zone          | Parameters   | Data range (%) | Mean | Std |
|---------------|--------------|----------------|------|-----|
| Crown         | Bulk density | 1.00 - 1.40    | 1.16 | 0.13|
| Crown         | Particle density | 1.98 - 2.32     | 2.11 | 0.14|
| Crown         | Porosity     | 39.86 - 54.75  | 44.78| 5.20|
| Crown         | Permeability | 0.02 - 3.23    | 1.31 | 1.05|
| Main-scarp    | Bulk density | 1.06 - 1.62    | 1.25 | 0.20|
| Main-scarp    | Particle density | 1.92 - 2.67     | 2.26 | 0.25|
| Main-scarp    | Porosity     | 15.68 - 54.48  | 43.18| 14.64|
| Main-scarp    | Permeability | 1.13 - 6.72    | 3.12 | 2.15|
| Main-body     | Bulk density | 1.03 - 1.31    | 1.13 | 0.13|
| Main-body     | Particle density | 2.06 - 2.29     | 2.14 | 0.11|
| Main-body     | Porosity     | 42.87 - 50.1    | 47.35| 3.20|
| Main-body     | Permeability | 0.37 - 1.99    | 1.04 | 0.69|
| Toe-slope     | Bulk density | 0.80 - 1.36    | 1.12 | 0.20|
| Toe-slope     | Particle density | 2.19 - 2.72     | 2.52 | 0.22|
| Toe-slope     | Porosity     | 49.08 - 63.31  | 56.07| 4.62|
| Toe-slope     | Permeability | 0.07 - 26.00   | 6.74 | 9.75|

The result shows that the highest permeability value is in the toe zone. This value is in accordance with the dominance of sand found in the landslide toe zone. According to Todd [9], the crown has a relatively slow permeability, the scarp has a medium permeability rating, the landslide body has a slightly slow permeability property, and the toe has rather rapid permeability. Cheng et al. [10] explained that soil deposits after landslides show low soil permeability. Noviyanto [11] also stated that low soil permeability is caused by soil compaction.
The Std values for bulk density and particle density are stable. However, the Std values are quite diverse in Porosity and Permeability. The highest Std value of porosity is in the main-scarp zone, as much as 14.64% (Table 3). The lowest value on porosity is in the main-body zone, 3.20% (Table 3). This Std range has a difference in the value of about 11%. The highest value of Std of permeability is in the toe zone, which is 9.75% (Table 3). The lowest value of permeability in the main-body zone is 0.69% (Fig. 4). The permeability value of the crown is the lowest or the slowest. The dominant soil texture affects the permeability, with many clay fractions in the research location causing the permeability value to be slow.

4.1.4 Liquid limit, plastic limit, and plasticity index. The highest value of liquid limit (LL) is in the main-scarp zone, the highest plastic limit (PL) value is in the body zone, and the highest plasticity index (PI) value is in the toe zone (Fig. 5). The value of the LL, PL, and PI are strongly influenced by the clay value. Liu [12] states that the Atterberg limit is determined based on clay. One factor influencing the Atterberg limit in determining soil plasticity level is water content [13].

The Std values for the LL, PL, and PI are quite diverse. The highest value for the LL parameter is in the toe zone, which is 13.51% (Table 4), while the lowest value in the crown zone is 2.76% (Table 4). The highest Std range is at this LL of about 11%. In the PL parameter, the highest value is in the toe zone, which is 9.23% (Table 4), while the lowest value is in the crown zone, which is 1.32% (Table 4). The highest Std value of the PI is in the toe zone, namely 6.80% (Table 4), while the lowest is in the crown zone, which is 2.34% (Table 4). The range of PI is not too far because it only has a difference of about 4% in value.

4.2 Analysis the effect of soil physical characteristics on the soil water availability

Based on the 11 soil characteristics tested, eight soil characteristics resulted in a higher correlation relationship on the soil surface, namely soil moisture, soil texture, bulk density, particle density, porosity, and plasticity index.

4.2.1 Soil moisture. The correlation between soil moisture and water availability at surface and subsurface depths is positive (Fig. 6). That means every increase in soil moisture, will followed by an increase in water availability. The effect of soil moisture on water availability at surface and subsurface depths is about 10% and less than 1%. Every 1% increase in soil moisture at the surface, it will increase the availability of water by 0.03 times.
4.2.2 Soil texture

4.2.2.1. Sand The correlation between sand and water availability at surface and subsurface depths is positive. That means every increase in sand content, will followed by an increase in water availability. The effect of sand content on water availability at surface and subsurface depths is around 7% and 2% (Fig. 7). Every 1% increase in sand content, will increase the availability of water by 0.07 times at the surface and 0.03 times below the subsurface.

4.2.2.2 Silt The correlation between silt content and water availability at surface and subsurface depths is positive. That means every increase in silt content, will followed by an increase in water availability. The effect of silt content on water availability at surface and subsurface depths is approximately 6% and 1% (Fig. 8). Every 1% increase in silt content, will increase water availability by 0.05 times at surface.

4.2.2.3 Clay. The correlation between clay content and water availability at surface and subsurface depths is negative. That means every increase in clay content, will followed by a decrease in water availability. The effect of clay content on water availability at surface and subsurface depths is about 13% and 1.5% (Fig. 9). Every 1% increase in clay content, will reduce water availability by 0.06 times on the surface and 0.02 times below the subsurface.
4.2.3 Bulk density. The correlation between bulk density and water availability at surface and subsurface depths is negative. It means that the increase in soil bulk density is inversely proportional to the increase in water availability. The effect of bulk density on water availability at surface and subsurface depths is around 2% and 4% (Fig. 10). Every 1% increase in bulk density will reduce water availability by 2.28 times at the surface and 3.22 at the subsurface.

4.2.4 Particle density. The correlation between particle density and water availability at surface depth is positive, while subsurface depth is negative. The increase in particle density value is directly proportional to the availability of water at the surface depth. In contrast to that, the inversely proportional subsurface depth the increase in particle density can reduce water availability. The effect of particle density on water availability is about 23% and 6% at surface and subsurface depths, respectively (Fig. 11). For every 1% increase in particle density, it will increase water availability 4.95 times at surface depth and decrease 2.9 times at subsurface depth.

4.2.5 Porosity
The correlation between porosity and water availability at surface depth is positive, while subsurface depth is negative. The increase in porosity value is directly proportional to the availability of water at the surface depth. In contrast, the inversely proportional subsurface depth the increase in porosity can reduce water availability. The effect of particle density on water availability is about 15% and less than 1% at surface and subsurface depths, respectively (Fig. 12). For every 1% increase in porosity, it will increase water availability 0.1 times at surface depth.
4.2.6 Permeability. The correlation between permeability and water availability at surface depth is negative, while subsurface depth is positive. The increase in the value of permeability is inversely proportional to the availability of water at surface depth. In contrast, permeability in subsurface depth can increase the availability of water. The effect of permeability on water availability at surface and subsurface depths is around 2% and less than 1%, respectively (Fig. 13). Every 1% increase in permeability, will reduce the available water at the surfacedepth by 0.07 times.

4.2.7 Liquid limit (LL)
The correlation between liquid limit and water availability at surface and subsurface depths is negative. That means if the LL increase, the water availability will be followed by a decrease. The effect of LL on water availability at the surface and subsurface depths is about 4% and 0.9%, respectively (Fig. 14). Every 1% increase in the LL will reduce the available water at the surface depth by 0.06 times and 0.03 times at the subsurface.

4.2.8 Plastic limit (PL)
The correlation between plastic limit and water availability at the surface is negative, while subsurface depth is positive. That means, if the PL increase in surface depth, the water availability will be decreased. The effect of PL on water availability at the surface and subsurface depths is around 20% and less than 1%, respectively (Fig. 15). For every 1% increase in the PL, it will reduce water availability by 0.2 times at surface depths and increase water availability by 0.02 times at subsurface depths.
4.2.9 Plasticity index (PI)

The correlation between plasticity index and water availability at surface is positive, while subsurface depth is negative. The increase in the value of the PI is directly proportional to the availability of water at the surface depth. In contrast to the subsurface depth, which is inversely proportional, the PI can reduce water availability. The effect of PI on water availability at surface depth is about 1%, and at subsurface depth is about 5% (Fig. 16). For every 1% increase in the PI, the availability of water will increase by 0.04 times at surface depths and decrease by 0.1 times at subsurface depths.

4.3 Analysis of the availability of water on landslide deposits

Available water is a moisture content that can be utilized by plants [14]. Available water is a crucial soil physics factor in describing the relationship between soil, water, and plants. Factors that influence the moisture content include soil structure, soil particle size distribution, soil colloid type, organic matter, and the type of cations absorbed [15].

| Soil depths | Crown | Soil water availability (%) | Main scarp | Main body | Toe slope |
|-------------|-------|-----------------------------|------------|-----------|-----------|
| 0-100 cm    | 5.94  | 6.34                        | 5.68       | 8.49      |
| 100-200 cm  | 6.91  | 9.29                        | 6.30       | 4.83      |

The difference in available water takes place in the Toe-slope. In the toe zone, the value of available water at surface depth is the highest among all zones, while the subsurface depth is the opposite, which is the lowest. This phenomenon can happen because the type of landslide at the research site is translational, so that the mixed and light material is on the toe. Masruroh [1] explained that the type of translational landslide has the characteristics of a planar-shaped landslide body so that the debris material is located at the toe of the landslide. Istiqomah [16] also explains that the toe of the landslide has the lowest height so that it becomes a deposition area or deposition of materials from above. Therefore, the surface of the toe zone, which is the disposition area, has pores available for more water.

Available water values measured by pF 2.54 and 4.2 at two depths indicate that the toe zone has more water availability for plants at surface depths. It is recommended to grow plants with a root depth of less
than 1 meter in this zone. Water available at two depths in the toe zone is sufficient for plants, unlike the available water values measured at the crown, scarp, and body zones. The three zones have more water availability at subsurface depths. This zone can be planted with plants with a root depth of more than 1 meter. Alternatively, plants with a root depth of less than 1 meter should use plants that do not require a lot of water or irrigation and have a short planting time.

5 Conclusion
Landslide area in the Bompon sub-watershed can be utilized as agricultural cultivation land. The soil physical characteristics in the landslide area vary for each zoning. The most affected soil physical property due to landslide activity is the moisture content, especially in toe zone. The highest water availability for plants on landslide-affected land is in the toe zone for the 0-100 cm depth and in the main-scarp zone for the 100-200 cm depth. So that the toe zone is more suitable for planting with annual crops, while the scarp zone is more suitable for planting perennial crops.

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