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Groundwater Occurrence Prediction using Regressions on Morphometric Variables in Upstream Progo Watershed, Yogyakarta

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Abstract - Geomorphological mapping has been done at the upstream part of Progo Drainage Area by measuring some geomorphological indexes and level of shallow groundwater level at 196 stations, to investigate connections between geomorphological characteristics and groundwater system in the area. These indexes are valley floor - height ratio (V_f), valley cross section (V_{ratio} o rV_r), stream gradient index (S_L), and drainage density (Dd). Based on the linear regression analysis, the four indexes show none to very weak correlation to water table at most locations. It means that all width, height, and width of the river valley do not control shallow groundwater level. However, some locations indicate a strong control of elevation to shallow groundwater level. The first case indicates that there is another controlling factor to the shallow groundwater system. Most likely, a deeper aquifer exists at those locations, which does not show up in the second case. All results give a preliminary indication that morphometry can be used to predict groundwater system in the area.

Keywords: morphometric index, quantitative geomorphology, water table, shallow groundwater

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Introduction

Water table in shallow groundwater could be controlled by the morphology of a local area. Groundwater potential can be determined by groundwater level. The flow of such groundwater can be determined by its water level. Some morphometric indexes are believed to highly correlate with groundwater level. This paper discusses such correlation in a much deeper manner.

Todd (1980) studied about the relation between river flow and groundwater level. When there is a connection of stream and free aquifer, this stream can be losing stream or gaining stream, depending on its relative water level. Sometimes, a gaining stream can change to a losing stream, or vice versa.

Whereas, Freeze and Cherry (1979) explained about topographic effect to regional flow system. Even at a homogenous geological area, topography would build complex groundwater flows. Usually, a higher area becomes a recharge area, whereas a lower area would be a discharge area. At the topographic configuration, hinge line is located closer to a valley floor compared to a hill peak.

As a study case, the correlation of geomorphology to groundwater level has been studied in Progo Watershed, especially at Yogyakarta Province and some regions nearby this province. The studied area is limited at the upstream part of this watershed (Figure 1). This part belongs to Sleman and Kulon Progo Regencies, Yogyakarta Province, and some areas of Magelang and Muntilan, Central Java Province.

This research has been done by geomorphological mapping in order to describe geomorphological characteristics of the studied area. This task is accompanied by measuring some geomorphological indexes: elevation (h), height difference (Δh), slope (α), height and width of stream valley, stream gradient, as well as the level of water table in the neighbouring areas. In the context of groundwater - river water interaction, there are two aspects to be discussed:

1. Geomorphology of a certain drainage area can influence local/regional groundwater potential, especially unconfined aquifer.
2. The change of some geomorphological variables of certain drainage basins from upward to downward control groundwater potential, especially in its quantitative potential. In this term, particularly in a large island, the quantitative potential can be represented as water table.

The aim of this paper is to identify the connection between morphometric indexes and shallow groundwater level as our basis to predict groundwater system in the area. The connection will be indicated by squared values (R^2) in the linear regressions.

Methods

The hypotheses would be proven by both geomorphology and hydrogeological mappings. The field task has been carried out within four quadrangle maps including the upstream Progo Watershed Yogyakarta, such as Sleman, Sendangagung, Mungkid, and Muntilan. There are about 49 locations by gridding of 2 x 2 km^2 in each sheet, with the total stations were 196 locations, but only 110 locations that have water table data (Appendix 1).

Basically, the field mapping was performed to know geomorphologic and hydrological characteristics in the studied area. This research has been completed by the analysis of some geomorphological response variables having been obtained by measuring the variables in Progo

Figure 1. Locality map of studied area is included in four sheet maps, those are: A= Mungkid, B= Muntilan, C= Sendangagung, D= Sleman.

Drainage Area, at the downstream part. The response variables used in this research (Wells *et al.*, 1988) are:

a. Elevation (h) and slope of morphology (α)

b. Valley floor - height ratio (V_f)

which can be formulated as follows:

$$V_f = \frac{V_{fw}}{(Eld - Esc) + (Erd - Esc) / 2} \quad \text{.......................} (1)$$

where:

Eld : Left part of valley height/ cliff
Erd : Right part of valley height/ cliff
Esc : Valley floor elevation
V_{fw} : Valley floor width

c. Valley cross section (V_{ratio} or V_r)

$$V_{ratio} = \frac{Av}{Ac} \quad \text{..} (2)$$

where:

Av : Width of valley cross section
Ac : Width of a half circle with radius H
ΔH : Valley height

d. River gradient index (S_L)

$$S_L = \frac{\Delta H}{\Delta L} xL \quad \text{..} (3)$$

where:

ΔH : Height difference of river elevation
ΔL : Length/horizontal distance of river
L : Total stream length of river segment

e. Drainage density (D_d)

$$D_d = \frac{\sum L}{A} \quad \text{..} (4)$$

where:

D_d : Drainage density
ΣL : Total length
A : Unit area

On the other hand, the groundwater potential has been analyzed from its occurrence in a shallow aquifer. Some data about it which have been taken are:

1. Groundwater level elevation
2. Aquifer description, including petrology, rock stratigraphy, and petrophysics (porosity and permeability).

The compilation of field primary combined with secondary data has been done to know the influence of geomorphology to shallow groundwater supported by statistic analysis. This statistic method was done by analyzing the regression line and their correlation coefficients.

Geomorphology of Progo Watershed

According to Van Bemmelen (1949), the researched area is included in West Progo Dome and Quaternary Volcanic physiography. The western part of the researched area is located at West Progo Dome. This dome is included in South Serayu Mountainous physiography, with long axis in almost south - north direction, while South Serayu Mountainous physiography has west - east orientation. The long axis of West Progo Mountain is in NNE - SSW direction with 32 km long, whereas its short axis shows WNW - ESE direction of 15 - 20 km in length (Figures 2 and 3).

The eastern part of the researched area is located at the slope of Merapi and Merbabu Mountains. This area usually has gently to steeply sloping morphology, in lower to upper slope of the mountains.

The area of West Progo Hills generally has a low potential of groundwater, because it is known as non-groundwater basin (Geological Agency, 2011). In addition, the area is dominantly occupied by West Progo Hill materials such as andesite breccia, tuff, lapilli tuff, agglomerate, and intercalation of andesitic lava flows (Rahardjo *et al.*, 1996).

Geomorphological Response Variable

Budiadi (2008) has measured some geomorphological indexes in West Progo Dome related with its tectonic setting. This research is better to

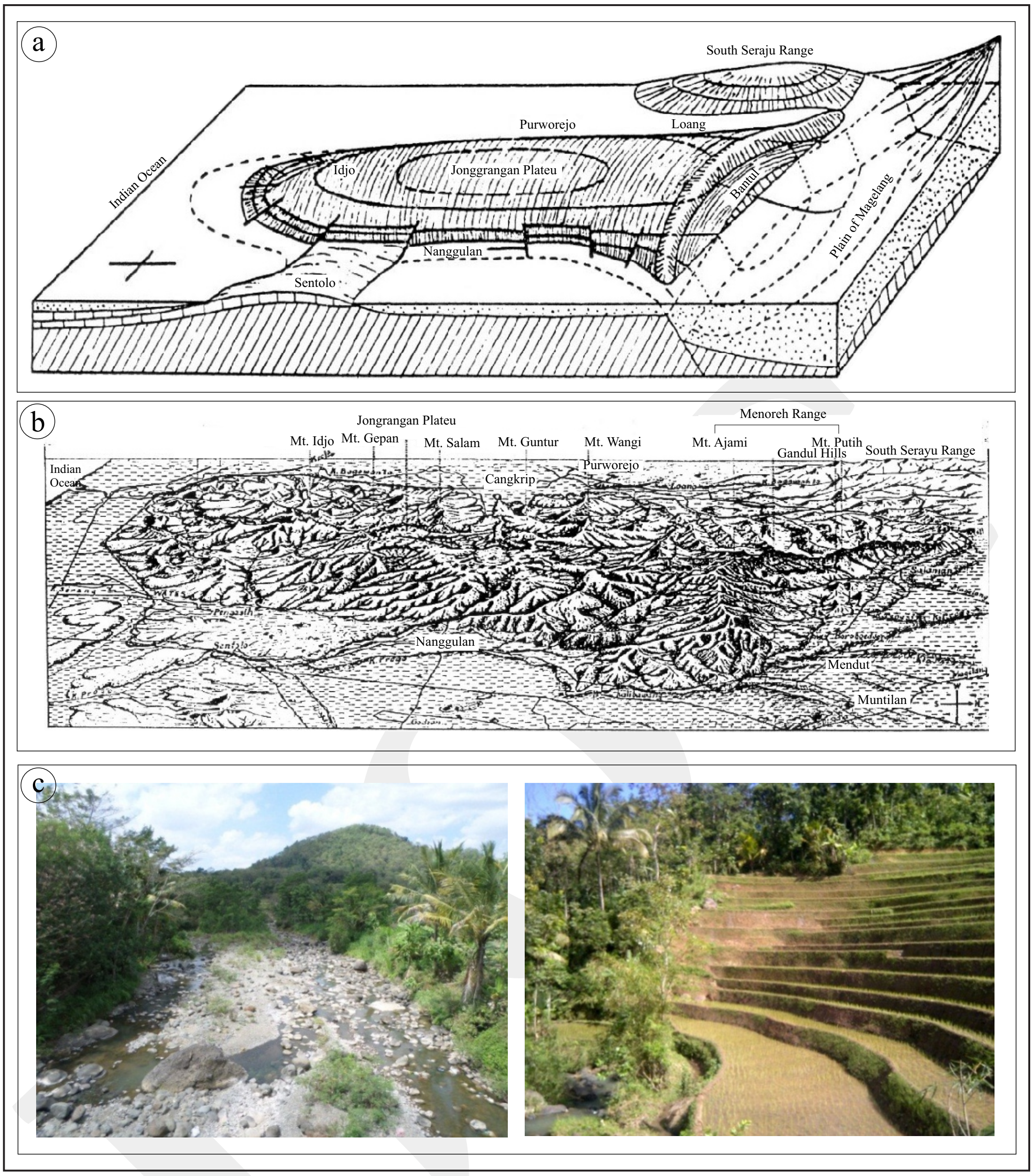

Figure 2. Sketch figures and photographs of researched area. a.Schematic block diagram of the West Progo Dome; b. Panoramic view of the West Progo Mountains (Van Bemmelen, 1949); c. Photograph of the western part of the researched area at West Progo and Mungkid.

be continued by geomorphological indexes study in relation with groundwater table. Some response variables have been analyzed in the area such as elevation, slope, valley floor-height ratio, valley cross section, and river gradient index. These variables can briefly be explained as follows:

Elevation (h) and slope (α)

The field survey has been done by using four topographic maps, *i.e.* Mungkid, Sendangagung, Muntilan, and Sleman Quadrangles. The first two quadrangles involve West Progo Hill area, while the rest are included in Mount Merapi area. Then, the researched area can be divided into two morphogenetic landforms, which are West Progo Hills and the slope of the Mount Merapi. The area at West Progo Hills (Mungkid and Sendangagung regions) usually shows moderate to steep morphology. On the other hand, the slope of Mount Merapi area

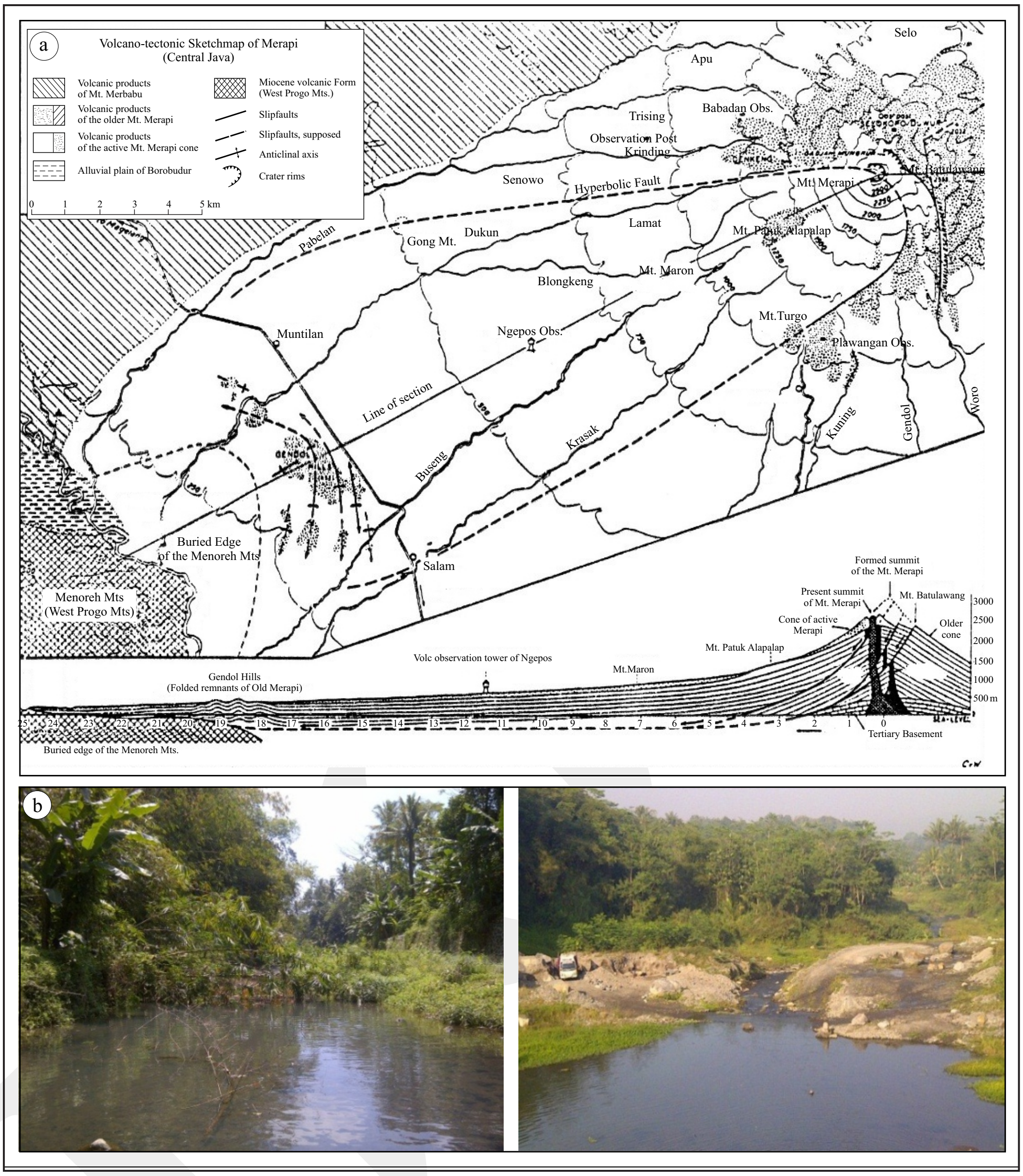

Figure 3. Sketchmap and photographs of the Merapi area. a. Geological sketch map and section of the Merapi (Central Java) and its western foot (Van Bemmelen, 1949); b. Photographs of the eastern part of the researched area at Sleman.

(Sleman and Muntilan regions) shows a high to moderate elevation with gentle morphology (Table 1).

Valley floor - height ratio (V_f), valley cross section (V_{ratio} or V_r), and river gradient index (S_L)

The three response variables of V_f, V_r, and S_L [calculation using equation (1), (2), and (3)] in the studied area can be summarized at Table 2. V_f in the studied area usually has more than 3, except at the northwest part. While, the value of V_r varies from 1.1 to 3.1. The river gradient has a high variety from up to downward of Progo Drainage Area, which could be controlled by structural or volcanic landforms.

Drainage Density (D_d)

Many rivers in the researched area have variable drainage density as shown in Table 3. It means that the area can be dense or distant in many places. Usually, the dense streams can be expected to be adequate groundwater resource.

Table 1. Average Value of Response Variable (h, ΔH, α) of Morphometry at the Studied Area

No	Part	Elevation/ h (m)	Height difference/ ΔH (m)	Slope/ α (%)	Explanation
1	Northwest (Mungkid)	291.3	30.1	17.2	coarse relief
2	Southwest (Sendangagung)	433.8	112.3	44.6	coarse relief, usually steep slope
3	Northeast (Muntilan)	503.1	12.9	55.7	slope of volcano, gentle to very steep slope
4	Southeast (Sleman)	236.4	23	25.6	slope of volcano, moderate to steep slope

Table 2. Response Variable of V_f, V_r, and S_L

No	Part	V_f	V_r	S_L	Explanation
1	Northwest (Mungkid)	1.8	1.2	212.6	narrow river floor but high scarp
2	Southwest (Sendangagung)	3.8	2.2	63.6	narrow river floor but high scarp
3	Northeast (Muntilan)	3	3.1	44.6	wider valley
4	Southeast (Sleman)	3.9	2.7	181	wider valley

Table 3. Sub-drainage Area (DA), Drainage Pattern, and Drainage Density

No	Sheet Area	Sub-Drainage Area	Drainage Pattern	D_d (/m)
1	Muntilan/Sleman	K.Blongkeng	Parallel	0.51
2		K.Bebeng/Krasak	Parallel	0.5
3		K.Putih	Parallel	0.39
4		K.Pabelan	Parallel	0.53
5		K.Elo	Parallel	0.64
6	Sendangagung	Kedungan	Subparallel	0.95
7		Sindon	Subdendritic	0.7
8		Pugoh	Dendritic	0.71
9		Srandu	Subparallel	0.17
10		Tlegung	Subdendritic	0.43
11		Tinalah	Subdendritic	0.37
12		Nungkep	Subparallel	0.45
13		Kamal	Dendritic	0.5
14		Tinalah	Subdendritic	0.37
15		Tangsi	Dendritic	0.25
16		Sileng	Subdendritic	0.27
17		Turusan	Subdendritic	0.52
18		Turusan	Rectangular	0.58
19	Mungkid	Elo	Parallel	0.48
20		Nglarek	Parallel	0.99
21		Sileng	Subdendritic	0.61
22		Pacet	Subparallel	0.65
23		Gending	Subparallel	0.65
24	Mungkid	Loneng	Subdendritic	0.5
25		Garung	Subparallel	0.66
26		Setro	Subparallel	0.51
27		Merawu	Subparallel	0.77
28		Tangsi	Subparallel-Subdendritic	0.55

River Morphology

The streams are located at a high elevation in the upstream part of Progo Drainage Area. Usually, the streams at West Progo Hills have high gradients as long as their steep morphologies. Moreover, many streams at the slope of Mount Merapi usually have lower and gentle flow gradients (Table 4 and Figure 4).

Water Table in Shallow Groundwater

Some streams in the researched area have lower surface water than the water table surrounding them, so they are effluent streams (gaining streams). On the other hand, influent streams also develop in some cuts of rivers, at Sendangagung (Bakosurtanal, 2001a), Mungkid (Bakosurtanal, 2001b), Sleman (Bakosurtanal, 2001c), and Muntilan (Bakosurtanal, 2001d) areas. Table 5 is the summary of the average value of groundwater table in the researched area.

There are some locations with water tables which reach more than 800 m in depth (Figures 5- 9). Those high levels of water table are usually located in a high topography, such as the upper slope area of Mount Merapi.

Correlation Between Geomorphological Response Variable and Water Table

Elevation (h) - Water Table

The correlation between ground elevation and groundwater table shows an encouraging result. These two variables have a strong relationship as shown by coefficient correlation value as high as 98,77% (r = 0.994) (Figure 5).

Table 4. Elevation of River Floor and Flow Gradient

No	Sheet	Elevation (h) (m)	Gradient (%)
1	Mungkid	278.7	7.9
2	Sendangagung	425.9	74.4
3	Muntilan	503.1	15
4	Sleman	235.1	9.2
	Total	356.5	26.7

Figure 4. Photographs of morphology of a river at Krinjing, Purwosari, one of small rivers at Mungkid area.

Table 5. Water Table Elevation Measured from Dug Wells

No	Area	Average of water table (m asl.)
1	Mungkid	207,92
2	Sendangagung	167,08
3	Muntilan	95,6
4	Sleman	170,36

V_f - Water Table

The V_f data have been calculated in each observed location. There are 110 locations that have water table data throughout the studied area which give 110 V_f data (Figure 6).

The shape or dimension of the river valley may be influenced by rain water storage capacity, thereby surface water has enough time to infiltrate. It is assumed that the larger the size of the valley

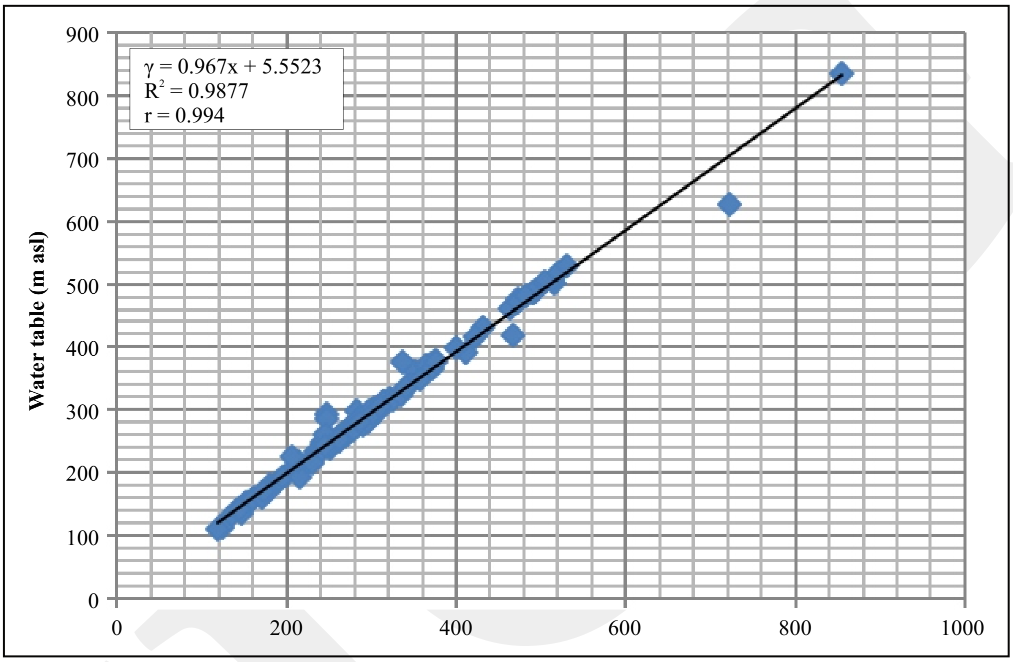

Figure 5. A correlation regression of ground surface elevation *vs*. water table, indicating an excellent relationship.

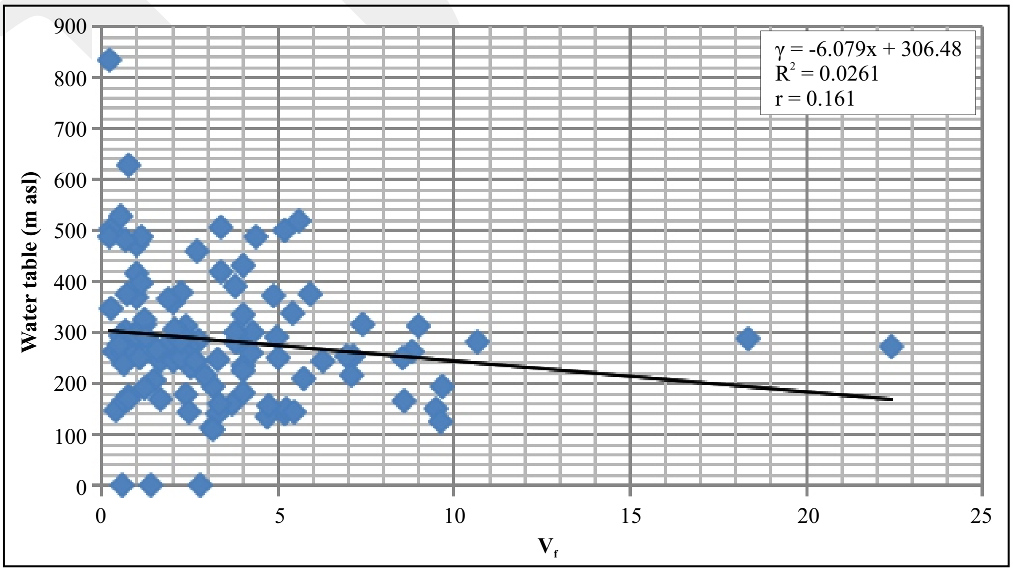

Figure 6. A correlation regression of V_f *vs*. water table, indicating a very weak or almost no relationship.

the greater the storage capacity, so the greater the volume of rainwater which can be accommodated. This large storage capacity means less runoff, because rain water can last longer and have more infiltration opportunities. Small V_f value indicates a narrow valley, with small rainwater capacity.

Unfortunately, the relation between V_f and groundwater table in the researched area does not show a good relationship, shown by the correlation index which is 2,61% ($r = 0.161$) only. It means that valley - floor height ratio has no relationship (Figure 6).

Both of floor width and cliff height do not determine the amount of groundwater, although their variables may determine how much rain water can be stored in. The ratio of the valley floor and height also does not influence the groundwater potential. It means that the morphology of the valley does not influence the amount of groundwater below the valley.

V_r - Water Table

Similar with V_f parameter, the V_r data can be obtained from 110 observed locations. Therefore, the regression can be derived from 110 plot data. The capacity of the rainwater catchment can be determined by the dimensions of the valley as storage. The dimension of the valley can also be seen from its V_r value. In accordance with the value of V_f, the small value of V_r also indicates a narrow valley with small rainwater capacity.

In line with V_f, then V_r also has a bad relationship with water table. Their correlation has the value of 4,06% ($r = 0.2$). It means that the valley cross section ratio does not correlate with groundwater level (Figure 7).

S_L -Water Table

Stream gradient index (S_L) has also been calculated from all observed locations. Unfortunately, it also has a bad or weak correlation with groundwater level. Their relationship in the researched area has the correlation coefficient value of 10,89% ($r = 0.33$) only (Figure 8).

D_d - Water Table

Each observed location which is included in the subdrainage has been calculated its stream density (D_d) value. This research has only consisted of 64 data. Each river may have different number of data. For example, Sileng River has five spot data, whereas Pacet River only has two plot data. The analysis of all data shows that stream density and water table have

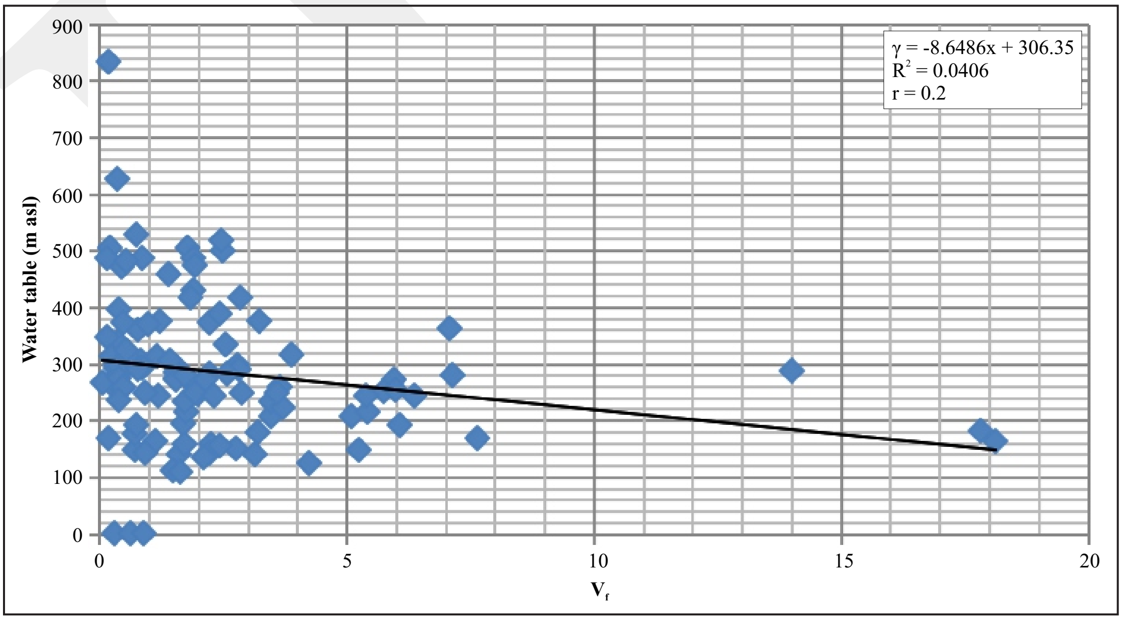

Figure 7. A correlation regression of V_r *vs*. water table, showing almost no or very weak correlation.

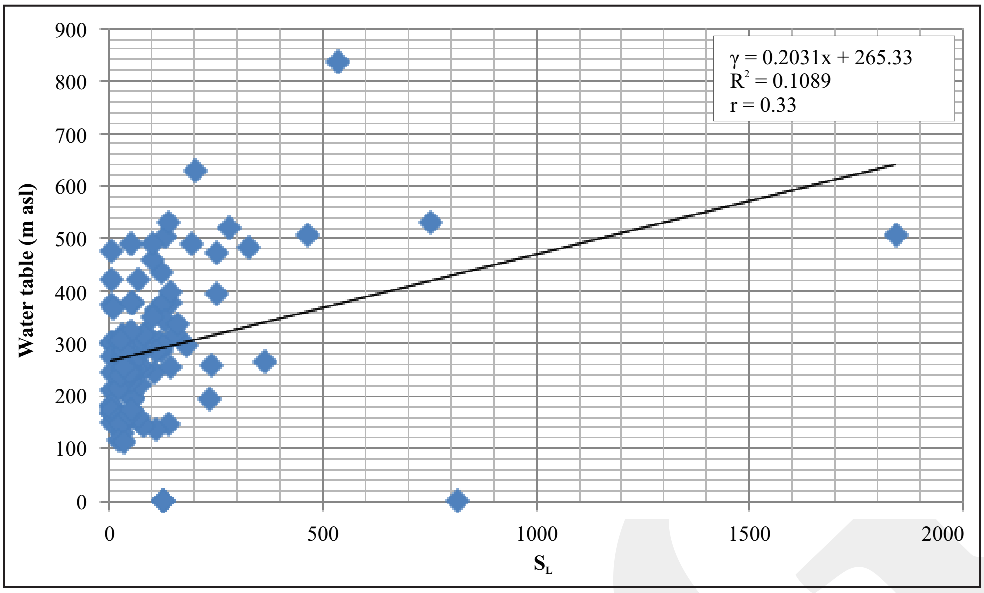

Figure 8. A correlation regression of stream gradient index (S_L) *vs*. water table, showing a bad or weak relationship.

relationship 4,6% (r = 0.214) only. It means that dense drainage pattern may not provide groundwater in such amount (Figure 9).

Discussion

The hydrogeology of Upstream Progo Watershed Area Yogyakarta varies in accordance with its geomorphology and geology. The areas of West Progo Hills generally have a little water reserved. Steep slopes effect the rainwater received and will quickly accumulate at the soil surface river channels and flow into the downstream areas. In this condition, the rain does not get infiltrated into the soil in sufficient quantity. In addition, the geology of West Progo Hills is supported by compacted materials. The materials were formed by the activity of an ancient Tertiary volcano and have impermeable characteristic. These materials are not able to store and drain the water, so the area has low

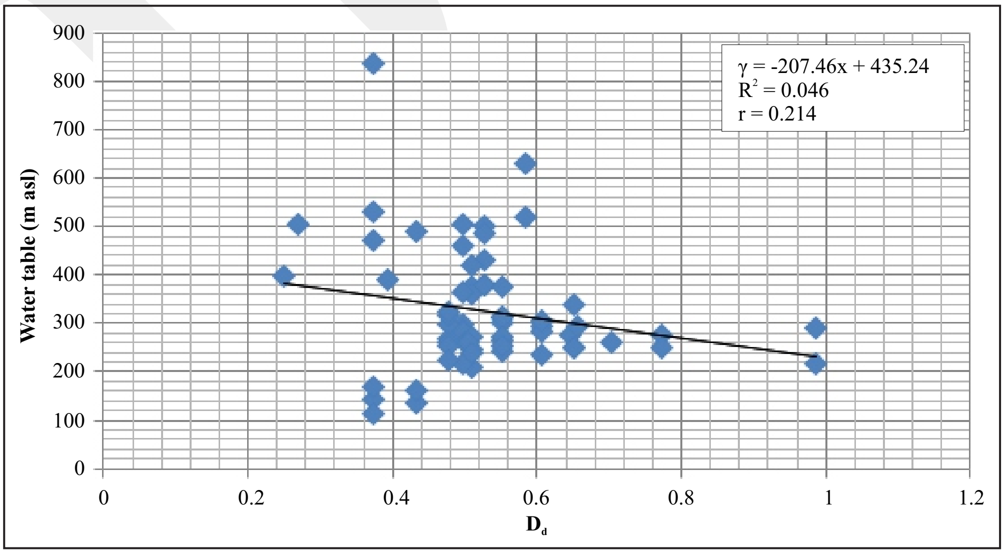

Figure 9. A correlation regression diagram of drainage density (D_d) *vs*. water table, displaying a bad or no relationship.

groundwater potential. The presence of water is also controlled by the break of slope morphology.

The availability of surface water in the West Progo Hills is influenced by the flow of some rivers. Progo River is the largest river providing a surface water supply in the area. Moreover, in Progo River, there are several streams flowing on West Progo Hills, such as Tinalah River in Samigaluh Subregency and Kayangan River in Girimulyo Subregency. Both rivers flow into the Progo River. Morphometric aspects covering the hills and river morphology in West Progo Hills generally have relatively coarse reliefs with relatively high river gradient. Drainage patterns developed to form dendritic or subdendritic patterns, indicating uniform or almost uniform resistant of bedded sediments or crystalline rocks.

Meanwhile, the hydrogeological conditions in the eastern part of the studied area are controlled by the geomorphology of Mount Merapi. The morphology of the steep to gentle slopes found on the slopes of Mount Merapi with drainage patterns tend to be parallel. This pattern indicates a moderate to steep slope of Mount Merapi. Then, the morphometric aspects of the studied area have been focused to get its relation to shallow groundwater level.

The landform of the studied area has difference genetic units, such as structural denudational units of West Progo Hills represented by areas in Mungkid and Sendangagung, and volcanic units of Merapi represented by areas in Sleman and Muntilan. The landform at the northern part (Muntilan) has a high elevation with smooth, gentle slope, and small height difference. Whereas, the southwestern part has a coarse relief with moderate large of height difference. The other parts (Sleman dan Mungkid) have a lower elevation and medium height difference. The big value of high difference and slope usually indicates the high resistant of rocks and many geomorphic processes which have occurred for a long period, such as weathering, erosion, and also mass wasting.

Some response variables show that only the topographic elevation has a strong correlation with groundwater level. It means that groundwater potential which is represented by groundwater level only relates with relief. While the other variables (V_r, V_f, S_L, and D_d) do not reveal correlation with groundwater level in the researched area (Table 6).

Table 6. Resume of Some Geomorphological Variable Relationship

No.	Variable	Correlation coefficient / R^2(%)
1	h -groundwater level	98.77
2	V_f - groundwater level	2.61
3	V_r - groundwater level	4.06
4	S_L - groundwater level	10.89
5	D_d - groundwater level	4.60

Valley floor - height ratio (v_f) and valley cross section (v_{ratio} atau v_r) have very weak or almost no correlation with groundwater level. Therefore, the morphometry of a river such as width, height, and space of river valley does not give any contribution to the increase of groundwater in certain areas.

Stream gradient index (S_L) gives a little more correlation with groundwater level if compared with V_f and V_r. It means that sometimes, a river slope may influence the groundwater table.

On the other hand, as shown by their coefficient correlation between stream density and groundwater level, the number of river do not necessarily influence the amount of groundwater. It can be understood because not all of river segments have influent type (losing water to the subsurface system).

CONCLUSION

The morphology of Progo Drainage Area has been analyzed to identify its connection with groundwater level. Given the coarse relief and steep stream gradient, the western part of Progo Drainage Area which is located at West Progo Hills shows a dendritic or subdendritic drainage pattern. It indicates uniform resistance of bedded sediments or crystalline rocks.

Gentle to steep morphology can be found at the eastern part of the researched area, formed by the slope of Mount Merapi with parallel or subparallel drainage pattern, indicating moderate to steep slopes. Landform with smooth, gentle slopes, and small height difference is represented by Muntilan area, whereas the southwestern part has a coarse relief. The other part, Sleman and Mungkid areas, has lower elevation and smoother reliefs.

Assessment of valley dimension can indirectly be approximated from the values of V_t and V_r. Small V_r and V_f values show relatively narrow V-shaped valleys. Valley floor - height ratio (v_f), valley cross section(V_{ratio} atau V_r), stream gradient index (S_L), and stream density (D_d) show no to very weak correlation with groundwater level, which is indicated by the coefficient correlation of 2.61% (r = 0.161), 4.06% (r = 0.2), 10.89% (r = 0.33), and 4.60% (r = 0.214). It means width, height, and the dimension of river valley do not control groundwater potential. On the other hand, the elevation of an area has strong correlation to groundwater with R^2 of 98.77% (r = 0.994). The correlation shows that landform controls groundwater level as one of the characteristics of shallow-unconfined groundwater system. In brief, the correlations give a preliminary indication that morphometry can be used to predict groundwater system in an area, especially for a shallow groundwater flow system.

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