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TOPOGRAPHIC CONTROL ON GROUNDWATER FLOW IN CENTRAL OF HARD WATER AREA, WEST PROGO HILLS, INDONESIA

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ABSTRACT: West Progo Hills is one of some hard water area in Indonesia. It doesn’t belong to the groundwater basin because it is difficult to get groundwater. Groundwater can be found in some places with a random point. Dug wells are usually found in the narrow area, as well as springs. By hydrogeological as well as hydro isotope approaches, this research wants to know about groundwater potential in West Progo Hills especially at the central part of it. The groundwater mapping has been done at Girimulyo - Kaligesing and surrounding area, to get some geologic data, water table measurement, and geomorphological data. The result of the research shows that the groundwater table usually follows the local topography. Groundwater table ranges 0.9 – 8 m below surface, it means shallow groundwater table. Dug wells are only locally found, as well as springs. Some springs often found at break of slope, it means that they’re controlled by topography. Based on the groundwater table from dug wells data, groundwater is conformable to the topographic condition. The relationship between elevation and groundwater table gives the correlation coefficient (r) as much as 99.99%. It means that relief is followed by the groundwater level. It can be concluded that relief has a strong correlation with shallow groundwater in the research area, although the stable isotopic data doesn’t support the altitude effect of it. Groundwater flows from high to low lands, such as the upper slope of hills to valleys.

Keywords: Groundwater, Topography, Spring, Dug well, Stable isotope

1. INTRODUCTION

This research has been carried out in a central part of West Progo Hills, which includes Kaligesing, Central Java Province and Girimulyo, West Progo, Yogyakarta Province, Indonesia (Fig. 1). The center of West Progo Hills is a hard water area. It is difficult to find groundwater resources. However, some dug wells and spring still can be found in random places, narrow area although in small numbers.

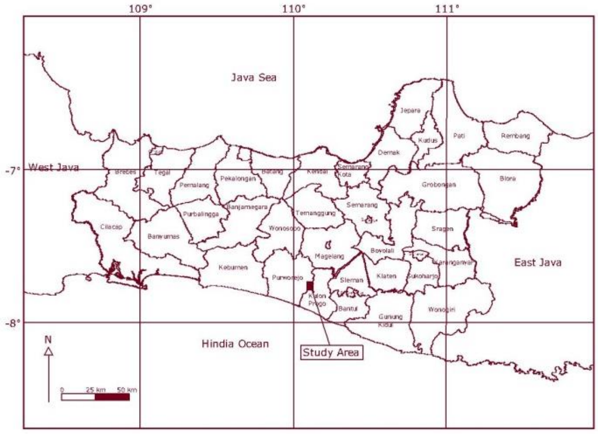

Fig 1. The research area includes in the central part of West Progo Dome [1].

West Progo Hills belongs to West Progo Dome physiography [1]. This area even includes in non-groundwater basin [2]. This area is not potential for groundwater. However, in this research area, it can be found some springs and dug wells. The springs and dug wells spread in the random area, sometimes many of them gathered in a narrow area, but it may be not found in other areas.

It is necessary to study water resource at non-groundwater basin area, moreover to meet the land use changes associated with the construction of a new airport in West Progo and the development of new tourist sites in the area. The rapid expansion of land use will have a significant impact on the availability of water resource [3]. Therefore, it is important to know changes in the water resource. Global estimates of groundwater storage changes can be used to estimate that groundwater depletion trends in any region throughout the world [4].

Groundwater resource in the research area has been studied by several researchers. The potential of groundwater in relation to the lineament also analyzed to understand the influence of lineament’s characteristics [5]. There is a strong correlation between the distance of lineament – spring to the numbers of spring. The springs are usually acted as a discharge of groundwater flow in the local area.

Groundwater resource of the study area can be evaluated by looking at numbers of spring as well as dug well. This potential of groundwater can also be discussed in its relationship to the topography.

The study area is hilly morphology with a mainly steep slope and high dissected morphology [5]. The coarse relief is usually shown by a narrow valley, steep slope, and blunt peak hills. There are some breaks of slope feature in several locations in which the spring may appear.

Hydrogeology characteristics should be understood to know water resource. Furthermore, the hydrological model may be developed for basin management which is useful for soil and water conservation [6]. One aspect that needs to be studied is the topographic relationship model for groundwater flow patterns.

2. METHODS

The research has been done by hydrogeological and geomorphological mapping in the central of West Progo Hills. The data which have been collected include hydrogeological variables (groundwater table and spring type) and also geomorphological variables (slope, elevation, relief).

Geological equipment was used include GPS, hammer, compass, and loupe. The slope is calculated from a topographic map and also directly measured in the field.

Stable isotopic data of ^{18}O and D have been taken to complete the analysis. These stable isotopes data have been taken from groundwater samples of selected springs and tested in Hydrology Laboratory of Indonesia National Nuclear Power Agency. The springs include 7 locations in Jonggrangan Formation and 7 locations in Old Andesite Formation aquifers.

3. REGIONAL HYDROGEOLOGY

West Progo Hills is dome physiography which has built mainly by three big ancient volcanoes i.e. Gadjah, Ijo, and Menoreh [1]. These volcanoes produced andesitic rocks such as andesite breccia and andesite lava. These volcanic products include in Old Andesite Formation. Beside this formation, West Progo Hills is also built by a series of Tertiary sedimentary Formation such as Nanggulan, Sentolo, and Jonggrangan formation. The research area in the central part of the dome is mainly built by Jonggrangan and Old Andesite Formations. Jonggrangan Formation is consists of coral, bedded limestone, tuffaceous marl, conglomerate and calcareous sandstone [7].

The aquifer system in the study area was constructed by andesitic volcanic rocks with a thickness of more than 300 m. These rocks have locally undergone quite intensive weathering, and form a thick soil (5-10 m). Based on the characteristic layers of massive, densely fractured rock, and groundwater occupies the cracks, the aquifer system in the study area can be classified as a cracked volcanic aquifer [8]. Groundwater in this cracked aquifer system flows as a complex flow and creates seepages. On a local scale, the groundwater level is not related in one place to another.

The existence of the basement rock of the Old Andesite Formation aquifer in stratigraphy cannot be detected because this formation is a body of intrusion and thick lava. The aquifer system in this area is interpreted as aquifers that are completely composed of volcanic rocks reach the basement. Because these volcanic rocks are exposed widely on the surface and are directly related to the atmosphere, the aquifer system can be classified as an unconfined aquifer [8].

Jonggrangan Formation mainly consists of bedded tuffaceous limestone which built an aquifer by its intergranular porosity. This formation is also densely cracked therefore secondary porosity is also well developed. This aquifer is supported by cracks and solution hole porosity, especially in coral, reef limestone.

4. RESULT AND DISCUSSION

4.1 Morphology of Research Area

The study area occupies in central West Progo Hills or core of dome physiography. It has variable morphology, mainly composed of high dissected, steep slope morphology. This area has an elevation of 187.5 to 850 m above sea level (asl), with slope developed from 5% (undulating) until more than 100% (very steep) [5].

Fig. 2 shows some lineaments of escarpments of the research area. This morphology can also be looked in the 3D block diagram as shown in Fig. 3.

Similar to Fig. 3, the morphology of the research area can be noticed from the southern side [3]. This landform shows a hard rock terrain built by hard, compacted rocks and made the rough relief.

The research wants to know about the relationship between groundwater flow and topographic aspects, therefore the observation locations have been chosen in dug wells and surroundings area (Table 1; Fig. 4). This table shows morphometric variables include the elevation and slope of landform.

From the slope map on Fig. 4, it appears that the research area is dominated by a landform with fairly steep slopes. The valley between the hills usually has a relatively gentle slope and generally found locally at a relatively narrow area.

The landscape of research area is similar to Samigaluh area which is located on the east of it, which has coarse relief, strong dissected hilly morphology [9]. This area is usually affected by balanced erosion, both horizontal and vertical erosion. However, there is a poor correlation between elevation as well as the other morphometric variable responses of a stream.

Fig. 2. Morphology of research area as seen from Jatimulyo Village, Girimulyo (top); and from Tlogoguwo Village, Kaligesing (bottom).

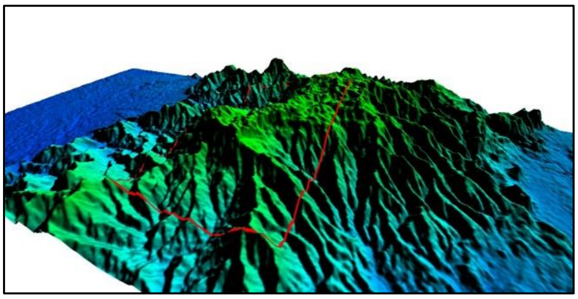

Fig. 3. Morphology of research area in the 3D diagram as seen from east direction.

Table 1. Location of dug well as observation spot area.

Well	UTM coordinate		Elevation (m)	Slope (%)	Gw. table (m)
	Northing	Easting			
W1	402803	9146709	717	15	715.5
W2	403055	9146716	741	17	736.4
W3	402914	9146504	716	18	711.44
W4	402972	9146491	716	15	710.6
W5	403071	9146491	427	17	424.8
W6	403323	9144843	734	14	730.2
W7	403644	9144597	743	20	738.83
W8	403578	9144480	754	21	747.9
W9	399443	9143192	298	25	296.1
W10	399483	9143149	294	28	292.1
W11	401554	9142896	600	28	598.8
W12	401440	9142800	600	24	598.6
W13	403058	9143528	687	12	682
W14	403056	9143501	687	14	681.5
W15	402955	9143421	687	13	680.5
W16	402868	9143319	687	15	681
W17	402905	9143289	687	15	680.5
W18	403033	9143066	725	17	719.2
W19	403033	9143019	725	20	719
W20	402912	9142833	750	21	744.3
W21	403302	9143013	717.46	25	716.56
W22	402746	9139995	669.4	30	667.4
W23	402877	9139999	643.6	31	635.6
W24	403430	9138812	520.88	30	519.6
W25	403527	9138406	482.67	33	481.45
W26	403071	9138006	324.3	32	321.3
W27	399665	9138373	462.68	15	461.6
W28	399723	9138318	465.8	18	464.8
W29	399015	9137910	391.8	45	390.6
W30	399333	9137742	476.8	47	474.8
W31	399284	9137727	476.6	46	475.1
W32	400808	9143186	502	25	499.9
W33	400865	9143223	512	15	511
W34	400002	9138458	444	35	441.1
W35	399839	9138247	437	30	434.2

4.2 Groundwater Flow

Groundwater flow can be interpreted based on the local groundwater table (Fig. 5). Unfortunately, dug wells are only found locally in several locations, even many areas do not have dug wells. It means that the availability of dug wells at the research area relatively small and the distribution is uneven.

Due to the availability of dug wells and local distribution, the groundwater contour pattern cannot be generated throughout the study area. This pattern of groundwater contours can only be made around dug wells areas so that the groundwater flow pattern cannot be interpreted in relation to other areas.

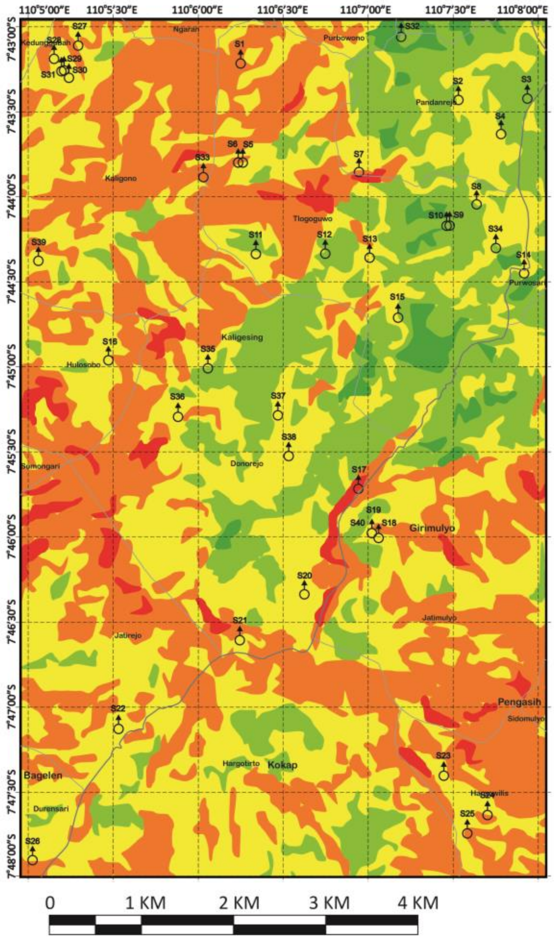

Fig 4. Map of a slope of landform in the study area.

Legend:

♁ : Spring

🟥 : Slope > 100%

🟧 : Slope 45% - 100%

🟨 : Slope 25% - 45%

🟩 : Slope 15% - 25%

🟩 : Slope 0 - 15%

Groundwater flow develops as a local flow system in the area. This system usually develops along with local relief [10]. In the local flow condition, the topography usually influences the groundwater table. The water table is coincident with the ground surface in the valley, sometimes produced spring, and forms a weak replica of the topography on the hills (Fig. 6). The flow lines deliver groundwater from recharge areas to discharge areas.

Discharge of groundwater occurs in nature when water emerges from underground [7]. Most natural discharge occurs as flow into surface water bodies, flow to the surface appears as a spring. This phenomenon let the appearance of depression spring type. The depression spring is formed where the ground surface intersects the water table.

There are some depression springs found in the research area (Table 2 and Fig. 4). These springs mainly found at the steep morphology of Old Andesite Formation, and sometimes can be met at Jonggrangan Formation rocks with single or combination type. For example, Mudal spring (S17) develops as depression, fracture, tubular spring. The tubular porosities even grow to be cavity ones.

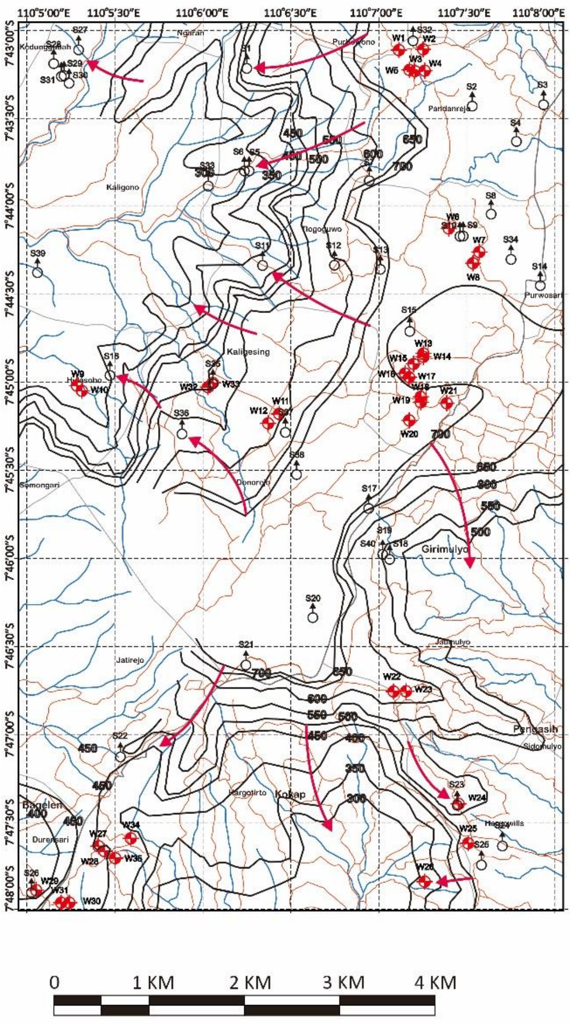

Fig. 5. Groundwater flow of shallow aquifer.

Legend:

⊕ Dug well

♁ Spring

〰 Groundwater table contour

→ Groundwater flow

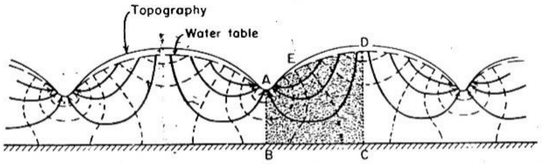

Fig. 6. Groundwater flow net in a two-dimensional vertical cross section (after Hubert, 1940 in [10]).

The depression springs prove that there are groundwater table lines cross steep cliffs or slope of morphology. It means that actually morphology or topography also control groundwater flow. In this term, spring will be a discharge of groundwater flow. Therefore, some groundwater flow lines usually lead toward spring as a discharge of it.

4.3 Topographic Control on Groundwater Flow

There are at least two parameters of topography that can be analyzed to see their influence on groundwater flow, i.e. elevation and slope. Groundwater tends to flow from a higher hydrostatic head (groundwater table) to the lower ones. The groundwater flow is represented as a groundwater table. These relationships can be seen in Fig. 7 - 8.

Table 2. Some depression type springs in the research area.

Spring code	Location	Coordinate		Spring Type
		Northing	Easting	
S1	Pandanrejo	401223	9146528	Depression
S2	Tlogoguwo	403580	9146131	Depression
S5	Tuk Songo	401210	9145447	Depression
S6	Tuk Songo	401208	9145447	Depression
S8	Tlogoguwo	403774	9145005	Depression
S9	Tlogoguwo	403471	9144773	Depression
S10	Tlogoguwo	403468	9144755	Depression
S11	Pagertengah	401387	9144466	Depression
S12	Tlogoguwo	402137	9144468	Depression
S15	Kalilo	402925	9143777	Depression
S16	Hulosobo	399792	9143316	Depression
S17	Mudal	402496	9141923	Depression, fracture, cavity
S24	Clapar 1	403892	9138389	Depression
S27	Kaligono	399464	9146723	Depression
S28	Kaligono	399223	9146585	Depression
S29	Kaligono	399205	9146580	Depression
S30	Kaligono	399314	9146451	Depression
S31	Kaligono	399368	9146377	Depression

The relationship between elevation and the groundwater table gives a coefficient correlation value of 99.99% (Fig. 7). It means that the groundwater table always follows relief or topography. There are many variations in groundwater table depth in a peak of the hill if it is compared within the valley. Sometimes, the groundwater table is found deeper in the hilltop. But in general, the shape of the groundwater flow line in a vertical cross section will be similar to topography (see Fig. 6).

Meanwhile, the relationship between the slope and the groundwater table show a worse value (Fig. 8). This relation is indicated moderate correlation by the r^2 value of 0.2933 or coefficient correlation (r) of 54.16%. Slopes generally affect rainfall to be infiltrated or runoff. The amount of rainwater that infiltrates the slope is also an important factor in the stability of soil [11]. Slope instability in a tropical country normally triggered by the high seasonal rainfall event as well as geological factors [12].

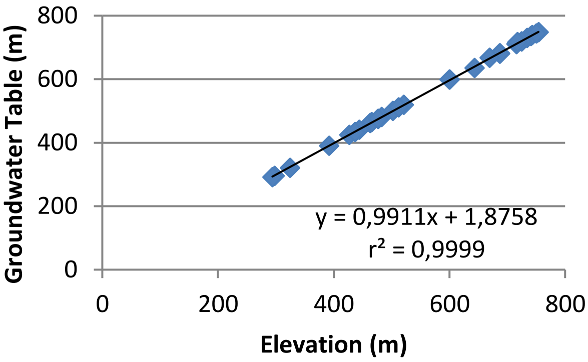

Fig 7. The relationship between elevation with the groundwater table.

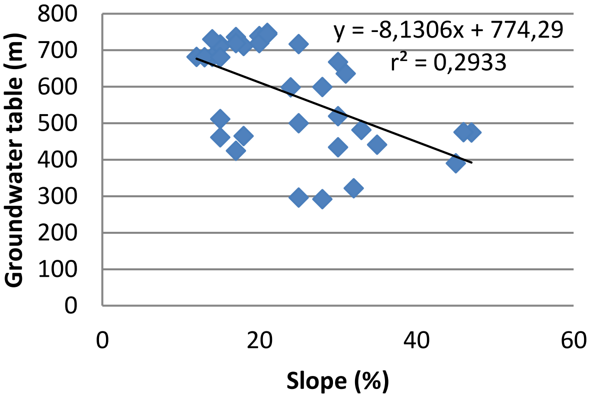

Fig. 8. The relationship between the slope with the groundwater table.

Although the relationship between slope and groundwater flow only shows moderate correlation, there are many discharges of groundwater flow controlled by the break of a slope of landforms. It means that landforms actually control groundwater flow because the flow usually goes toward spring as a discharge point.

Many steep slope landscapes made a break of slope in the research area. This condition triggers the occurrence of springs. Then, those springs can change the direction of the groundwater flow. The groundwater flows principally from recharge to discharge area [13].

There may be changes in water resource such as groundwater pattern or its quantity. It is related to behavior and trends of dynamic change include relationship and interaction of variables in the system under different a spatial and temporal parameter such as water quality [14]. Therefore, the topographic changes may influence the groundwater flow pattern.

Such as the pattern of groundwater flow in free aquifers in general, the pattern of shallow groundwater flow in the study area flows following the topography. This condition does not only occur in free aquifers, but it can occur in confined aquifers. The direction of groundwater movement in the artesian aquifer may coincide with the flow of the rivers, and the slope of the groundwater flow varies, with the large values in the groundwater discharge zone [15].

The addition of dug wells will also cause the groundwater flow to change direction. Therefore, in an urban area, groundwater flow may vary locally from time to time and can change depending abstraction. Nevertheless, the study area is not an urban area so there is rarely the addition of dug wells.

The isotopic data are evaluated to complete the analysis (Table 3). From the 40 springs found in the field, 14 well-selected springs were chosen to collect isotope data. All data were taken in dry season.

In any certain area regionally, there is an altitude effect can be determined from isotopic data of springs from some different elevations. These phenomena yield a distinct correlation exists between the ^{18}O and D values and elevation [9]. Principally, precipitation will have a light isotope content in place with higher elevation [17] as well as shown in Jakarta Basin [18]. Unfortunately, this altitude effect in the study area is invisible (Fig. 9).

Table 3. Stable isotope data from springs.

No.	h (m)	δ^{18}O (‰)	δD (‰)
S1	512	-7,4	-42,1
S4	747	-7,25	-45,5
S7	665	-6,84	-42,2
S11	409	-7,34	-43,1
S13	705	-7,4	-46,6
S14	710	-6,6	-39,3
S16	340	-6,88	-41,1
S17	664	-7,39	-45,1
S20	728	-6,72	-38,9
S21	706	-7,39	-41,2
S25	437	-5,51	-34,7
S26	400	-6,45	-36,8
S29	311	-6,45	-38,8
S39	211	-6,8	-41,3

Fig. 9 explains that there is a very weak correlation between elevation and groundwater. This correlation only has r^2 very small. Nevertheless, the isotopic value usually lighter with the increase of altitude.

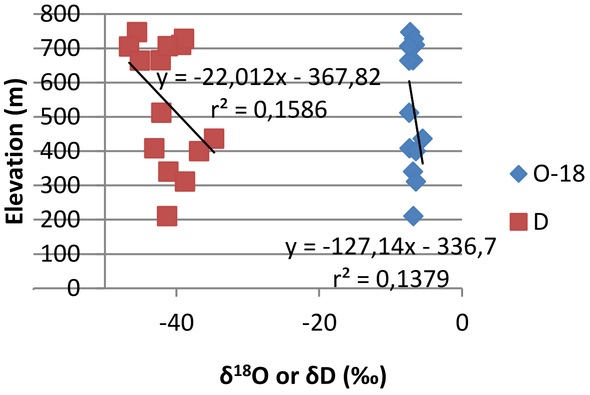

Fig. 9. The poor relationship between δ^{18}O or δD values with elevation in the research area.

Actually, there is a narrow range of altitude in the study area. Moreover, there is a coarse relief result in an unclear difference in isotopic values. It can also be interpreted that groundwater flows in the local system, in a short time, where the evolution process hasn't been occurred to make any change of isotopic value or enrichment. The recharge may be in a near area with no significant difference of altitude, therefore the value of isotopic enrichment is still unclear. Poor correlation may also be caused by a narrow altitude range and a wide range of isotope values. Therefore, the estimated elevation of the recharge zone is difficult to determine based on groundwater isotope content in the study area.

5. CONCLUSION

The topographic parameters that affect groundwater flow are elevation and slope of landscape with a moderate - very strong correlation. The relationship between elevation and groundwater gives a correlation coefficient (r) of 99.99% (very strong), while the slope makes r-value of 54.16% (moderate). Unfortunately, the isotopic value doesn't support this phenomenon, however, this isotopic data prove a variable value of local groundwater flow that is not controlled by altitude effect.

6. ACKNOWLEDGMENTS

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