Geosonar for impermeable layer mapping in urbanized Upper Belik catchment, Yogyakarta

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Abstract. The scarcity of water in most Yogyakarta grounds water basin is because of decreasing the groundwater recharge as the implication of the build-up area growing. One exception is in Upper Belik Watershed in which more than 95% covered as paved area. In order to reduce the runoff, the infiltration well must be applied. The artificial well design depends on the characteristics of impermeable layer that can be seen by its depth. So the analyst of impermeable layer depth is extremely important to be researched. Distribution of the impermeable layer can be interpreted using Geosonar. Therefore, the purpose of this research is to find the distribution of impermeable layers in Upper Belik Catchment. The primary data used systematic random sampling base on grid size 125x125 m. Spatial data analysis of the impermeable layer utilized to visualize the result of material type which consists of sand, little gravel, tuff, clay sands, sandy clay, and gravel in research location. Variation of impermeable layer depth divided into 5 classes which are: I (9-10 m); II (10-20 m); III (20-30 m); IV (30-40 m); and V (>40 m). The composition of the impermeable layer material dominated by clay and tuff in Upper Belik watershed and located below the groundwater level.

1. Introduction

Water use is increasing as the population grows [1]. The growth followed by population growth also triggers an increase in the use of a build-up area as settlement. The land commission's awakening zone has reduced in urban catchment areas. This condition affects increased surface runoff in the wet season and decreasing of groundwater during the dry season [2]. There is a need for water management in urban areas, which concerned with the physical condition of each region.

The Upper Belik Catchment located in the urban area of Sleman Regency. Sleman Regency has grown significantly in the past ten years and experienced some major improvement [2]. Sleman Regency overpopulated since 2005 has shown an increase in land use and water use [3]. Public water consumption is supplied by groundwater as much as 51.83% [4]. The use of groundwater is used to cater to people's domestic water needs and a large part of the hotel and apartment industries [5]. A part of the catchment area has rainfall up to 1,500- 2,000 mm/ year [3]. These conditions make the study area have limited potential water use. However, the lack of water management in urbanized areas resulted in more runoff during the rainy season and reducing the amount of groundwater. As a result, the increasing number of water uses in dry season causes shortages of fresh-water and a significant decrease in groundwater level.
Therefore, heavy rain could create puddles and floods in downstream area of Belik Catchment because of overflowing river (Figure 1). However, the groundwater level decreases by 30 cm/year [6] [7].

![Figure 1. Inundation occurrence in parts of Belik Watershed.](image)

Surface runoff can be reduced by creating flood management infrastructure like artificial wells [8]. The government, especially the environmental related agencies, have been actively built the artificial wells [9]. Unfortunately, the existence of volcanic pyroclastic deposits and the characteristic aquifer had not yet been considered. Among the pyroclastic deposits, there is an impermeable layer that affects the unveiling of the water into the ground. The making of the artificial wells in the area with waterproof layer depth needs to consider the existence of the impermeable layer [10]. Therefore, the aim of this study is to find out the distribution of impermeable layers in Upper Belik Watershed. Distribution of the impermeable layer can used to hydrological management planning to reduce high surface run off. Hydrological management planning can be applied like planning artificial wells.

2. Methodology

2.1 Study Area

Upper Belik Watershed is located in the urban area covered 88 Ha. Administratively this watershed is part of Sleman Regency, Special Region of Yogyakarta Province, Indonesia. The area belongs to Caturtunggal dan Condongcatur villages. Geographically this location is at coordinate 110°22'43"-110°23'29.4" E and 7°45'53.1"-7°45'45.6" S with land use dominated by built-up area [11] (Figure 2). Based on the geomorphologic conditions, research areas are located at the volcanic plain, which has slope steepness of 0-2%. Its geologic formation is the Young Merapi Volcano Formation ($Q_{mv}$). The material consists of tuff, volcanic ash, agglomerate breccias, and molten lava [12]. This formation has the potential for good aquifer [13]. The catchment area in Upper Belik Watershed forms pool when rain vame heavily [2].
2.2 Methodology
This research follows the descriptive quantitative analysis and utilizes both primary and secondary data. Primary data obtained from the field is impermeable layer depth, while secondary data used is Log-Bor obtained from the Public Works Department (Dinas PPK, Sleman Regency).

2.2.1 Sampling Data Impermeable Layer
The primary data is data dept of the impermeable layer taken from Geosonar survey, while secondary data is Log-Bor. The Geosonar was applied by mean of stratified random sampling base on 125x125 meter grid size on a scale of 1:5000 (Figure 3). The grid size selection based on consideration of land use and large area research. Therefore, grid size can represent area research. Surveys were made possible, since the area of the study was dominated by pavements and asphalt roads (Figure 4). However, selection of measuring samples should be on the outdoors area with minimum area $2m^2$. However, Geosonar works by emitted a signal on UHF frequency, which transmitted towards the ground surface. After a while then the waves are reflected by ‘objects’ which have different density characteristics with their environment. The sonar antenna then receives the wave reflection. The characteristic of wavelengths reflected and the resulting time delay is then analyzed internally by a microcontroller. The result is a value of layer depth, and the layer porosity percentage. Based on the porosity percentage value, then the amount of groundwater flow potential can be determined. Geosonar is practically operated by someone who has a ‘sense’ and has been trained. In addition, the results of mapping the characteristics of aquifer bedding (stratigraphic) are validated with drill-log data. This data is usually obtained when drilling a deep well or when sounder works on soil mechanics in preparation for the high building construction. Because there is no bore-hole data at the research location, the closest bore-hole data is used as a comparison.

![Figure 2. Landuse Map in the Upstream of Belik Watershed.](image-url)
The result from Geosonar measurement then compared with Log-bor data and previous research results as well. Data obtained are point data of layered structure. The measurement uses Geosonar gives other information such as effective porosity, as well as potential groundwater discharge. Based on effective porosity data, the type of material under the ground can be identified [14][15]. Table 1 shows the values of effective porosity related to the type of material. The data is then analyzed and visualized in the form of a map.

Material consist of alluvium and diluvium. Alluvium is poorly sands, consist of clay, gravel, sand and finer material on flood plains [16], while diluvium is accumulated from the surrounding hills [17].
The quantity of water that can be stored in the material on soil/lithology defined as its porosity. Porosity is a presentation of part of a material that is porous to its total volume [14]. Effective porosity is a comparison of the pores’ interconnected volume to the volume of total rock expressed in percent. Clay materials tend to have high density of matter, as a large amount of micropores does, but it is difficult to obtain water. In contrast with sand, because it has small micropores, this condition makes sand both in storing and holding the water greater than clay [18].

Table 1. Porosity and Coefficient of Permeability.

| Material                | Porosity (%) | Effective Porosity (%) | Permeability |
|------------------------|-------------|------------------------|--------------|
| Alluvium               |             |                        |              |
| Clay                   | 45-50       | 5-10                   | $10^4 - 10^6$|
| Clay silt              | 35-45       | 5-8                    | $10^3 - 10^2$|
| Sand                   | 30-35       | 20-25                  | $10^1 - 10^2$|
| Sand and gravel        | 25-30       | 15-20                  | $10^1 - 10^2$|
| Dilluvium              |             |                        |              |
| Clay                   | 50-60       | 3-5                    | $10^5 - 10^6$|
| Clay and silt          | 40-50       | 5-10                   | $10^5 - 10^6$|
| Sand                   | 35-40       | 15-20                  | $10^2 - 10^3$|
| Sand and gravel        | 30-35       | 10-20                  | $10^2 - 10^3$|

2.2.2 Research flow charts
The steps of research consist of preparation, collecting data, and also data processing and data analysis. Preparation steps consist of a literature study and the location of this research. The stage of field data collection is composed of research area observations, collecting secondary data Log-bor data, and topographic map. Then a prefleld activity was undertaken to determine the ground test point, followed by the Geosonar test based on grid method. The analysis consists of spatial analysis with a 2D impermeable map. The data analysis would be the basis of the output and recommendation of this research. The flowchart is shown below in (Figure 5)

![Figure 5. Flow Chart of Research Methodology.](image-url)
3. Results and Discussion

3.1 Aquifer Condition

The area of study belongs to the Merapi Aquifer system [19]. Based on secondary data, the primary lithology of Upper Belik watershed is the volcanic deposits, especially pyroclastic material. The sediment can serve as a layer that carries potential multilayer aquifer [20]. Based on Geosonar measurements in the field, material that dominates the research area is sand, gravel, tuff, clay, and breccia. The composition of the material makes the research area a good aquifer, which is easy to absorb as well as to release the amount of groundwater.

3.2 Distribution of Impermeable Layer Depth

Analysis of the impermeable layer and ground surface material in the research studies to identify the characteristics of the subsurface layer are done by measurement and interpretation of Geosonar data. The number of locations identified by Geosonar is as much as 52 points. Those measurements reveal the depth of lithology layer, variety, and the potential discharge of groundwater. The value of matter produced by geosonar measurement represented the effective porosity and then interpreted the type material (Table 2).

| Coordinate | Effective Porosity (%) | Material |
|------------|------------------------|----------|
| 432173, 9141678 | 42 | Tuff |
| 432529, 9141817 | 28 | Clay |
| 432166, 9142139 | 33 | Clay |
| 432534, 9142164 | 37 | Tuff |
| 432295, 9142204 | 20 | Tuff |
| 432109, 9142296 | 32 | Clay |

Table 2 shows the value of effective porosity at some location of Upper Belik watershed. The small of the value of effective porosity makes it harder water to infiltrate such as clay. The depth of the layer of lithology formation at some locations can be seen in the 2D cross-section of geo sonar (Figure 6). Based on these images, it can be seen sand and pebbles dominate soil surface materials with impervious materials of clay and tuff. Both points were chosen because they can represent the impermeable layer, it is tuff dan clay. Both points Figure 6 too show them different depth in the impermeable layer. These conditions indicate 2D cross-section bore-hole data (Figure 7) soil surfacenyam is sand and pebbles [21].
Figure 6. Data Interpretation from Geosonar Measurement for Sample Point Number 36 (left) and 38 (right).

Figure 7. Cross-section of Bore-hole Data in Faculty of Biology UGM

The impermeable material that dominates the upper layer is clay which scattered at 30 locations in different depths. Clay has smaller hydraulic conductivity than the tuff as indicated by their low effective porosity value. This value suggests that the existence of clay layers can affect the soil's ability to infiltrate the water. The presence of this impermeable material needs to be considered, of course, in the water
management practice, thus it can minimize the surface runoff whenever heavy rains occurs. The depth position of the clay is most in between 20-29 m, however for some locations its less than 10 m i.e. sample point number 38 (Figure 6).

The depth of the outer layer is based on the extension of Geosonar which divided into 5 classes (Figure 7) as follow: I (9-10 m), II (10-20 m), III (20-30 m), IV (30-40 m), and V (>40 m). The depth domination of the impermeable layer is 20-30 meters with a thickness of around 0.3-3.1 meters. The depth of the outer layer of the class refers to the nearby data (bore-hole), which has the value between the lengths of the distance [22]. Bore-hole data (Figure 7) show impermeable layer can be found at the depth of 20-25 meters with material sandy loam. This value represents in common with the measurement result geo sonar. It shows the results of measurement have good validation. [20].

4. Conclusion
Based on the data calculation the depth of the imperils divided into 5 classes which are I (9-10 m); II (10-20 m); III (20-30 m); IV (30-40 m); dan V (>40 m). The position of the impermeable layer is 20-30
meters below the surface and has depth by 0.3 – 3.1 meters. The distribution of the impermeable layer is mostly below the groundwater level, so water management in reducing surface runoff and handling the recharge to groundwater may use a runoff well or recharge well.

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