



GIS-Based Shallow Groundwater Potential Zone Assessment Using ALOS AVNIR-2 Remote Sensing Data (Case Study: Bedog Sub-Watershed, Yogyakarta)

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ABSTRACT: *This research aimed to determine how effective the integration of remotely sensed data of ALOS - AVNIR 2 and Geographic Information System (GIS) to assess the shallow groundwater potential zone in Bedog Sub Watershed and spatial analysis of potential groundwater produced in the form of a map. Primary data used is the image of ALOS - AVNIR 2 supported by some thematic maps and other data. The method used is integrate the remote sensing techniques and GIS by buildup shallow groundwater potential zone map in Bedog sub watershed with parametric approach (for the origin of volcanic landforms with sand aquifer material). For potential groundwater contained in landforms from solusional processes, the method used is the measurement of groundwater potential in the field with quantitative descriptive approach. The accuracy of interpretation from each parameter are for parameter of soil texture resulting 75 % of accuracy, 77.78% of slope and 85% of land cover. Shallow groundwater potential maps generated from the origin of volcanic landforms with material aquifer of sands produces shallow groundwater potential in 3 classes (low potential, moderate potential and high potential) through the measurement of shallow groundwater level information in the field. It is able to be generalized to information of aquifer formation that contain of it. Shallow groundwater potential in landforms from solusional processes with a limestone rock as a material shows very varied potential shallow groundwater which have been seen from differences phenomenon in the field.*

Keywords : Remotely sensed data of ALOS - AVNIR 2, GIS, terrain parameters, shallow groundwater potential

1. INTRODUCTION

Human needs water for survival and groundwater reserves can be an alternative water in economic household needs. Several advantages of groundwater compared to surface water is the availability of groundwater is not affected by the season and the quality is better relatively, assuming it stored in aquifers with suitable rock formations both in quality and quantity. Groundwater constitutes the largest accessible freshwater reserve on Earth and plays a critical role in sustaining domestic water supply, particularly in regions where surface water availability is seasonal or unreliable (Freeze & Cherry, 1979). Moreover groundwater supply is greater than surface water supply and easily available (especially for shallow ground water in unconfined aquifer) and in their distribution was easy relatively except for a few areas located in the landform which requires groundwater distributed in confined aquifer and in underground rivers flow as occurs in karst areas.

ALOS (Advanced Land Observing Satellite) was launched in January 2006 by the Japan Aerospace Exploration Agency (JAXA) gives several specifications related to the ability to extract parameters that are used in Shallow Groundwater Potential Zone Assessment. With four bands that used in AVNIR - 2 sensor (Advanced Visible and Near Infrared Radiometer type 2) which consists of visible band to near infrared band is very helpful in interpret parameters that are used in shallow groundwater potential zone assessment, especially for land cover parameter and other terrain parameters that can be interpret visually anyway. Spatial resolution of 10 m giving an advantage in medium scale thematic mapping and very appropriate to the area study. GIS are very useful in the process of analysis and modeling. Modeling a complex features on the earth surface can be seen more simple through the quick processing. Terrain parameter retrieval regarding to shallow groundwater potential zone assessment from remote sensing imagery is possible and it will be better supported by GIS. Phenomenon mapping especially in earth surface with remote sensing approaches can be associated with the retrieval of information through a spectral response that is owned by each type of remote sensing imagery and terrain introduction that can be interpreted from the visual imagery as well.

Bedog sub watershed is the landscape that has diverse terrain condition for shallow groundwater potential assessment. Merapi aquifer system that located in Bedog sub watershed has the ability to store shallow



groundwater variously assessed from parameters such as rock types, landforms, soil texture, slope and land cover. Information on the spatial distribution of groundwater potential is important for communities to understand, and one effective medium for conveying this information is through maps. Maps enable people to comprehend natural phenomena more easily than purely descriptive information. Therefore, the integration of Remote Sensing with GIS in the production of maps is essential.

2. RESEARCH METHOD

Research area is in Bedog sub watershed, Yogyakarta Special Region (Figure 1). Bedog sub watershed has an area of approximately 130 km² and is directly adjacent to the east side by Winongo sub watershed and the west by Kenteng sub watershed. Bedog sub watershed is located in the landscape that have diverse terrain condition for shallow groundwater potential zone assessment. Merapi aquifer system that located in Bedog sub watershed has the ability to store shallow groundwater variously assessed from parameters such as rock types, landform, soil texture, slope and land cover. It is similar what Todd and Mays (2005) done, that the occurrence and movement of groundwater are primarily controlled by geological formations, soil texture, slope, and land cover, which together determine infiltration capacity and aquifer storage potential. Bedog sub watershed administratively through 2 regencies and 1 municipality. They are Kab. Sleman, Yogyakarta City and Kab Bantul. Kab Sleman including Turi District, Pakem, Sleman, Mlati, Gamping and Godean. While for the Bantul Regency including Kasihan District, Sewon, Pajangan and Pandak.

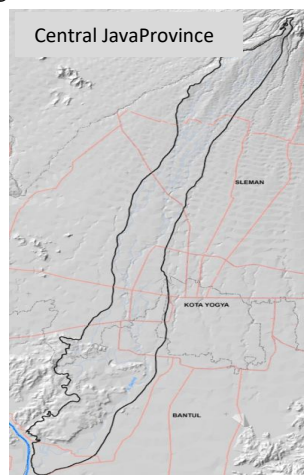


Figure 1. Research Location in Bedog Sub Watershed

The method used in this study is the integration of remote sensing and GIS techniques by integrating information of terrain parameters which used for determining shallow groundwater potential zone assessment in Bedog sub watershed generated through the process of interpretation in remote sensing techniques with the help of Geographic Information System. Groundwater potential zone mapping using remote sensing and GIS has been successfully applied in other complex terrain regions, demonstrating that weighted overlay and multi-parameter integration can effectively discriminate recharge areas with moderate to high groundwater potential (Pitchaimani et al., 2024). Recent research also shows that remote sensing and GIS are effective tools to integrate multiple terrain, hydrological, and geological datasets for hydrogeological zonation in diverse climatic and lithological environments (Taibi, B. E., 2025). In GIS, mapping and spatial analysis processes related to spatial distribution of shallow groundwater potential in Bedog sub watershed would be done.

3. RESULTS AND DISCUSSION

3.1. Geometric Correction of ALOS – AVNIR 2

Remotely sensed data of *ALOS - AVNIR 2* is the primary data for the research in shallow groundwater potential zone assessment in Bedog sub watershed. Although the image has been corrected to the IBI level to indicate that was corrected geometrically, this correction is still in global correction. Therefore local correction is needed related to overlay processes which performed as one of the methods in data processing in order to all attributes of terrain parameter resulting from the image have the same position and coordinate reference. Geometric correction process is carried out referring to the RBI maps of Indonesia (*Peta Rupabumi Indonesia*) of the study area at 1:25.000 of scale. Geometric correction is performed by using the 3rd polynomial order method. This method emphasizes in determining of *Ground Control Point* (GCP) in accordance to topography of the study area. Research area with complex topography and mountainous, should takes more GCP than flat topography (Figure 2). In this case, geometric correction was performed in remotely sensed data of *ALOS - AVNIR 2* which first had performed a



subsetting data process (selection or cutting area of the image) so the image is more representative in presenting Bedog sub watershed area. Bedog sub watershed is mountainous in upland where lies on Merapi slope and has hilly topography in downstream which located in *Sentolo* formation. A relatively flat area is in the center of the Bedog sub watershed dominated with land cover of built up area. Selected Ground Control Point in this case is 42 points with the *RMS Error* value is 0.985440.

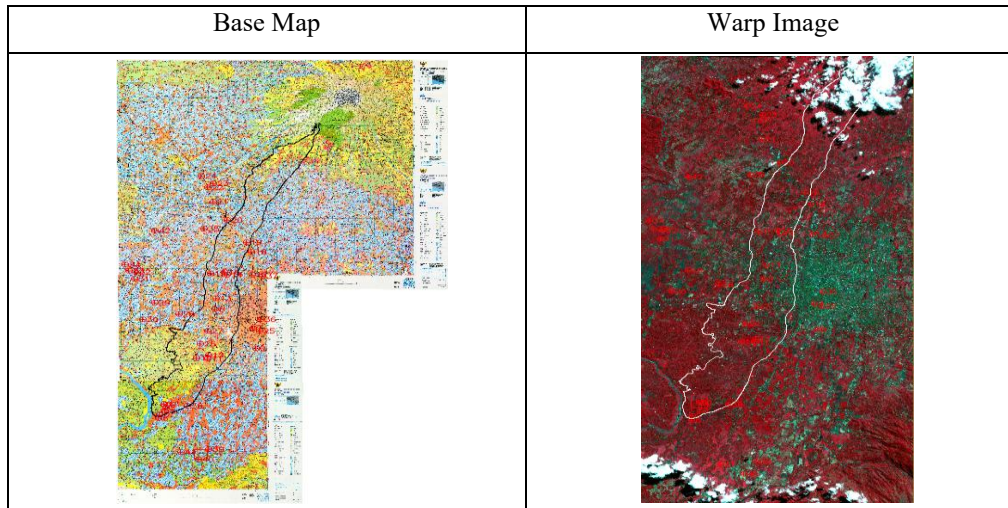


Figure 2. GCP Distribution Around Bedog Sub Watershed

3.2. Rock Type Interpretation and Ground Truthing

Rock types have the most important role in storing and draining groundwater or one of these roles. In creating tentative thematic map of rock types is based on the interpretation of the results of the *TIN* model (*Triangular Irregular Network*) which build based on the digital vector data of *RBI* contour and made into *DEM* (*Digital Elevation Model*) in raster format. *TIN* models are models that show the appearance of the topography of the earth's surface that connects elevation points through irregular triangles. This model is capable of visual displaying of terrain conditions in Bedog sub watershed because one factor in assessing of rock type is topography. *DEM*-based terrain analysis provides an effective means to derive morphometric parameters that are essential for spatial groundwater modelling (Wilson & Gallant, 2000). Flat topography tends to have different kinds of rock types than in hilly and mountainous topographies (Figure 3). This caused by several factors like resistance properties of rock and consistency of rock against exogene process. Field check conducted qualitatively with field observations in surface rock or rock in soil profile (Figure 4). The resulting interpretation of rock types can be noted qualitatively as fairly accurate because its process of interpretation relatively visible to do in visual interpretation with assisted of geological map.

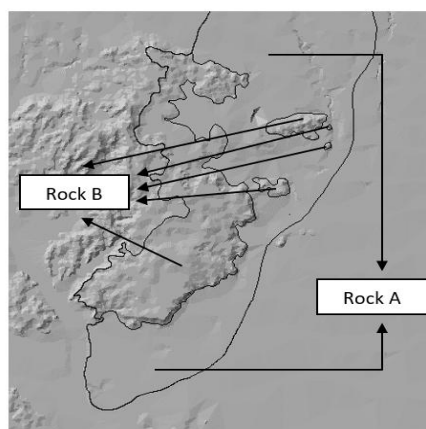


Figure 3. DEM TIN of Bedog Sub Watershed (upstream area) in rock interpretation

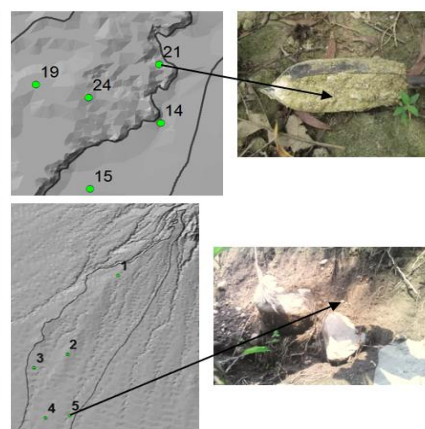


Figure 4. Field check of rock types in point field



3.3. Landforms Interpretation and Ground Truthing

Landforms represent the integrated expression of lithology, structure, and geomorphological processes, and therefore serve as a fundamental unit for groundwater potential analysis (Verstappen, 1983). Landform is one complex parameter used in assess a groundwater potential. Landform can be viewed from several elements, such as the topography of the terrain, the materials on the field, geomorphological processes and other supporting information such as land cover information. As in the interpretation of rock types on the first parameter, the interpretation of landform also using TIN which derived from DEM since visually regarded as an effective way in terrain assessment. Interpretation of landform performed by deduction of general landform information which is then classify into sub landform units. An example is the interpretation of rock types that have been done in the previous process can be used as initial data in buildup landform tentative map due to the type of rock or material information is one of the information required in the buildup of landform information.

Field check for this landform systems conducted qualitatively with observations of forming elements of landforms information in the field that is combination of topographical information, rocks and processes that occur in a field (Figure 5.). Field check is essential to evaluate the reliability of thematic maps derived from remote sensing, particularly for groundwater potential assessments (Congalton & Green, 2009). Information of rocks that observed in the landforms systems has the same kind of rock in major, that is kind of limestone rocks. For topographic information and processes that occur in the field, this information presents the appearance of a very complex and accordance with the tentative map of landforms created and combined with other terrain parameters in buildup of terrain unit map for field checks. Topography and geomorphological processes information very dominate in this landform systems.

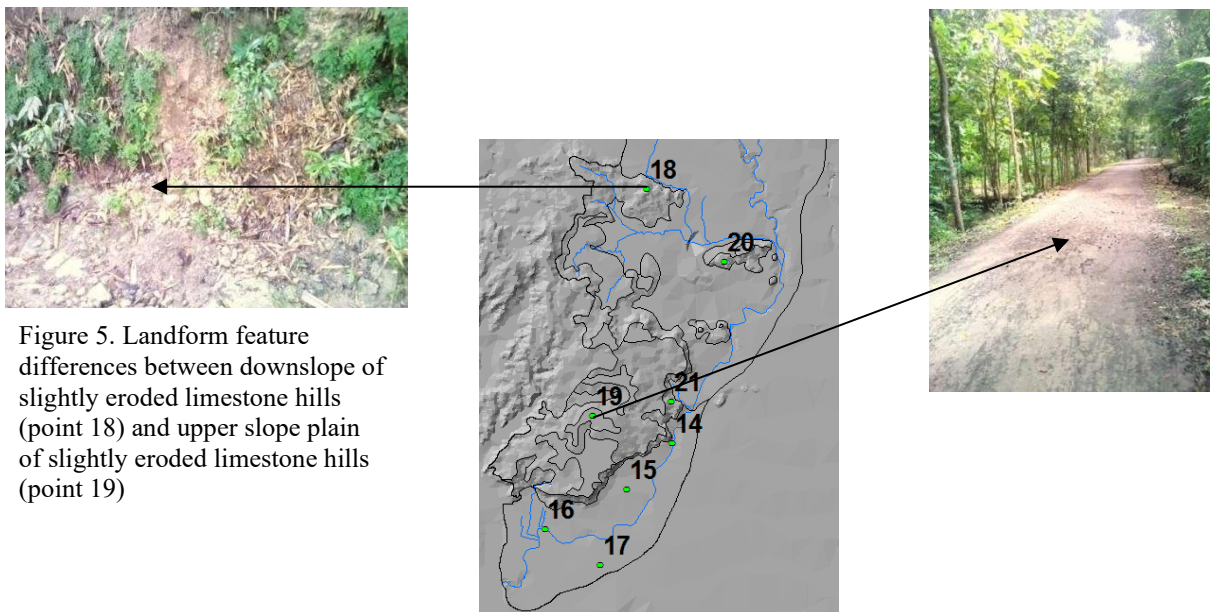


Figure 5. Landform feature differences between downslope of slightly eroded limestone hills (point 18) and upper slope plain of slightly eroded limestone hills (point 19)

Accuracy of landforms is performed by comparing the classification of landforms from interpretation with the actual features in the field. The interpretation able to results in overall accuracy of fairly accurate because its process of interpretation relatively visible to do in visual interpretation by distinguishing differences in earth's surface topography.

3.4. Soil Texture Interpretation and Laboratory Check

Soil texture takes a role on infiltration process. Each soil texture has been recognized based on particle size. Soil particles with relatively small size have tight spatial arrangement with less pores so it gives difficult performance of surface water to be infiltrated into the soil. In contrast, soil particles with relatively large size have a large spatial structure with more pores and water easily infiltrate into the soil. Terrain with relatively coarse soil texture has a relatively high potential for groundwater. Then terrain with smooth texture relatively has low potential for groundwater.



Identification of soil texture spatially through TIN models derived from the DEM can be done through differences of relief and morphological of the earth surface. Interpretation of soil texture is only performed on the landforms from volcanic processes that has sandy sedimentary rocks for final model building of groundwater potential zone map of Bedog sub watershed. Differences of rocks on the earth surface in rock types, structure, stratigraphy and age will affect the resistance properties of the rock so that it will affect into relief where the rocks are. Differences in relief as elevation difference information, shape and length of slope. The differences in relief will affect of differences in the physical, chemical and biological characters of the soil and at last will affect to the utilization. All the information about the relief, the materials and processes that occur already contained in the information of landforms, so that within the definition of these landforms can be use to know the type of soil texture in the buildup of tentative thematic map of soil texture. In identifying soil texture, it is done on the landforms from volcanic processes which have divided into several sub landforms. One of approaches in identifying soil texture is in the definition of sub landform. Here are the results of interpretation of soil texture on each sample point (Table 1). Interpretation of soil texture produce overall accuracy of 75%.

| Field Point | Terrain | Interpretation | Laboratory Test |
|-------------|--|----------------|-----------------|
| 1 | Middle slope of Merapi volcano in fluvial system | Loamy sand | Loamy sand |
| 2 | Middle slope of Merapi volcano | Loamy sand | Loamy sand |
| 5 | Bottom slope of Merapi volcano in fluvial system | Loamy sand | Loamy sand |
| 6 | Bottom slope of Merapi volcano | Sandy loam | Sandy loam |
| 11 | Foot plain of Merapi volcano in fluvial system | Loamy sand | Loamy sand |
| 12 | Foot plain of Merapi volcano | Loamy sand | Loamy sand |
| 14 | Alluvial plain of Merapi volcano in fluvial system | Loamy sand | Sandy loam |
| 17 | Alluvial plain of Merapi volcano | Sandy loam | Loamy sand |

Table 1. The comparison of soil texture interpretation and its laboratory test (Source : DEM/TIN Interpretation, field check and laboratory)

3.5. Slope Mapping and Ground Truthing

Slope derived from digital elevation models significantly influences surface runoff and infiltration processes, thereby affecting groundwater recharge potential (Moore et al., 1991). Slope take a role in determining of overland flow flows distributed as surface runoff or absorbed into the soil. Water infiltration into the soil is due to the influenced by gravity. Different of slope causing the force of water into the soil will be split. In areas with steep slopes, the rain water will tend naturally flow into surface water than infiltrate into the soil, because no significant barriers for water surface. In flat slope, water force will tend infiltrate to soil profile. It tends to have water infiltrated into the soil than the one in steep slope. Therefore, the potential for groundwater in this area is relatively has a high potential. Tentative thematic map of slope made from the results of digital data processing of the contour. Buildup of this map is only performed for the landforms from volcanic processes that have sandy sedimentary rocks for the building of final map (shallow groundwater potential map in Bedog sub watershed). Contour data obtained from Indonesia Digital Topographic map with contour intervals of 12.5 meters. The contour data in vector format is converted to raster format for processing and classification slope digitally and then check it in the field (Figure 6). Slope accuracy is performed by comparing slope classification from tentatif map and actual slope in the field. Accuracy of slope produces overall accuracy of 77.78% .

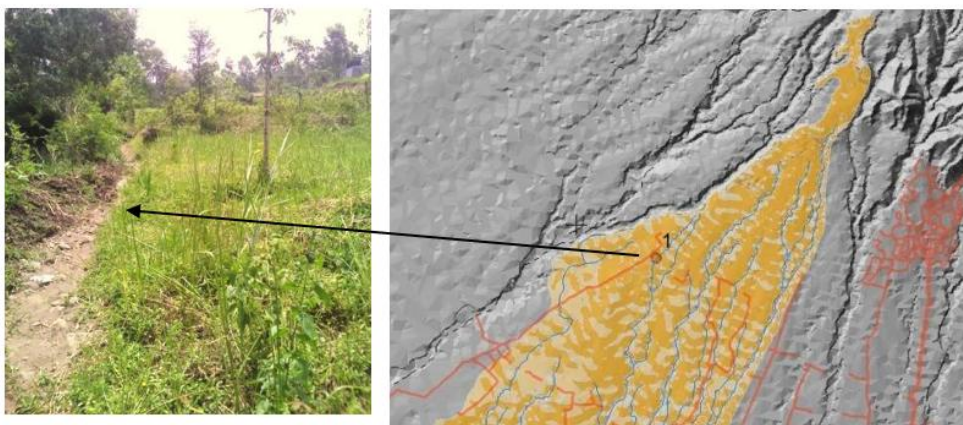


Figure 6. Slope measurement in the field (point 1) in middle slope of Merapi volcano



3.6. Land Cover Interpretation and Ground Truthing

Interpretation of land cover is only performed on the landform from volcanic processes that has sedimentary rock in order to build a model of the final map of shallow groundwater potential zone assessment in Bedog sub watershed. Vegetation cover influences groundwater recharge through interception, evapotranspiration, and enhanced infiltration associated with root systems and soil structure (Scanlon et al., 2002). The assumption used is that if the land is grown by vegetation with high canopy density, so this land has the higher potential of groundwater. But if the field is grown by vegetation with low density it will have a low potential of groundwater as well. In this case, researchers classifying land cover which concentrated on the type of vegetation and the assumption of it related to the density of land cover and the information related to the ability of wood vegetation in retaining rainwater in the process of stemflow. Classification is done by a qualitative approach. The classification has been made will affect to the digital interpretation process. Interpretation of land cover was performed digitally with multispectral supervised classification methods. Interpretation is done by using a composite image of 432 in order to easily recognize objects of vegetation and easily distinguish from other classes. Multispectral image classification using visible and near-infrared bands is effective for distinguishing vegetation density and land cover characteristics relevant to hydrological studies (Lillesand et al., 2015).

The selection of *ROI (Region of interest)* chosen in such a way in the pure pixels, which means the only one pixel is composed of 1 type of land cover so the selection of ROI will have a sample to a digital value that can differentiate pixel values on other land cover classification (Figure 7). Land cover field check conducted on a field point locations on the landform from volcanic processes (Figure 8). Accuracy test of land cover performed by comparing land cover classification in interpretation process with actual features in the field. Overall accuracy for multispectral classification of land cover is 88 %.

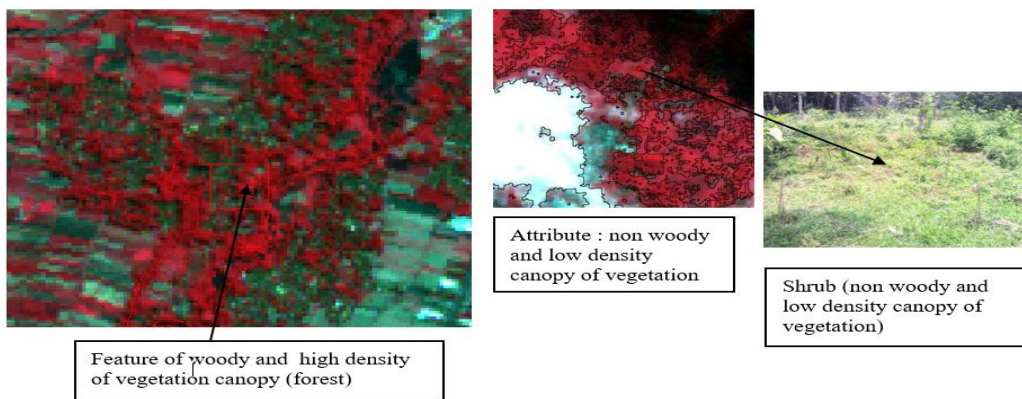


Figure 7. ROI selection and each features of high density canopy of vegetation

Figure 8. The comparison of multispectral classification in the image (left) and actual land cover in the field (right)

3.7. Groundwater Level Measurement in Dug Wells

The measurement of groundwater level in aquifers is to obtain the existing data of shallow groundwater potential in the field. It can be used as comparison on final model as shallow groundwater potential zone map (Figure 9). Water level measurements are performed on each field point that has been determined on the landform from volcanic processes that has sand materials and landform from solusional processes that has limestone as a materials.

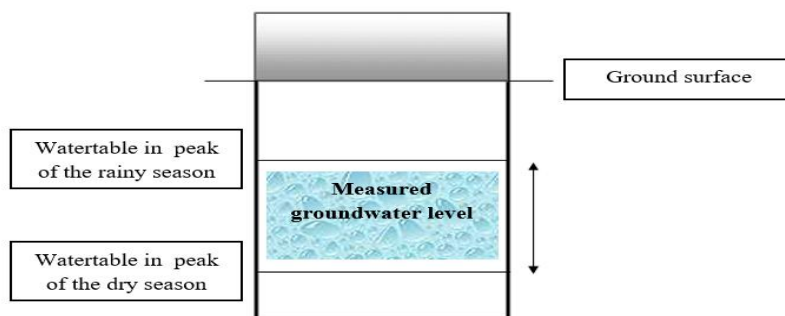


Figure 9. Groundwater level measurement in dug wells



The measurement of groundwater level in dug wells are conducted at 10 measuring points in the landforms from volcanic process (resulting +/- 1-5m water level) and 16 measuring points on the landforms from solusional process (resulting +/-1m water level). Most of the watertable depth on the dry season (measured from ground surface) is in the range of 2 to 9 meters in aquifer sand.

3.8. Shallow Groundwater Potential Zone Mapping in Bedog Sub Watershed

Shallow groundwater potential map is the final map which made from overlay process (matching methods). It is a processes that match terrain parameters as a data or map builder and distributed into shallow groundwater potential classes (Figure 10). Matching method which used is *Weighted Factor* methods. This method is considering the weight of each input to produce the final model. Input in the related processes is input of terrain parameters map that has attributes or class information. Matching process is only can be done on landform from volcanic processes which has probability to form sand aquifer because it allows the construction of a landform model that produces the final result, shallow groundwater potential zone map. Another thing that used as consideration is landforms from volcanic processes result aquifer material which has probability formed an aquifer with most sand materials. It is caused the landform from volcanic processec are landforms that has conformity and consistent related to parameters of land that influence it (shallow groundwater). While in the landforms from solusional processes, interpretation is only done to the border of landforms in visual way (not the development of terrain parameters). This landform restrictions are related to the barrier of potential groundwater that occurs on each dug wells as the measuring point. For groundwater level from field check, the data divided into 3 classes with regular interval classes method (appropriate to shallow groundwater potential zone map as a final map), (Table 5).

| Groundwater level | Class |
|-------------------|----------|
| +/- 0 - 1.6 m | Low |
| +/- 1.7 - 3.3 m | Moderate |
| +/- 3.4 - 5 m | High |

Table 5. Shallow groundwater level classes division in the field

The comparisons which are conducted produce the information about difference classes between shallow groundwater potential that occur in shallow groundwater potential zone map which is generated through the processing data and field measurements of groundwater level. The differences shown at Table 6.

| Field points | Landforms | In map | In field/groundwater level |
|--------------|-----------|----------|----------------------------|
| 1 | V4 | Low | Low = +/- 0 m |
| 2 | V4 | Low | High = +/- 4.75 m |
| 3 | V4 | Low | Low = +/- 1.5 m |
| 4 | V4 | Low | Moderate = +/- 3.2 m |
| 5 | V5 | Moderate | Moderate = +/- 3.06 m |
| 6 | V5 | Moderate | Moderate = +/- 3.06 m |
| 7 | V5 | Moderate | Moderate = +/- 2.31 m |
| 8 | V6 | Moderate | Low = +/- 1.45 m |
| 9 | V6 | Moderate | Low = +/- 1.23 m |
| 10 | F1 | Moderate | Moderate = +/- 3.24 m |

Table 6. The comparisons between shallow groundwater potential map with field measurement data

- Symbol information of landforms :
- V4 : Middle slope of Merapi volcano
 - V5 : Bottom slope of Merapi volcano
 - V6 : Foot plain of Merapi volcano
 - F1 : Alluvial plain of Merapi volcano

Groundwater level measurement data in field is data that can be used to correct the shallow groundwater potential final map. In this case there are a many things that should be considered. There are the possibility of error in measurement of groundwater level in the dug wells, especially when determining the lowest watertable at the peak



of dry season and pay attention to other things such as excessive use of groundwater potential that has impact on groundwater level in the field. The final map (shallow groundwater potential zone map in Bedog Watershed) regarding the measurement of groundwater level data on the dug wells has 60% of accuracy.

Pixel values information which are displayed visually in the colour/ shallow groundwater potential zone classification can be generalized to restrict the aquifer borders on each groundwater level. From upstream to downstream, the first border is a groundwater rare zone and there is no groundwater wells in this area. Location of tis zone is in Turi village, Manggungsari district, on the upper slopes to the middle slopes of Merapi volcano. Then in the downward area, the visualization of the pixel value has show into the most of low groundwater potential with 0,5 to 1,6 meters of level in the middle slope and bottom slope of Merapi volcano partly. Then in the lower area of the aquifer, it has been able to store groundwater potential in low to moderate scale, which has level about 0,5 to 3,3 meters on the bottom slope and foot plain of Merapi volcano. Further, groundwater potential in alluvial plains of Merapi volcano entered into aquifer with has moderate to high class which has about 3.3 to 5 meters of level. Each aquifer coverage depicted on the following table (Table 7):

Table 7. Aquifer classes in storing shallow groundwater potential

| Aquifer classes | Coverage (km ²) |
|--|-----------------------------|
| No aquifer/rare groundwater | 8.2 |
| Low groundwater potential aquifers. It has about 0.5 to 1.6 meter of level | 18.6 |
| Low to moderate groundwater potential aquifers. It has about 0.5 to 3.3 meter of level | 73.4 |
| Low to high groundwater potential aquifers. It has about 3.3 to 5 meter of level | 11.5 |

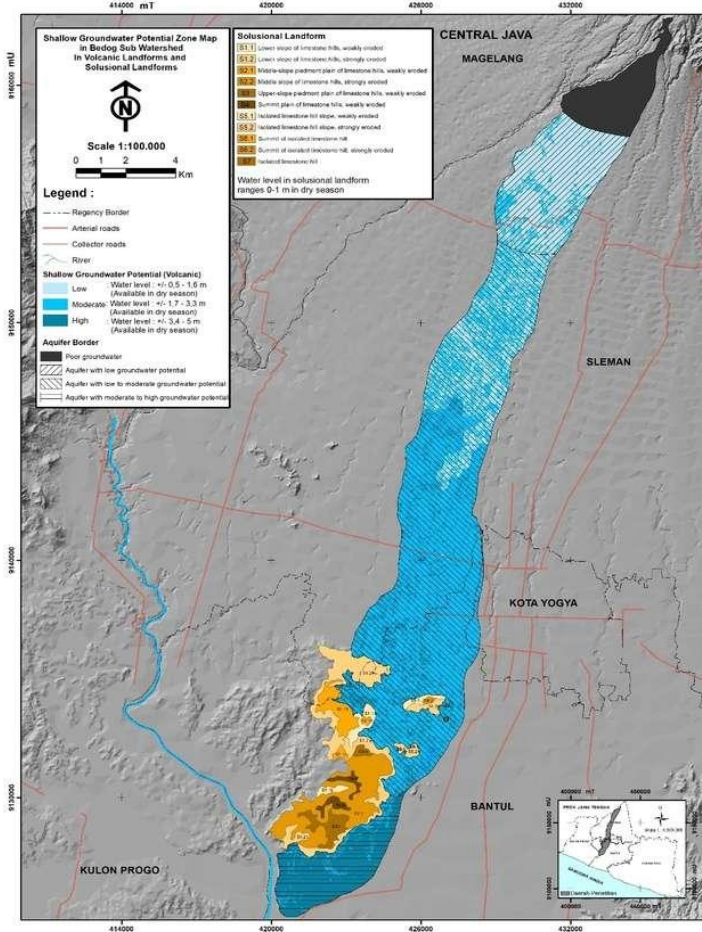


Figure 10. Shallow Groundwater Potential Zone Map in Bedog Sub Watershed



Groundwater potential that occurs at landforms from solusional processes are fully known through groundwater level measurements in dug wells in the field and didn't through a parametric approach (development of the final map by overlaying parameters in landform from volcanic processes). Therefore in solusional landform has varied groundwater potential in the field. The information about the diversity such as the drought of groundwater in dug wells in the dry season and some are still storing groundwater even in low level. There are dug wells that has a very high level in the rainy season and some are relatively equal to whole seasons and there are groundwater potential differences in the same landform in other locations and depth's diversity of the wells until meet the formations of rocks that can store water. Generally it can be seen at the landforms from solusional processes that the higher elevation where the wells is, there will be deeper wells were dug to get groundwater availability in the dry season.

4. CONCLUSION

Integration of remotely sensed data of ALOS - AVNIR 2 and Geographic Information System capable to producing shallow groundwater potential zone information in Bedog Sub Watershed through the accuracy of terrain parameters. For the parameters of soil texture, the accuracy are 75% . While the parameters for slope is 77.78 % and for land cover is 85%.

Groundwater level from volcanic processes with sand as a aquifer material produce three (3) classes of shallow groundwater. These 3 classes are able to be generalized to aquifer information that stored its groundwater potential. Groundwater Potential that stored in the each aquifer class are no aquifer or rare groundwater with an area 8.2 km² of coverage, low groundwater potential (groundwater level approximately 0,5 to 1,6 meters) with an area of 18.6 km² of coverage, groundwater potential with low to moderate (groundwater level approximately 0,5 to 3,3 meters) with an area of 73.4 km² of coverage and the last class is a groundwater with moderate to high potential (groundwater level approximately 3,3 to 5 meters).

Shallow groundwater potential from solusional processes in geological formations of Sentolo describes in varied conditions. The diversity of the phenomenon of groundwater potential in this area is the differences of groundwater potential information that displayed through the groundwater level in the same landform at another location. And then the diversity of well depth to found aquitard rock formations (rock formations that can store groundwater but limited to stream it). In this case aquitard was found in sandy clay texture.

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