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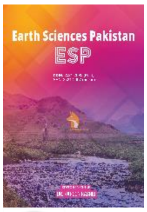

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RESEARCH ARTICLE

GROUNDWATER MODELING IN SANGON HAMLET AND SURROUNDING AREAS USING FINITE DIFFERENCE METHOD

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ABSTRACT

Sangon Hamlet is included in the mountains which are dominated by andesite rocks and volcanic breccias which cross each other and have a distribution of joints and faults forming a fracture. The fracture is a medium for draining water in the area. There is a difference in ground water level as seen from the well. To re-detail the groundwater flow that has been formed, a groundwater flow pattern modeling is carried out. The modeling is done by numerical method assisted by Modflow Flex Software. For building the model, it is necessary to prepare a concept model, calibration and validation. In this area there are 2 aquifer systems, namely unconfined aquifers and aquitards. Furthermore, the model was calibrated using the sensitivity analysis method. The calibration results are obtained, namely the RMS value of 8.74% with a standard error estimate of 1.27 m and a correlation coefficient of 0.98. From this model, it is known that the flow of water moves from the northwest-north area in the form of a plateau by heading to the east-southeast area which is a lower plain and towards the Plampang River.

KEYWORDS

Aquifer, Calibration, Fracture, Groundwater, Software

1. INTRODUCTION

The availability of groundwater in an area is the most crucial problem, considering that groundwater is the most important component in life sustainability. In some areas, especially in the plateau which are dominated by volcanic rocks, they are often faced with major challenges regarding groundwater that is difficult to obtain. However, in fact, not all plateau areas have water shortages, and even a lot of water potential can be found if these problems can be analyzed according to the existing ground water flow concept. This groundwater flow research was conducted in Kalirejo Village, Kulon Progo, Yogyakarta. The area is located at an altitude of 50-450 m above sea level and has a undulating and hilly physiography. Kalirejo Village is formed from the Old Andesitee Formation, where the lithological composition of the area is dominated by crosses between volcanic breccia, Andesitee, and alluvial rocks resulting from rock weathering.

Geological structures such as joints and faults are often found in the study area, where the presence of fractures is the most important thing in the process of flowing groundwater in volcanic rocks. To be able to know the concept of groundwater flow in the area, a groundwater modeling is carried out using the Finite Difference method, by building a visual using Modflow Flex software. In this study, it is expected to provide results in the form of information regarding conceptual hydrostratigraphy and prediction of groundwater flow patterns in the research area, so that the results of these studies can be used as a reference in proper and correct exploitation of groundwater.

2. LITERATURE REVIEW

In previous studies, groundwater modeling has been widely used in cases of water availability in an area (Aghlmand, 2019). Building a model aims to provide an approach to complex field conditions into a simpler numerical calculation. However, the level of accuracy of a model is largely determined by its simplification value based on various assumptions used when modeling. The model will have a low accuracy value if it uses a lot of assumptions. The concept of groundwater modeling was discovered by Darcy. The component observed in the groundwater concept is the difference in the hydraulic head used to find the direction and speed of flow based on Darcy's Law (Masud, 2002). According to Darcy's Law, the hydraulic conductivity of rocks is an important property in the movement of groundwater. For cases on a field scale, a simplification with numerical calculations is needed, namely the Finite Difference method. The form of the Finite Difference equation is written by replacing the partial derivative of the differential equation representing 3D groundwater flow for heterogeneous and anisotropic conditions: (Anderson, 2015).

$$\frac{\partial}{\partial x}\left(Kx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Ky\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kz\frac{\partial h}{\partial z}\right)\pm W = Ss\frac{\partial h}{\partial t}$$

where,

Kx, Ky, Kz = Hydraulic conductivity in the x,y,z directions

h = Ground water level

W= Flux by calculating the adding factor, for example: pumping or adding from other sources.

Ss = *Specific storage*

x, y, z = Coordinate direction

t = Time

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In this research, groundwater flow pattern modeling is assisted by Modflow Flex software. The modeling stages consist of making a conceptual model, determining model boundary conditions, calibration and model validation.

2.1 Conceptual Model

The conceptual hydrogeological model is a representation of the groundwater system combined with the interpretation of geological, hydrological, and water balance conditions. Such models can provide information on subsurface characteristics and help reduce uncertainties governing groundwater flow and contaminant transport in the study area (Torres, 2020).

2.2 Model Boundary Conditions

Numerical simulation boundary conditions are used to describe the physical condition of the seepage boundary, namely the condition of the groundwater table which is considered constant from the seepage area. Rainfall infiltration is the main source in the study area (Xie et al., 2020). Boundary conditions are obtained based on natural conditions that support the research area, such as mountainous areas, stratigraphic layer boundaries, contours, lakes and rivers, because they are easier to identify and conceptualize.

3. Model Calibration and Validation

The results of numerical calculations in the software have differences when compared to actual conditions in the field, so that some errors will be found during the modeling process. Therefore, the model is calibrated to suit the conditions in the field. During the calibration process in this modeling, the value of the hydraulic conductivity or groundwater recharge will be adjusted in the model according to the simulated groundwater level and the measured groundwater level. This calibration will compare the hydraulics head calculated by the Modflow simulation with the Root Mean Square Error (RMSE) method that is available in the software. The calibrated model must give a result that is a minimum RMSE value and has a match between the head measured in the field and the modeled one (Tahershamsi, 2018). If it has been calibrated, then the model has been validated and is ready for the next stage, namely prediction of groundwater flow patterns.

4. Research Methodology

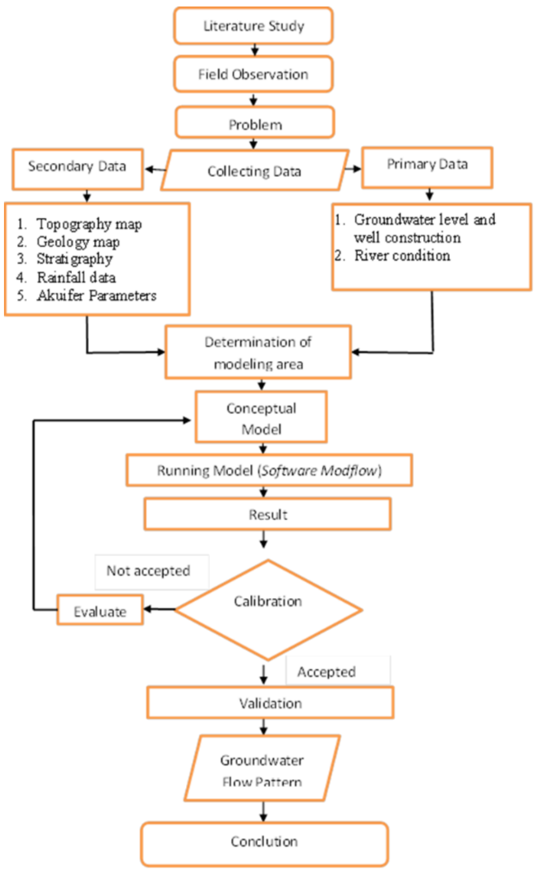

Figure 1: Research Flow Chart

The initial step taken is non-field activities including literature review activities on themes related to research. Literature study covering the theoretical basis of geological and hydrological conditions of the research area, as well as groundwater modeling techniques and software to be used. Next, field observation includes activities in the form of direct observation of conditions, problems, and factors that influence the research. Followed by secondary data collection.

4.1 The second step is taking primary and secondary data in the field

4.1.1 Secondary Data

Secondary data were obtained from the literature (previous research) and from related agencies. The data needed to support this research include :

- Recharge. The research area has a recharge of 226 mm/year.
- Stratigraphy and geology of the research area. According to the results of a detailed geophysical exploration survey of ESDM D.I. Yogyakarta in 2020, which was obtained from the correlation between 3 geoelectric points in each hamlet, namely Sengir Hamlet, Sangon 1 Hamlet, and Sangon 2 Hamlet (Figure 2). The stratigraphic composition of the study area and its surroundings is in the form of volcanic rock, namely altered rock, Andesitee, and volcanic breccia with different thicknesses (Table 1) and (Figure 3).

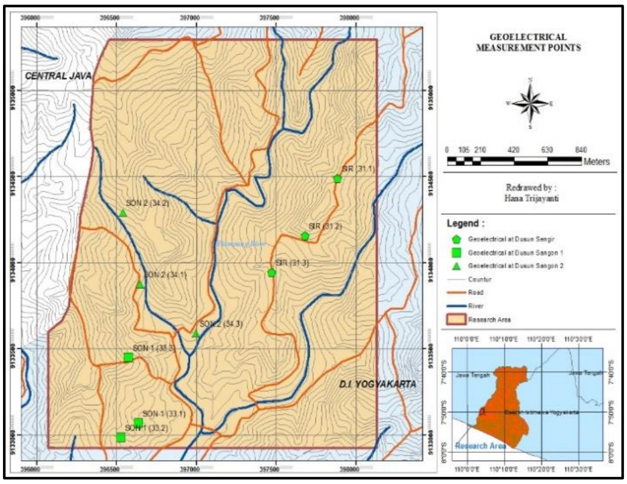

Figure 2: Map of Geoelectrical Measurement Points

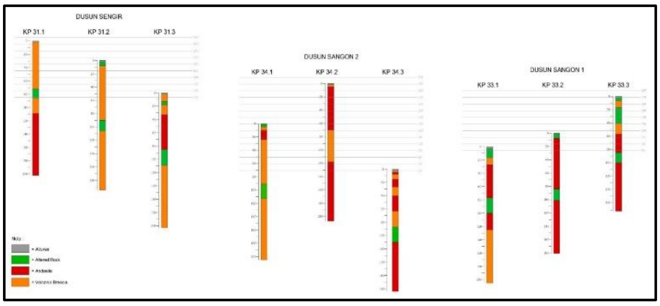

Figure 3: Geoelectrical Point Correlation (ESDM D.I. Yogyakarta in 2020)

Primary data collection can be seen in Table 1 and Field data collection points can be seen in Figure 2.

Table 2: Primary Data and Parameters

No.	Primary Data	Parameters
1	Groundwater	a. Coordinate position of resident well b. Well condition (well diameter and depth) c. Physical and chemical conditions of groundwater in the well
2	River flow	a. River width b. River water level/elevation c. River water depth

Table 1: Geoelectric Mapping Data for Sengir Hamlet, Sangon 1 Hamlet, and Sangon 2 Hamlet (ESDM D.I. Yogyakarta in 2020)

POINT		X	Y	ELV	LAYER	DEPTH (m)	THICKNESS (m)
Sengir	**31.1**	397884.7	9134491	255	Soil	0-1	1
					Volcanic Breccia	2-72	70
					Altered Rock	72-86	14
					Volcanic Breccia	86-109	23
					Andesite	109-202	93
	31.2	397680.2	9134159	226	Soil	0-2	2
					Altered Rock	2-8	6
					Volcanic Breccia	8-90	82
					Altered Rock	90-106	16
					Volcanic Breccia	106-195	89
	31.3	397472.4	9133946	177	Soil	0-2	2
					Volcanic Breccia	2-13	11
					Altered Rock	13-18	5
					Volcanic Breccia	18-37	15
					Andesite	37-85	52
					Altered Rock	85-109	24
					Volcanic Breccia	109-203	94
Sangon 1	**33.1**	396635.2	9133066	96	Soil	0-3	3
					Altered Rock	3-17	14
					Volcanic Breccia	17-27	10
					Andesite	27-77	50
					Altered Rock	77-100	23
					Andesite	100-125	25
					Volcanic Breccia	125-205	80
	33.2	396525.1	9132986	116	Soil	0-1	1
					Altered Rock	1-8	7
					Andesite	8-84	76
					Altered Rock	84-101	17
					Andesite	101-181	80
	33.3	396573.1	9133450	172	Soil	0-2	2
					Altered Rock	2-7	5
					Volcanic Breccia	7-17	10
					Altered Rock	17-41	24
					Volcanic Breccia	41-57	16
					Andesite	57-85	28
					Altered Rock	85-100	15
					Andesite	100-173	73
Sangon 2	**34.1**	396645.6	9133877	131	Soil	0-1	1
					Altered Rock	1-5	4
					Volcanic Breccia	5-10	5
					Andesite	10-24	14
					Volcanic Breccia	24-91	67
					Altered Rock	91-113	22
					Volcanic Breccia	113-205	92
	34.2	396537.5	9134291	191	Soil	0-2	2
					Volcanic Breccia	2-5	3
					Andesite	5-70	65
					Volcanic Breccia	70-118	48
					Andesite	118-207	89
	34.3	396998.5	9133589	63	Soil	0-3	3
					Volcanic Breccia	3-5	2
					Andesite	5-8	3
					Volcanic Breccia	8-15	7
					Andesite	15-27	12
					Volcanic Breccia	27-40	13
					Andesite	40-63	23
					Volcanic Breccia	63-87	24
					Altered Rock	87-110	23
					Andesite	110-184	74

4.1.2 Groundwater

Groundwater data collection includes:

- measurement of construction and groundwater level. Data collection was carried out on 7 wells by taking into account the point of existence of the wells, namely estimates of wells located at a higher elevation and at a lower elevation.

- Position coordinates, with GPS (Global Position System).

- Measuring the diameter of the well with a meter.

4.1.3 River Data

River data collection includes:
- River water level/elevation, with GPS (Global Position System).
- Depth of river water.
- Physical conditions, by observing the height of the river slopes using a meter.

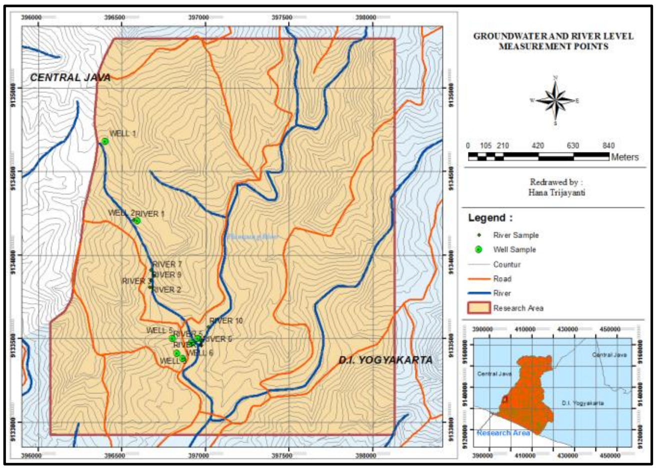

Figure 4: Map of Groundwater and River Level Measurement Points

The geological structures that developed in the research area are in the form of joint structures and brecciation in Andesitee rocks, tensile joints and faults in the form of shear joint that are not filled with minerals, shear faults with a southeast-northwest longitudinal direction, normal faults with a west-east direction are also found. around the Andesitee and dacite breakthrough dome bodies. The analysis of the Sangon fault resulted in the position of the N265°E/32° fault plane opening to the east with the name Right lag slip fault based on Richard's classification, 1972, which can be seen in Figure 5 (Widagdo et al., 2017). The existence of faults and joints that are relatively tight, makes the rock cracks and splits apart. Rocks that are dominated by cracks result in the emergence of a groundwater flow medium so that it can fill the cracks in the rock. This is related to the geological structure and complex geological conditions (Cahyadi, 2017). Therefore, the aquifer system in the study area can be classified as a fractured volcanic aquifer. In this aquifer, there are several springs through a gap system, with generally small flow rates, between 2 and a maximum of 10 L/second. This shows that the aquifer has low permeability (Kusumayudha, 2010).

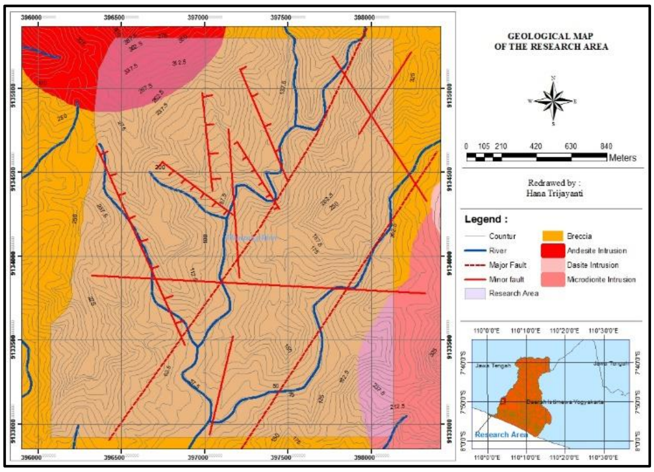

Figure 5: Geological Map of the Research Area

5. Finding and Discussion

From data collection and development of field observations, obtained results that can support the modeling process.

5.1 Aquifer Characteristics

The main characteristic of the aquifer is the value of hydraulic conductivity. In this study, the value of hydraulic conductivity is determined by building assumptions from the data of previous studies conducted in different places but with almost the same rock formation. The method used in determining the value of the hydraulic conductivity is the packer test. The results of the hydraulic conductivity values obtained are listed in Table 3.

Table 3: Hydraulic Conductivity Value (Golder,1999)

Material	Hydraulic Conductivity (ms^{-1})
Soil	$8x10^{-2}$
Altered Rock (Weathered Rock)	$8x10^{-4}$
Andesite	$2,79x10^{-6}$
Volcanic Breccia	$1,25x10^{-8}$

Based on this value, it is known that the hydraulic conductivity in the study area can be different in each lithological layer, which is between $1,25x10^{-8}$ to $8x10^{-2}$. This can be influenced by the type of rock and the influence of the geological structure.

5.2 Hydrostratigraphy of Research Area

Rocks in the study area are dominated by volcanic rocks which can be grouped into 4 types of lithology, namely soil, silt, andesite, and volcanic breccia. These rocks have experienced many crossing positions to insertions caused by geological structural factors. The presence of strong joints and faults were found in almost the entire study area. From these types of lithology and structures, it is possible to group rock layers into a large group of a groundwater-carrying system called a hydrostratigraphic unit (Table 4).

5.3 Groundwater Elevation

The measurement results show that the groundwater level in the study area has variations in groundwater level, ranging from 0.66 to 3.56 m from the ground surface (Table 5).

5.4 Groundwater Modeling

5.4.1 Conceptual Model

An understanding of the groundwater system is carried out by analyzing the hydrological and hydrogeological conditions. The analysis aims to develop a conceptual or basis for building a model in the research area, so as to obtain accurate results and represent the actual situation in the field. Morphologically, the research area is at an elevation of 50-450 meters above sea level. The highest elevation is in the North-West part, while the lowest elevation is in the South-Eastern part. Most of the research area is in the form of medium to high plains in the form of hilly and undulating topography.

Hydrologically, there is one small river near the mining area that flows into a large river, the Plampang River. These rivers flow from the northwest to the southeast. The Plampang River is used as a hydrogeological boundary in groundwater modeling. Meanwhile, the mining area and tailings pond are in the center of the model research area. Geologically, the research area is in the Old Andesite Formation. Based on the correlation of geoelectrical data, the Old Andesite Formation is dominated by volcanic rocks, such as alluvial rocks, breccias and andesites that cross each other and have different thicknesses. In the research area, many geological structures were found, such as joints and faults, which play a role in the formation of heterogeneous rock compositions and as a medium for groundwater flow that enters through cracks in volcanic rocks.

Hydrogeologically, alluvial which is weathered rock from volcanic rock becomes an aquifer layer that can store and release groundwater, which is also supported by the presence of fractures in volcanic rock. Therefore, there are two aquifer layers, namely the upper alluvial group as the unconfined aquifer, and the volcanic rock group that has cracks as the semi-unconfined aquifer. Unconfined aquifers are in the form of sediments that vary in thickness from 1-14 meters, while semi-unconfined aquifers have a thickness of 5-10 meters. The base of the aquifer in the study area is volcanic breccia which belongs to the Old Andesite Formation.

Tabel 4: Hydrostratigraphy Unit								
Location Name	**Geoelectric Point Data Code**	**X**	**Y**	**Top Elevation (masl)**	**Thick (m)**			**Aquifer Type**
					Layer 1	**Layer 2**	**Layer 3**	
Sengir	31.1	397884.7	9134491	255	107	52	0	Unconfined aquifer
	31.2	397680.2	9134159	226	105	0	90	Aquitard
	31.3	397472.4	9133946	177	35	50	115	Bedrock
Sangon 1	33.1	396635.2	9133066	96	25	52	75	Unconfined aquifer
	33.2	396525.1	9132986	116	7	173	0	Aquitard
	33.3	396573.1	9133450	172	55	115	0	Bedrock
Sangon 2	34.1	396645.6	9133877	131	112	0	93	Unconfined aquifer
	34.2	396537.5	9134291	191	117	88	0	Aquitard
	34.3	396998.5	9133589	63	87	96	0	Bedrock

Table 5: Measurement of Groundwater Level				
Well Code	**Coordinate point**		**Elevation (mdpl)**	**Groundwater Elevation (m)**
	X	**Y**		
Well 1	396402.5	9134683	255	1.33
Well 2	396595.9	9134206	183	0.8
Well 3	396831.7	9133412	84	1.24
Well 4	396954.6	9133501	68	3.56
Well 5	396805.1	9133501	96	5.1
Well 6	396866	9133382	68	0.66
Well 7	396919.4	9133475	68	1.38

5.4.2 Model Calibration and Validation

The calibration process uses a sensitivity analysis method (trial and error) to adjust the hydraulic conductivity values in the model to actual conditions (Table 6). From the calibration results, the RMS value is 8.74% with a standard error estimate of 1.27m and a correlation coefficient of 0.98 (Figure 6), meaning that the model made has been validated and has a high level of accuracy and is stated according to conditions in the field.

Table 6: Model Calibration Parameters		
Parameter Input	**Uncalibrated Model**	**Calibrated Model**
K1 (Alluvial)	$8x10^{-2}$	$2x10^{-4}$
K2 (Andesite)	$2,79x10^{-6}$	$2,78x10^{-7}$
K3 (Volcanic Breccia)	$1,25x10^{-8}$	$1,25x10^{-8}$
K4 (Frakture)	$8x10^{-1}$	$2x10^{-3}$
Recharge	226 mm/year	300 mm/year

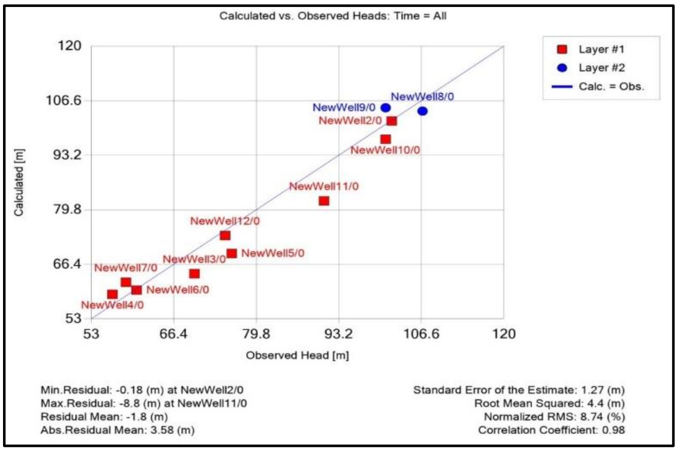

Figure 6: Calibration Results

The model that has been validated can be seen the pattern of groundwater flow (Figure 7). It is known that in this study it was found that the catchment area is in the northwest-north area which is a higher plain, so that the flow forms a flow pattern flowing towards the east-southeast area which is a lower plain and enters the Plampang big river.

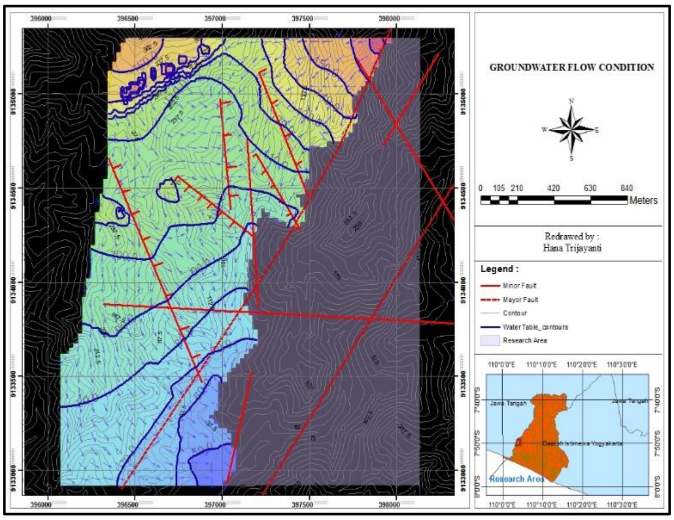

Figure 7: Map of Groundwater Flow Condition

6. Conclusion

The research area belongs to the mountains which are dominated by andesite rocks and volcanic breccias which have undergone endogenous processes in the form of tectonic phenomena shown by rock crossings due to the role of geological structures that are often found in the field, namely joints and faults that form a fracture. The fracture becomes a medium for draining water in the area. This can be seen in the difference in ground water level that can be seen from the well. So, to detail the groundwater flow that has been formed, a groundwater flow pattern modeling is needed. The modeling is done by numerical method assisted by Modflow Flex Software. The first modeling stage is to form a model concept by classifying the aquifer system and determining the model boundaries and the location of the major fractures in the area. It was found that there are 2 aquifer systems, namely unconfined aquifers and aquitards. The model is then calibrated.

The calibration results are obtained, namely the RMS value of 8.74% with a standard error estimate of 1.27m and a correlation coefficient of 0.98, which means that the model has been validated and has a high level of accuracy. From this model, it is known that the flow of water moves from the northwest-north area in the form of a plateau by heading to the east-southeast area which is a lower plain and towards the Plampang River. In developing research on groundwater, this step can be applied in various regional conditions, not only applied to hard rock, but also to relatively soft rock. The application of the methods and software used is not only able to calculate groundwater flow patterns, but can also be applied to various cases, such as being able to predict the movement of contaminants in groundwater, seawater intrusion, and groundwater utilization rates in urban and industrial areas.

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