GROUNDWATER MODELLING TO PREDICT FLOW AND NEGATIVE IMPACTS OF GROUNDWATER ABSTRACTION IN MAKASSAR CITY SOUTH SULAWESI

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ABSTRACT

This study titled groundwater modeling to predict flow and negative impact of groundwater abstraction in Makassar which aims to create a model of groundwater flow patterns and predict a negative impact of groundwater exploitation on the shallow aquifer in Makassar such as a decline of groundwater level and increase of sea water intrusion in the future. Hydrological and hydrogeological data such as rainfall, temperature, evapotranspiration, infiltration of groundwater, aquifer conductivity, and geometry of the aquifer were collected in order to understand the groundwater natural system as a basic to make the conceptual model of the study area. From this conceptual model, numerical models created and run to obtain results of groundwater modeling, it is groundwater flow patterns. The results of modeling then calibrated on field data to obtain the value of the model error and parameter sensitivity analysis is then performed to obtain a smaller error value so that the model is ready to be applied.

Keyword: groundwater modelling, groundwater level decline

NTRODUCTION

Along with the development and rapid advancement of Makassar, Makassar was also experiencing some problems, one of them is clean water. The increasing of population and industrial development led to increased demand for groundwater and directly cause negative impacts on the availability and quality of groundwater, one of them is groundwater level decline.

Groundwater sources most widely used by the public is groundwater in the shallow aquifer (depth of ± 50 meters) because of the easy to get it. Therefore, groundwater in the shallow aquifer is that susceptible to negative impacts, namely a decline in groundwater table elevation.

To reduce the negative impact of the use of groundwater in the city of Makassar in the future, it is necessary to create a model for the shallow aquifer in the study area as a frame of reference that can be used as a consideration tool in the management of groundwater for sustainable development and solving problems related to groundwater.

Regional geology of research area refers to the Geological Map Sheet Ujung Pandang, Benteng, and Sinjai by Sukamto and Supriatna 1982. Geomorphology of study area consists of alluvial plains and coastal morphology and morphology of weak-strong undulating hills. Stratigraphy of the study area consists of alluvium and coastal sediments, volcanic rocks Baturappe-Cindako, basalt and basalt dikes, and Camba Formation. According Mudiana, et al., 1982, regional hydrogeology of study area showed that the study area is part of Makassar groundwater basin with aquifer productivity good to lower. Sediment of alluvium and coastal is a productive aquifer formations and volcanic rock Baturappe-Cindako and Camba Formations is an aquifer formations with low productivity.

Groundwater is an integral part of the hydrological cycle. Groundwater conditions of an area also is determined by hydrological conditions. Hydrology such as level of rainfall, evapotranspiration, runoff, and infiltration. Groundwater is water located beneath the ground surface layers that contained in the layer of water-saturated zone. In Rahardjo (2002), based on the its hydraulic value, rocks can be classified into four types, namely aquifers, aquitard, aquiclude, and aquifug. Aquifer is a layer that can store and discharge large amounts of groundwater. Productive or not an aquifer is largely determined by the characteristics of the aquifer such as porosity, hydraulic conductivity, transmissivity, specific yield, and storativity. In view of the value of hydraulic conductivity, aquifer can be divided into four types, namely unconfined aquifers, semi-unconfined aquifer, confined aquifer and semi-confined aquifer.

Groundwater model is a tool to describe the complex groundwater conditions in nature into a simple mathematical form. Modeling aims to know the condition of groundwater in nature and as a tool to overcome the problems related with groundwater. According to Spitz and Moreno (1996), in designing groundwater models must combine some components of modelling, namely data collection, natural system design and conceptual models, determination of mathematical models, solutions, calibration, and simulation. In making the model also needs to know the boundary conditions of modeling areas such as head control, flow control, and no flow boundary.

Groundwater is a limited resource. Therefore, groundwater exploitation continuously can result in negative impacts. The negative impact that often happens is a decline in groundwater level. When groundwater is exploited, groundwater level will decrease and continue to decrease until it reaches equilibrium at a lower level or if exploitation of groundwater carried out continuously until exceeds the infiltration rate, the aquifer will dry. Large decline of groundwater level can lead to dryness of the shallow wells, pumping costs are increasing, decreasing the efficiency of the well, need to deepen or replace the well, and the intrusion of sea water (UNEP-DEWA, 2003).

RESEARCH METHODOLOGY

Generally this research is divided into five stages : the preparation stage, field investigations, modeling stage, results and discussion, and conclusion. The preparation stage[(1)] in the form of problem formulation, literature review and secondary data collection in the area of research, secondary data namely topographic maps, meteorological data (rainfall and temperature), the regional geology map skala1:250.000, regional hydrogeology map 1:250.000, boreholedata, population data, and the well pump test data.

Field investigation[(2)] in the form of groundwater table elevation measurements to determine the pattern of groundwater flow and calibration process of modeling results, the groundwater table elevation measurements, the data should be taken systematically in order to be representative to the study area, so be able to describe the actual condition of research area and measurement of the river to determine the leekage factors/ surface water leaks into groundwater. The parameters measured in the measurement of the river is the length, width and depth of the river, also take samples of river bed sediments to estimate vertical hydraulic conductivity values. Values parameters above used to calculate the conductance of the river that describes the relationship between surface water and groundwater.

Modeling phase [(3),] the model is

designed based on existing data. This stage consists of four parts: the analysis of data, secondary data and primary data were analyzed to obtain the data input/parameter in modeling. Run models, in this section will be obtained the result of modelling in the form of groundwater flow patterns. Calibration of the model, the process of comparing the value of groundwater table elevation observations and calculations, the results of calculations must show correlation with the results of observation.Model applications, in this section, the calibrated model, applied and simulated toproblems that occurred in the study area. Stage results and discussion [(4),] this stageis to discuss the results of study according to research problems. Stage conclusion[(5),] this stage concludes the discussion and should be suitable with the objectives and the research hypothesis.

CHARACTERISTICS OF RESEARCH AREA

The City of Makassar located at elevation varies between 0-25 meters above sea level. Makassar City is a flat coastal area with the slope level of 0-15%. Meanwhile, based on the classification of the slope, mostly located on the slope of 0-8%. Makassar City flanked by two rivers namely Tallo rivers and Jeneberang river with the outfall in the western part of the City of Makassar. For morphological conditions, the generally morphology of Makassar can be divided based on the forms of relief, topography, and rock constituent to several units of morphology, namely: weak undulating hills morphological unit, morphological unit of notched plain inundation, flood plains morphological units, and the plains and coastal morphological unit.

Lithological characteristics of Makassar City is divided into two formations of volcanic rock, volcanic rocks in the study area derived from Camba Formation (Tmc) which is interspace between marine sedimentary rocks and volcanic rocks and formations Baturape-Cindako (Tpbv) consisting of lava, breccia, tuff, and conglomerate and alluvial and coastal deposits (Qac), this deposits consists of a mixture of clay, silt, sand, gravel that has not been consolidated. The alluvial deposits include current coastal sediment, the sediment of the river and marsh sediment.

Besides from geological maps to describe the lithology of study area, especially subsurface lithology used borehole data that has been obtained in the study area. From the borehole data is known that in the study area consists of several lithofacies such as sandy clay, fine-coarse sand deposits, clayey sand, sandstone, and siltstone.

Hydrological conditions of the study area is known from meteorological data such as rainfall, evapotranspiration, runoff, and infiltration. The rate of annual average rainfall obtained from data collected for 11 years from 2003 to 2013 from Meteorology Climatology and Geophysics Board of Makassar is 2905 mm/year. Evapotranspiration values by Turc equation obtained 1721.86 mm/year.The amount of surface water runoff is calculated using the method of Sharma and surface runoff water in research areas is obtained by 46.90 cm/year or 469 mm/year. The level of infiltration of the study area is calculated based on the simple concept of the groundwater balance, therefore obtained values of groundwater infiltration in the study area is 714.14 mm/year or 24.58% of the annual average rainfall.

From the results of measurements of groundwater table shows that the groundwater flow pattern of the study area moves to the sea. Hydrostratigraphical condition of research area known from the borehole data that consisting aquifer from fine sand, silty sand, and sandstone materials, aquitard from sandy clay materials, and aquiclude form siltstone layer. Aquifer consists of two types, namely the unconfined aquifer and semi-unconfined aquifer. Siltstone refers as the base of aquifer systems in research area. Conditions of seawater intrusion in study area based on the principle of Ghyben-Herzberg has reached distance approximately 2.5 kilometers into the groundwater aquifers in the study area.

ANALYSIS AND DATA PROCESSING

Conceptual model of the research area consists of hydrological and hydrogeological boundary. Referring to the hydrogeological conditions of the study area, types of aquifers in the area of the model consists of two types of aquifers are unconfined aquifer and semi-unconfined aquifer. Hydrogeological boundary in the study area are two rivers that serve as a model boundary. Two rivers that act as river and sea as a constant head, and the model boundary in the east side, the presence of hills formed by volcanic rocks considered as impermeable layer areas/impermeable zone and serve as no flow boundary.

Infiltration of groundwater in the study area is only taken from infiltration by rainfall. The value of groundwater infiltration into the aquifer is 714.14 mm/year and evapotranspiration value is the value of the actual evapotranspiration occurring in the field, this evapotranspiration value of 1721.86 mm/year, the value of infiltration and evapotranspiration are also used as input parameters (boundary) in this research.

Model area covers 128.8 km^2 located between E764728.923-E775745.3092 from east to west and S9424700.69-S 9435684,279 from south to north. In this study used finite difference grid. Model area descritisized into the unit cell of 100×100 m^2.

After the model has been descritisized, all parameters have been entered, so the model is ready to run. The modeling results firstly obtained named uncalibrated models, with 8.49% of error value. Parameter values need to be changed to obtain a smaller error value, in this case the value of recharge and hydraulic conductivity, the results of this model is called the calibrated model and obtained an error rate of 7.674%. The modeling results show that the groundwater flow moving toward the sea in the model area.

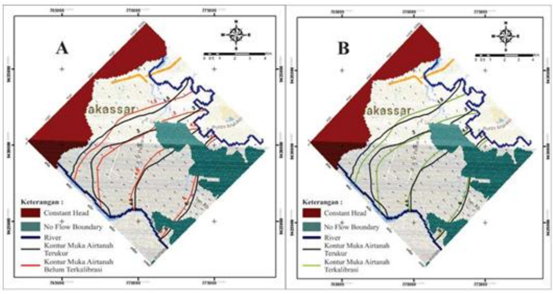

Figure 1 Groundwater flow pattern (A) Not calibrated (B) Calibrated

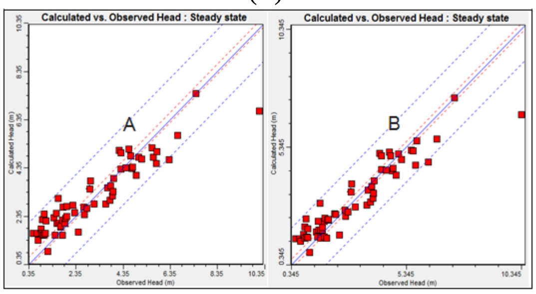

Figure 2 Graphic of *Calculated vs Observed Head*. (A) Not calibrated (B) Calibrated

MODEL APPLICATION

To apply the model, it will require other information such as population density and land use. This information is needed to determine the location of the pumping and use of groundwater for pumping discharge. The population density in the city of Makassar around 8000 people/km^2. The pattern of population distribution occurs unevenly, accumulated in the center of city and city growth centers. In terms of land use, residential area is land-use with the largest area in the study area. This is because the population density of Makassar which is quite large. To simulate the model in years 2018, 2023, 2033, and 2043, need to know prediction of the growth of population in the model area to estimate the needs of domestic groundwater. Prediction of population growth is determined by the rate of population growth is shown in **Table 1.**

Table 1 Projection of Population Growth in Makassar City

Year	Projected Population
2018	1270295
2023	1387448
2033	1655165
2043	1974539

In the research area, groundwater use only about 15.17% of the total population. Assuming the use of groundwater in the study area of about 147 L/s. Pumping scenarios are shown in **Table 2** as follows:

Table 2 Scenario pumping groundwater research area

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year	2018	2023	2033	2043
Population	192 704	210 476	251 089	299 538
Use of Groundwater (m^3 / day)	28304	30 915	36 880	43 996
Number of wells	10	10	10	10
The well pump discharge (m^3 / day)	2830	3092	3688	4400

After simulating the scenario above, therefore obtained value of the decline in groundwater level in the study area. In 2018 the average groundwater level decline is 0.55 m, in 2023 amounted to 0.82 m, in 2033 is 153 m, and in 2043 amounted to 2.095 m.

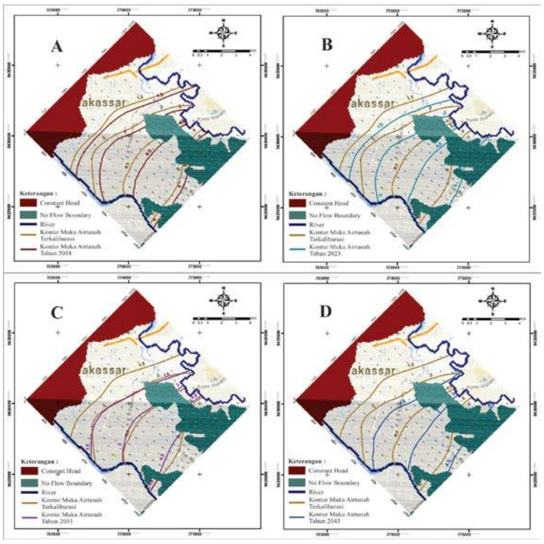

Figure 3 Groundwater level decline. (A) in 2018, (B) in 2023, (C) in 2033, (D) in 2043

CONCLUSIONS AND RECOMMENDATION

Conclusion

From the results of this study can be made some conclusions based on the objectives to be achieved, namely:

1. The pattern of groundwater flow in shallow aquifer based on the result of groundwater modeling is moving towards the sea/beach in Makassar Strait in area of research.
2. The value of groundwater level decline in shallow aquifer in the study area based on the results of the model application for some scenarios run in 2018 is an average of 0.55 meters, in the year 2023 amounted to 0.82 meters, in the year 2033 of 1.53 meters, and

in the year 2043 amounted to 2.095 meters. Value of decline in groundwater level is different for each place in the study area.

Recommendation

The result of this research is prediction of groundwater level decline in studt area, model run in steady state condition, for a better result of modeling must consider factor of time, so recommended to make model in unsteady state condition.

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