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Determination of Groundwater Flow Pattern in Jombang Regency, East Java, Indonesia

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Abstract— Groundwater is a natural resource which moves following the hydrological cycle and its existence is hidden below the soil surface. In order to be beneficially used, the flow pattern of groundwater potential is an important aspect. Determination of groundwater flow patterns can be done by modeling. The objective of this study was to determinate the groundwater flow pattern in the study area. Modeling of groundwater flow pattern in the study area was based on the data of 70 wells scattered in Jombang regency, with variations in the depth of 50–127 m BGL on confined aquifer. Groundwater flow modeling was done using a computer program package Visual MODFLOW 2011.1 (demo version/a trial lisence). The output of the model was the groundwater flow pattern in the study area, has been calibrated by comparison of the ground water level measured by the groundwater level depiction of the model results based on criteria: correlation coefficient = 0.989, root mean square error = 2.97 m, and mean absolute percentage error = 4.75%. Groundwater flow pattern in the study area flows from areas with high topography in the Southeast section of the study area leading to an area with lower topography that is to the Northwest and to the North which is ended in the Brantas River as a natural hydrological boundaries of the study area.

Keywords— Flow pattern, groundwater, Jombang regency, modeling.

INTRODUCTION

Jombang regency, East Java province of Indonesia is one of the areas where the potential for groundwater has been developed for irrigation purposes [11]. The groundwater is a natural resource which moves following the hydrological cycle and its existence was hidden below the soil surface. The existence and potential of groundwater are important to determine in order to use its potential for irrigation. One important aspect of the existence and potential of groundwater is the flow pattern.

In effect of existence of groundwater is hidden under the ground surface, flow pattern is very difficult to trace when using a system analysis approach. Related to aspects of the presence of groundwater, the determination of groundwater flow pattern can be done in a way to model it. Several researchers used modeling techniques to analyze the flow of groundwater such as Amah and Agbebia [1], Jafar et al. [2], Kaviyarasan et al. [3], Okengwu and Nyenke [6], Oseji [7], Oseji and Ofomola [8], Tirtomohardjo and Setiawan [12], Waheedullah et al. [13], and Waspodo [14].

Generally, these studies basically showed the same results, that groundwater flows areas with high topography leads to the area with low topography. The difference from those studies is that the groundwater flow pattern in each study area are affected by the condition of the geomorphology of each study area.

The objective of this study was to determine the groundwater flow pattern in Jombang regency, East Java, Indonesia. The benefits expected from this study were to find out wheter the groundwater flow pattern is able to use as a source of irrigation water in the study area and it can be used as a guide in the management of groundwater in the future.

DESCRIPTION OF THE STUDY AREA

The study area falls in Jombang regency, East Java Province, Indonesia. The study area is located between latitudes of 7˚26'3.84" – 7˚46'58.08" S and longitudes of 112˚05'4.92" – 112˚28'11.28" E. The total region of the study area covers 803.06 km^2 and consists of 16 districts in Jombang regency. Map of the study area is given in Figure 1.

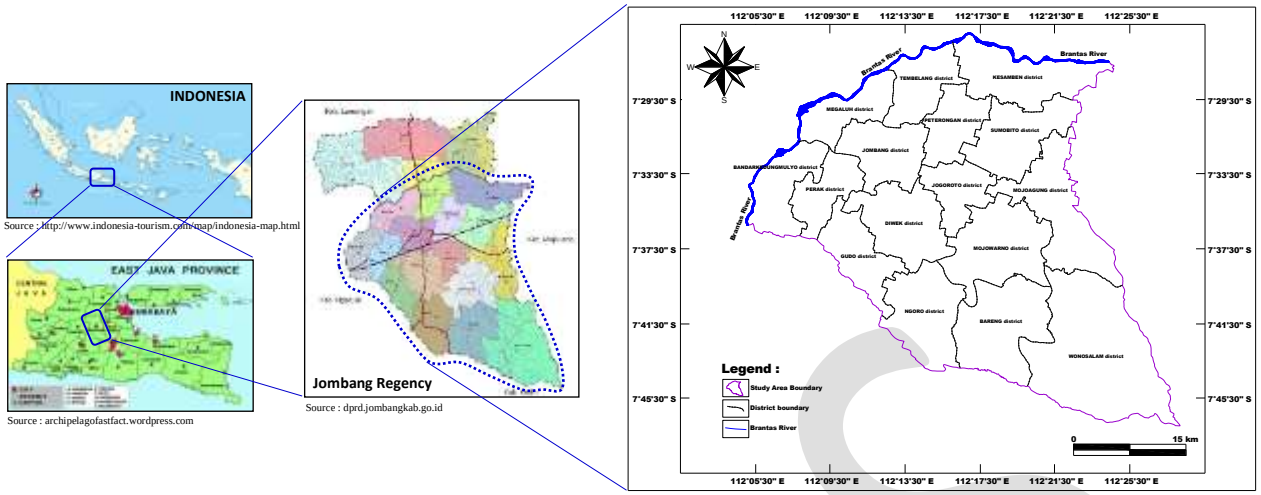

Fig. 1: Map of the study area

Based on Systematic Geological Map Indonesia Kediri quadrangle (1508-3) and Mojokerto quadrangle (1508-6) [5, 10], the rock formations in the study area is dominated by young Anjasmara volcanics, laharic deposits, and alluvium. Young Anjasmara volcanic formation composed by volcanic breccia, tuff, lava and lahars. Laharic deposits formation composed by volcanic pabble-sand, tuff, clay and plant remains and archeological artefacts. Alluvium formation composed by pabble, gravel, sand, clay, and mud.

Based on Hydrogeological Map of Indonesia sheet X Kediri (Jawa) [9] and according to occurrence of groundwater and productivity of aquifers, the study area is devided into 6 sections. Those are: (1) extensive and highly productive aquifers in which flow is intergranular, (2) extensive and productive aquifers in which flow is intergranular, (3) extensive and highly productive aquifers in which flow is both through fissures and interstices, (4) extensive and mederately productive aquifers in which flow is both through fissures and interstices, (5) locally productive aquifers in which flow is both through fissures and interstices, and (6) regions without exploitable groundwater.

MATERIALS AND METHODS

Modeling of groundwater flow pattern in the study area was based on the data of 70 wells scattered in the study area, with variations in depth of 50–127 m BGL on confined aquifer. The information of wells were obtained from the Kegiatan Pendayagunaan Air Tanah BBWS Brantas, Kementerian Pekerjaan Umum dan Perumahan Rakyat. Coordinates of the location of each well latitudes and longitudes) along with the elevation of the land surface is determined directly in the field using GPS Garmin 60.

The following maps were used as the base maps. Digital Topographical Map Indonesia scale 1:25,000 (sheets: 1508-323, 1508-324, 1508-332, 1508-341, 1508-342, 1508-333, 1508-334, 1508-343, 1508-344, 1508-612, 1508-621, and 1508-622) (published by Coordinating Agency of National Surveying and Mapping) were used to delineate the limits of the study area. Systematic Geological Map Indonesia scale 1:100,000 (1508-3 quadrangle and 1508-6 quadrangle) (published by Geological Research and Development Centre) were used to determine the distribution of the rock formations in the study area, and Hydrogeological Map of Indonesia scale 1:250,000 (sheet X) (published by Directorate of Environmental Geology) was used to determine the presence of groundwater potential and regions without exploitable groundwater which describes the area of utilization and groundwater recharge areas.

The groundwater flow model for the study area was developed using Visual MODFLOW 2011.1 (demo version/a trial lisence). The study area was modeled by creating a spatial discretization of an aquifer system with a mesh of blocks called cells, the locations of which are described in terms of rows, columns, and layers [4] which represents the contents of the aquifer unit. Input data provided includes: hydraulic conductivity, pumping wells, dan initial head value. The boundary conditions imposed to simplify the modeling of groundwater flow includes: (1) the groundwater recharge area is located in the Southeast section of the study area is a mountainous region with the initial assumption of groundwater flow toward the Northwest and North where the river is a natural hydraulic boundary, (2) the groundwater movement that occurs due to the height differenandce press, dan (3) no leak in the aquifer system.

Model calibration was calibrated to check the accuracy of the parameters used in the model by comparing the groundwater level modeling results with static groundwater level measured [14] based on data of 70 wells that are used to build the model. The assessment criteria used in the calibration of the model were correlation coefficient (R), root mean square error (RMSE), and mean absolute percentage error (MAPE). Model verification was performed to assess the feasibility of the model that has been built before the model was used in accordance with the purpose of modeling. Verification of the model was done in the same way with the calibration but using data from 10 wells that aren't used to build the model. Application of the model was made to describe the model of groundwater flow pattern in the study area.

RESULTS AND DISCUSSION

The initial step in building the model is to import a map the study area that have been digitized into a computer program package Visual MODFLOW 2011.1 (demo version/a trial lisence). The map of the the study area was discretized into cells in the form of nets square 100 x 100 along the direction of the row and column directions in which each cell has a square area of 400 m x 400 m. The number of layers along the vertical direction of the ground surface to the bottom following the number of layers of rock in the study area. The map of the study area that has been digitized and discretized shown in Figure 2.

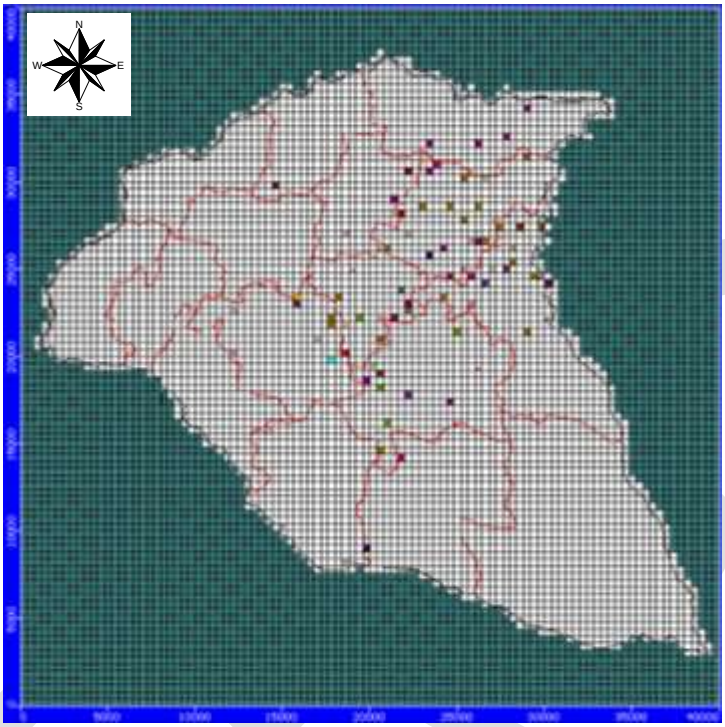

Fig. 2: A spatial discretization in the study area

After the process of data input and parameterization models reconstruction is then performed a study area in the form of a model three-dimensional (3-D). Reconstruction of the study area in the form of 3-D models performed as visual control of input data and parameters measured were modeled so that the model can be built closer to the real situation in the field. Based on the reconstruction as shown in Figure 3, it can be seen visually that the models built closely depicted the conditions in the field. Southeast section of the study area is the highland/mountainous assumed as a groundwater recharge area is located in the Wonosalam district and shape of the earth's surface relief sloping towards the Northwest and North to the boundary of the natural hydrological known as the Brantas River.

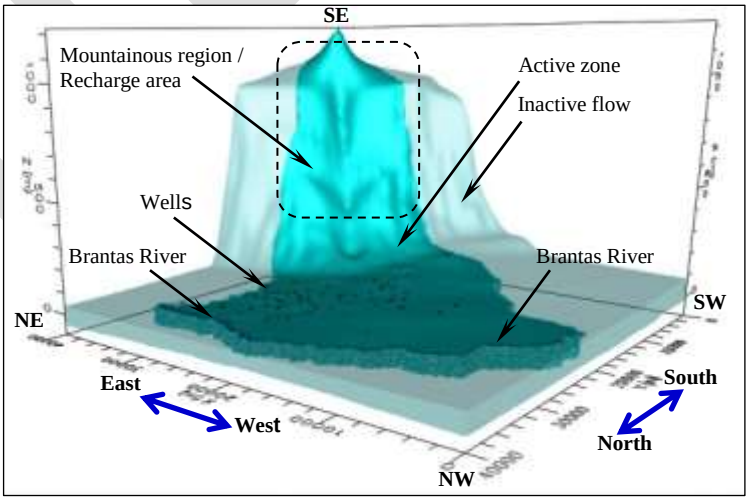

Fig. 3: 3-D model view of the study area

The output of the model shown is the pattern of groundwater flow. Level of reliability of models built was shown in the process of calibration and verification of the model. Calibration and verification of the model was done by comparing the groundwater level resulted from the model built with measured groundwater level. Measured groundwater level was determined based on the land surface elevation measured directly in the field using a GPS was reduced by the depth of the static groundwater level.

The results of model calibration showed the correlation coefficient between the groundwater level depiction of the model results with measured groundwater level (R) = 0.989, RMSE = 2.97 m, and MAPE = 4.75%. Verification of the model built showed the value of R = 0.977, RMSE = 3.26 m, and MAPE = 5.62%. The results of modeling of groundwater flow pattern in the study area is shown in Figure 4.

Noting the results of the reliability analysis of the model both at the stage of calibration and verification of the benchmark realibilty, then the constructed model to describe the groundwater flow pattern in the study area was considered having good reliability. In general, the groundwater flow pattern in the study area flows from areas with high topography (mountains) to areas with low topography (plains) and consistent with the results of previous studies. The groundwater flow pattern is controlled by geomorphological factors [1] and follow the topography [3].

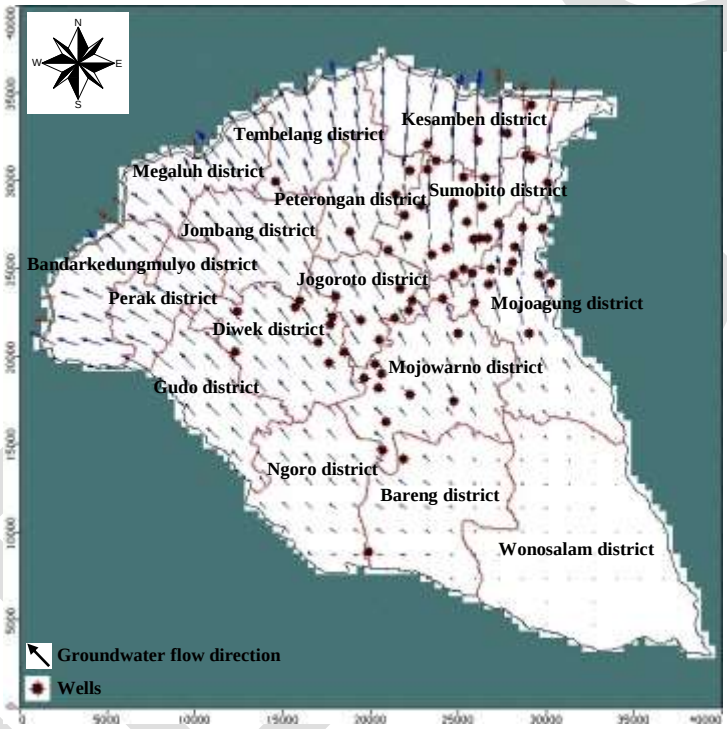

Fig. 4: The groundwater flow pattern model in the study area

Specifically in the area of study, groundwater flow pattern flows from the Southeast section of the study area (Wonosalam district) as a groundwater recharge area to the Northwest to the Bareng district, Mojowarno district, and Mojoagung district. From the Bareng district groundwater flow direction heading to the Northwest to the Ngoro district and Mojowarno district, continues to Gudo district and Diwek district, continues to Perak district and Jombang district, and then the flow directs towards Bandarkedungmulyo district and Megaluh district. Groundwater flow direction from Mojowarno district headed to the Northwest and to the North. From Mojowarno district, the groundwater flow leads to Northwestern pass Jogoroto district, then headed to the Jombang district and Peterongan district, and continues to the Megaluh district and Tembelang district. For groundwater flow is towards the North, from Mojowarno district the direction of flow towards the Western section of the Mojoagung district, next to the Sumobito district, Peterongan district, and headed to the Kesamben district. Groundwater flow direction from the Mojoagung district towards the North until in Sumobito district and continues to the Kesamben district. All of the flow direction ended in the Brantas River as a natural hydrological boundaries of the study area.

CONCLUSION

The pattern of groundwater flow in the study area is determined by topography study areas, flows from high topographic (mountains) to areas with low topographic (plains) areas. The groundwater flows from the Southeast section of the study area (Wonosalam district) toward the Northwest and North section of the study area. Both directions of the stream end in the Brantas River as a natural hydrological boundaries of the study area.

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