Jakarta Groundwater Basin Recharge – Discharge Boundary Area Map: A Preliminary Study

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Abstract. The most important component in groundwater basin are recharge and discharge area. The direction of recharge component is downward while discharge is upward. To discover local recharge and discharge boundary area of the Jakarta groundwater basin, this experimental research is using many cross sections and some hydraulic parameters of many studies that has been conducted before, then simulated it in finite element program SEEP2D (GMS) and finally validated it with bore log and monitoring wells. Ten cross sections selected from 3 studies based on head contour, stratigraphy and groundwater river interaction to be simulated in finite element method SEEP2D (GMS) then the result is validated. Since the result of the investigation is not finished yet, this paper wants to demonstrate the methodology that being conducted in the research with the horizontal map hypothesis. The map hypothesis is evident compare to the real situation of Jakarta groundwater basin today and it is approved that the method that is being used in this research is eligible and appropriate to find the boundary area of recharge and discharge. In the future this recharge and discharge boundary area horizontal map of Jakarta groundwater basin result will encourage many practical solutions in supporting Jakarta groundwater basin management.

1. Introduction

A groundwater basin consists of recharge area and discharge area. In a recharge area there is a component in the direction of groundwater flow near the surface that is downward, otherwise in a discharge area there is a component in the direction of groundwater flow near the surface that is upward [1]. Topography, geology or combination between them determine the character and location of recharge and discharge area [1].

The study of Jakarta groundwater within a 1439 km² area has been observed gradually since more than 2 decades ago. The outcome of the investigation produces delineation of regional recharge and discharge area of Jakarta groundwater basin in the example [2], [3] and [4] but the recharge discharge boundary area map of the Jakarta groundwater basin have not been invented yet until today. To discover local recharge and discharge boundary area in the Jakarta groundwater basin, this experimental research is using many cross sections and some hydraulic parameters of many studies that has been conducted before, then simulated it in finite element program SEEP2D (GMS) and finally validated it with bore log and monitoring wells. Since this recharge discharge boundary area map of the Jakarta groundwater basin has not existed yet in any studies before, this developing research is fundamental to develop a better groundwater management in the Jakarta groundwater basin.
2. Theoretical consideration and related researches

2.1. Groundwater flow model for Jakarta groundwater basin

The flow equations for all aquifer types are obtained from two basic principles: continuity and Darcy’s law. While continuity demands the conservation of mass, Darcy’s law states that in an isotropic porous medium the specific flow rate is proportional to the negative head gradient [1].

2.1.1. Two Dimensional unsteady, saturated, confined, isotropic flow for horizontal direction

The equation of flow for unsteady through a saturated anisotropic porous medium with homogeneous and isotropic soil characteristic [1] is:

\[
\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T} \frac{\partial h}{\partial t}
\]

where \( h \) = Piezometric head, \( S \) = Storage coefficient, and \( T \) = Transmissivity

Analytical solution for unsteady, saturated, confined, homogeneous is known as the Theis solution:

\[
h_0 - h(r, t) = \frac{Q}{4\pi T} W(u)
\]

where \( W \) = Well function, \( T \) = Transmissivity, \( Q \) = Pumping rate

2.1.2. Two Dimensional unsteady, saturated, unconfined, isotropic flow for vertical direction

Groundwater general equation for unsteady, unconfined, aquifer [1] is mathematically described as:

\[
\frac{\partial}{\partial x} \left( \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{\partial h}{\partial y} \right) = \frac{n_e \partial h}{K h \partial t}
\]

where \( n_e \) is effective porosity, \( h \) is pressure head, \( K \) is hydraulic conductivity and \( x, y \) is Cartesian coordinate. The equation known as Boussinesq’s approximation equation [5]. Because this is a nonlinear equation, it is not possible to obtain an analytical solution in general, but Neuman (1972) approached the general equation above with the analytical solution:

\[
h_0 - h = \frac{Q}{4\pi T} W(u_a, u_b, u_c)
\]

where \( W(u_a, u_b, u_c) \) = Unconfined function, \( T \) = Transmissivity, \( Q \) = Pumping rate

2.2. Development of data set for simulator needs of Jakarta Groundwater Basin Management (2018)

Riko Apriatresnayanto in his thesis [2] conducted groundwater research on the Jakarta CAT with Parameters input in Modflow simulation for run test Jakarta groundwater basin simulator consist of boundary condition both horizontal and vertical boundary, land elevation (contour), initial condition, general head, specific head, groundwater aquifer parameters such as hydraulic conductivity as well as specific storage / yield, sources and sink such as rivers, lakes, wells which are included of recharge and discharge.

In accordance with Darcy's principle that the direction of groundwater has a beginning at high groundwater pressure, the recharge area leads to the area with the lowest groundwater pressure, namely the discharge area. The model formulation and planning process is carried out by selecting cross section in area where there is an increase or decrease in groundwater head pressure. In figure 1, for example, the eastern part of the south has a higher water pressure than the surrounding area. Because the area is an area with the highest groundwater, the area is a recharge area. Conversely the area with the lowest groundwater pressure in Figure 1 is depicted in blue color, then the area is a discharge area. Five locations with either increase or decrease groundwater head pressure is formed into a cross section of each with south – north orientation, then the five cross sections will be simulated in SEEP2D (GMS).
2.3. Stratigraphy and Hydro stratigraphy Groundwater Jakarta (2002)

In the results of research by Lambok hutusoi et al [3] shows a stratigraphic sequence from old to young in the Jakarta groundwater basin. Based on the dominance of lithology and stratigraphic position of each rock unit found rock units which are aquifers, axles and bedrock units.

Refer to lithology composition and stratigraphy position, unit rock that in charge of aquifer in Jakarta Groundwater basin are Kaliwangu middle Formation, Genteng Formation, Serpong Formation, Citalang Formation, and Endapan Volcanic Quarter. Unit rock that role as an akitar are Kaliwangu upper and lower Formation. Unit rock that role as a bed rock are Bojongmanik Formation, Jatiluhur Formation, Parigi Formation, Subang Formation, and Basal Gunung Dago as locally. Stratigraphy and Hydro stratigraphy Groundwater research founded 4 zones in Jakarta groundwater basin. First Zone (Aquifer 1) include Citalang Formation and Quaternary Volcanic Deposits. Second zone (Akuitard 1) is Upper Kaliwangu Formation. Third zone (Aquifer 2) consisted of Middle Kaliwangu Formation and Serpong Formation. The lowest zone, which is the fourth zone (Akuitard 2) is Lower Kaliwangu Formation.

All 3 south – north cross sections resulted in Stratigraphy and Hydro stratigraphy of the Jakarta Groundwater basin research [5] are being calculated numerically with SEEP2D (GMS) and also will be validated using data bore log and monitoring wells.

2.4. Groundwater – surface water interactions of Ciliwung River streams, Bogor Jakarta (2013)

The methodology applied in that study [4] was a combination of surface field measurements consisting of geological observations, groundwater flow net analysis, and hydro chemical analysis. Field measurements were taken at 65 stations, consisting of groundwater samples from digging wells at left and right part of the river bank and river water samples. Observations were conducted in May to August 2006 and were selected based on geology, according to the regional geological map and groundwater well availability.

Based on groundwater flow net analysis, the team identifies three groundwater and river water relations at the Ciliwung River stream. First type (effluent stream) that was identified from Bogor to Katulampa (Segment 1) which has the groundwater moved out to the river. Second type (Perched stream) was recognized at the University of Indonesia (UI) area (Segment 2). Results from geoelectrical survey suggested that aquifer layers were not directly in contact with the river basement. It was located on average 5 m below the riverbed. The last type is the Third type (influent stream) that was divided into four sub segments: from UI to Pasar Minggu, Pasar Minggu to Salemba, Salemba to Mangga Besar, and Mangga Besar to Muara. All locations exposed influent stream type. This segment was generally covered by alluvium deposit, which played the role of aquifer. The aquifers were located directly under the river stream. Based on water level measurements, river water level was higher than groundwater (influent stream type). River water infiltrated the underlying aquifers in divergent pattern, with < 0.1 % of hydraulic gradient.
From 3 west – east direction in the interaction of groundwater and water surface ciliwung river, this research will use 2 of them which are perched stream and influent stream. Effluent stream is not being used in this research because of most of the area not within the territory of the Jakarta Groundwater basin. The 2 cross river ciliwung cross section segment are being simulated and will be validated in this research to find the recharge – discharge boundary area of the Jakarta groundwater basin.

3. Recharge – discharge cross sections map methodology and modelling

The formulation and planning of this model are planned by determining the cross section that will be modeled in the SEEP2D (GMS) program. There are ten (10) cross sections needed for determining recharge discharge boundary areas modeling, including: five (5) North – South cross sections based on the result of the simulator 2018 [4] which is cross sections 2 – 2, 3 – 3, 5 – 5 and 8 – 8; three (3) North – South cross sections based on the results of the stratigraphic and hydro stratigraphic research [4] which is cross section 1 – 1, 4 – 4 and 7 – 7; and the last two (2) West – East cross sections based on the result of groundwater flow and the ciliwung river interaction research [2] which includes cross section 9 – 9 and 10 – 10. All the cross sections are delineated in figure 2.

The stage of methodology of this research includes: (1) Review (2) Formulation and Model Planning (3) Initializing Model Software (4) Building Model (5) Calibration and (6) Validation. First step to the fourth step is called Preparation Step. Preparation step before modeling is to collect the values of the horizontal hydraulic conductivity (K 1) and the values of the vertical hydraulic conductivity (K 2) based on previous researches and literatures. Different values of K 1 and K 2 will be taken to developing of each model. For five cross sections from the simulator [4], the result from lithology correlation Hydrogeology Unit (HGU) and soil type in borehole module (MTDR) will be used meanwhile the rest hydraulic conductivity values for another cross section use appropriate values from the recent studies. The model is exported to the GIS so that the exact position of the longitude and latitude coordinates can be identified. The last step before conclusions and suggestions is model validation by ensuring that the recharge-discharge limit obtained is in accordance with the coordinates of the system when found in the actual location. Bore log and monitoring wells data area used also in the step of validation.

The data collection in this experimental research is based on secondary data and third data. The secondary data are supported by the previous study of the Jakarta groundwater basin. This includes many cross sections and some hydraulic parameter like the horizontal hydraulic conductivity (K 1) and vertical hydraulic conductivity (K 2). The third data that is produced by interpretation of bore log soil test that is also being enhanced in this research. Both the data type is utilized quantitatively. This research started in the beginning of February 2019 and the recharge discharge boundary area map is expected to be finish by the end of this year. This paper is published in order to support hypothesis of this research where stand at the middle of this research time frame. This 2 dimensional (2D) analysis methodology research is a new approach in finding a certain boundary area of recharge discharge in the Jakarta groundwater basin. The boundary area of recharge discharge in a horizontal map of Jakarta will be presented first time approximately at the end of this year.
4. Hypothesis and discussion

From the groundwater contour head map we selected 3 recharge areas and from the stratigraphy research indicates also 3 recharge areas in groundwater basin of Jakarta \[3, 4\]. The three coordinates with the highest head value resulted by the simulator is labeled with (a), (b), (c) in table 1. Each coordinate has hydraulic head more than 60 m. Otherwise, around 10 km to the south of Serpong Well, Bulok Kulon Well and Gunung Putri Well, the Stratigraphy study shows the area that coincides with impermeable formations that acts as a barrier for another groundwater water flow (no flow) from South, so these three areas also respond as a recharge area. In summary, from the simulator research and the stratigraphy study \[3, 4\] assume that there are 6 recharge area (table 1) hypothetically.

The 3 lowest hydraulic head those we can find in simulator area has less than 10 meters in head pressure value. These 3 cones depression are labeled with (d), (e) and the coast of North Jakarta. Since they have the lowest hydraulic head, the best hypothesis for these areas is a function of discharge area. Almost the same concept from the stratigraphy we will find in the map that all the water direct to Java Sea. In total there are 3 discharge areas (blue color) in figure 4.

| Simulate Source | Stratigraphy Source |
|-----------------|---------------------|
| Coordinate UTM / Area | Approximated area |
| **Recharge area** | | |
| (a) \(6^\circ9'16'' S 107^\circ1'6'' E\) (Tambun, West Java) | \(\approx 10\) km to south from Serpong well (Curug, Parung, West Java) |
| (b) \(6^\circ26'28''S 106^\circ52'12'' E\) (Jatijajar, West Java) | \(\approx 10\) km to south from Bulok Kulon well (Bojong, West Java) |
| (c) \(6^\circ22'57'' S 106^\circ46'28'' E\) (Sawangan, West Java) | \(\approx 10\) km to south from Gunung Putri (Gunung putri, West Java) |
| **Discharge area** | Java Sea |
| (d) \(6^\circ12'37'' S 106^\circ55'29'' E\) (Pulogadung, Jakarta) | |
| (e) \(6^\circ15'53'' S 106^\circ42'33'' E\) (Perigi kulon, Banten) | |
| The coast of North Jakarta | |

There are two interesting phenomena also in figure 4. Discharge area (blue color) adjacent with recharge area (green color) in west south perimeter area. Another phenomenon that we can find is there is recharge area (green color) near to the discharge area (blue color) in east north of Jakarta.

![Figure 4](image-url)
groundwater basin territory. All phenomena eager us to hypothetically say that there are local groundwater systems in Jakarta groundwater basin. One of the example of the cross section is being simulated in this paper (figure 3). From that figure we can see after running SEEP2D (GMS) the result shows that regionally groundwater flow from south to north. This is evident compare to the real situation of Jakarta groundwater basin today and it is approved that the method that is being used in this research is eligible and appropriate to find the boundary area of recharge and discharge.

5. Conclusion
From theoretical consideration and paper review about Jakarta groundwater, the only thing that can be found is recharge discharge area map but not the recharge discharge boundary area map. This research is intended to determine the recharge discharge boundary area and to plot each area in a horizontal map. The finite element method in SEEP2D (GMS) program will be simulated in this research, including recharge and discharge boundary area map of Jakarta groundwater basin hypothesis (figure 4). Since the result of the investigation is not finished yet, this paper wants to demonstrate the methodology that is being conducted in the research and recharge discharge boundary area horizontal map hypothesis. In the future, this recharge and discharge boundary area horizontal map of Jakarta groundwater basin result will encourage many practical solutions in supporting Jakarta groundwater basin management.

6. References
[1] Freeze, R.A and Cherry, J.A. *Groundwater*. Prentice Hall, Englewood Cliffs, New Jersey (1979).
[2] D. E. Irawan, R. F. Lubis, H. Silaen, B. Brahmanryo, P. Sumintadireja dan D. J. Puradimaja. *Groundwater–surface water interactions of Ciliwung River streams, segment Bogor–Jakarta, Indonesia*, Springer-Verlag Berlin Heidelberg 2014
[3] Lambok M Hutasoit, Agus Mochamad Ramdhan dan Muhammad Fachri, *Stratigrafi dan Hidrostratigrafi Cekungan Airtanah Jakarta*, (2002)
[4] Riko Apriatresnayanto, *Pengembangan perangkat data untuk kebutuhan simulator pengelolaan airtanah pada Cekungan Airtanah Jakarta*, tesis (2018)
[5] Fetter, C.W, *Applied Hydrology* Prentice – Hall, (2001)

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