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Groundwater and solute transport modeling at Hyporheic zone of upper part Citarum River

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Abstract. Groundwater and surface water interaction is an interesting topic to be studied related to the water resources and environmental studies. The study of interaction between groundwater and river water at the Upper Part Citarum River aims to know the contribution of groundwater to the river or reversely and also solute transport of dissolved ions between them. Analysis of drill logs, vertical electrical sounding at the selected sections, measurement of dissolved ions, and groundwater modeling were applied to determine the flow and solute transport phenomena at the hyporheic zone. It showed the hyporheic zone dominated by silt and clay with hydraulic conductivity range from 10^{-4}~10^{-8} m/s. The groundwater flowing into the river with very low gradient and it shows that the Citarum River is a gaining stream. The groundwater modeling shows direct seepage of groundwater into the Citarum River is only 186 l/s, very small compared to the total discharge of the river. Total dissolved ions of the groundwater ranged from 200 to 480 ppm while the river water range from 200 to 2,000 ppm. Based on solute transport modeling it indicates dissolved ions dispersion of the Citarum River into groundwater may occur in some areas such as Bojongsoang-Dayeuh Kolot and Nanjung. This situation would increase the dissolved ions in groundwater in the region due to the contribution of the Citarum River. The results of the research can be a reference for further studies related to the mechanism of transport of the pollutants in the groundwater around the Citarum River.

1. Background

Citarum River flows from Cisanti Lake, Wayang Mountain to Java Sea. This river flows through 12 cities and many people rely on Citarum water for their daily life. Citarum River is known as one of the most polluted river in the world [1]. It was caused by urban and industrial waste along the riverbanks. Other than taking their water supply directly from the river, people also taking the water from dug-well along the river.

Interactions between Citarum River and the shallow groundwater (hyporheic zone) is very important to understand. Release and sink of dissolved metals or ions between the two environment i.e. surface water of Citarum River and groundwater in the hyporheic zone should be known to understand environmental problems. One of the method that can be applied to monitors transfer ions between river and groundwater is by observing total dissolved solid (TDS) at Citarum River and the hyporheic zone. In this study, the method was applied and combined with vertical electrical sounding at hyporheic zone of Citarum River and hydrogeology numerical simulation.

2. Research Area

In this study, research area is limited only to upper part of Citarum River, from Cisanti Lake to Saguling Reservoir. Regional geological map of research area shows that research area consists of 4 main formations: Kosambi Formation (lacustrine deposits, mostly is clay), Cibeureum Formation (volcanic deposits), Tertiary Volcanic and Intrusive Rocks (**Figure 1**). Typical hydrostratigraphy along the hyporheic zone is shown in drilling log at **Figure 1**.

One of drilling log from Gedebage area were analyzed and shows alternate layer between sandstone and claystone.

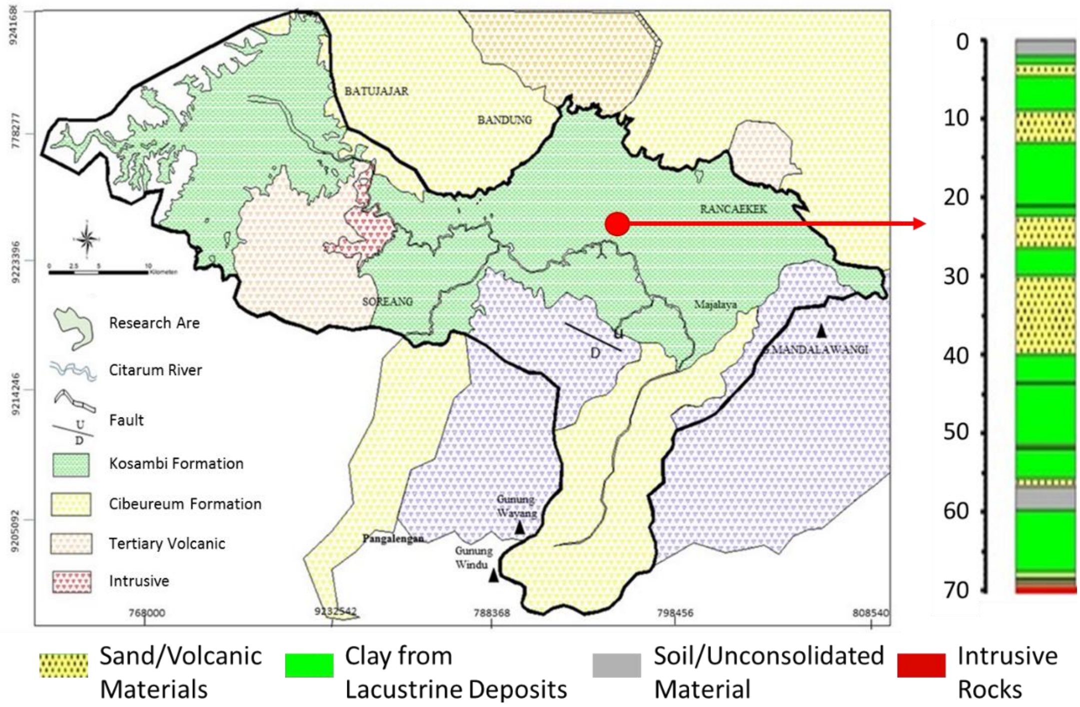

Figure 1 Geological Map of Research Area (modified from [2]).

3. Field Works

Field works were conducted in year 2014-2015. The field works are including: vertical electrical sounding (VES) and also mapping of groundwater level and TDS value along the hyporheic zone consist of TDS value measurements and resistivity method. VES was conducted at 3 locations: Cisanti Lake, Citarum River, and Saguling Reservoir; the results were used to get sub-surface condition at hyporheic zone at (1) Cisanti Lake, (2) Bojongsoang, and (3) near Saguling Reservoir (**Figure 2**).

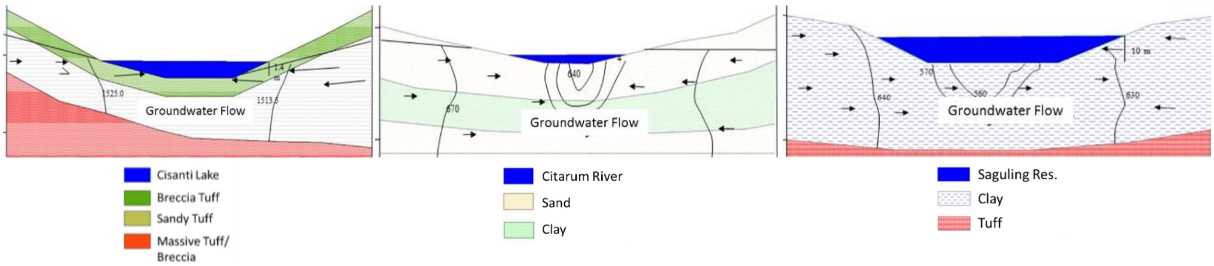

Figure 2 Lithology based on VES Results, Left: Cisanti Lake; Middle: Bojongsoang; Right: Saguling Reservoir. The arrows show groundwater flow direction based on groundwater level measurements at the 3 locations.

TDS values and groundwater level were measured from the dug-wells along the river (**Figure 3**). Total dissolved ions of the groundwater ranged from 200 to 480 ppm while the river water range from 200 to 2,000 ppm. Based of spatial distribution of TDS values, it can be distinguished that southern part of Citarum River has higher TDS values than the northern part. High value of TDS (>1200 ppm) from the surface water i.e. Citarum River are located at Nanjung and Bojongsoang area (**Figure 3**). These areas are known as industrial zone and high population density.

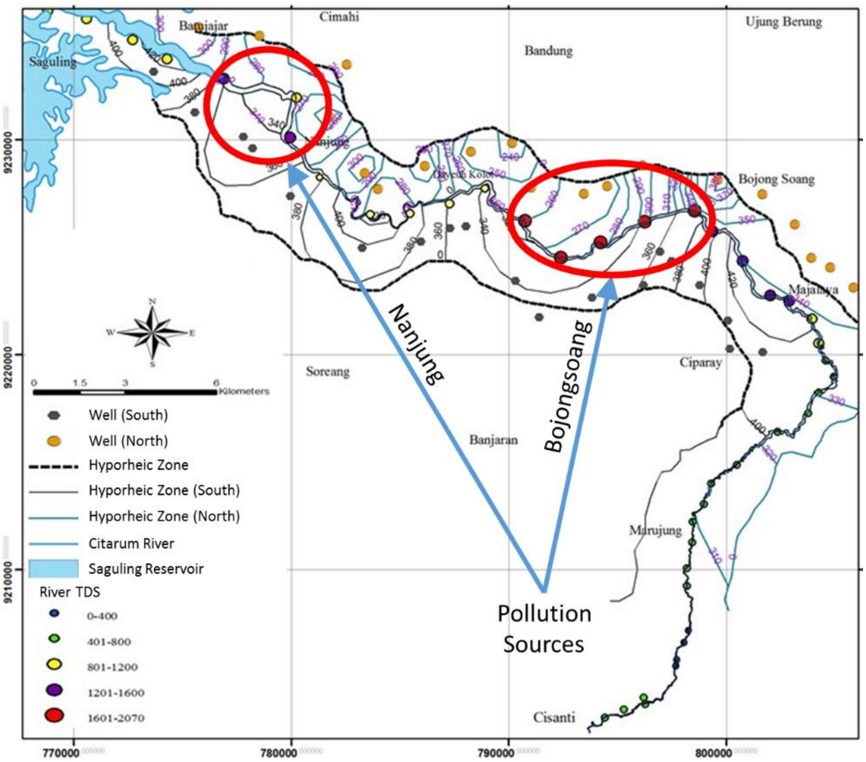

Figure 3 TDS Value Distribution

4. Groundwater Flow and Contaminant Transport Simulation

Hydrogeological model was built to simulate the interactions between Citarum River and groundwater at hyporheic zone. The simulation aims to predict dissolved ion transport between surface and groundwater, by advection and dispersion equations. Rock samples from the hyporheic zone were tested to get hydraulic conductivity values. The results show that the hydraulic conductivity at hyporheic zone ranged from 10^{-4} to 10^{-8} m/s. The parameters for simulation are summarized in **Table 1** and the 3D physical model is shown at **Figure 4**.

Table 1. Parameters Used in Hydrogeological Model

Parameter	Value
Hydraulic Conductivity	Aquifer (low permeability): K = $10^{-6} \sim 10^{-4}$ m/s; in hyporheic zone, silty sand
	Aquitard (lower permeability) : K = 8 x 10^{-8} m/s; in hyporheic zone in deeper part
Storativity	Aquifer: Ss = 7.8 x 10^{-4}; Sy = 0.21; Eff. Porosity = 0.2; Tot. Porosity = 0.56
	Aquitard: Ss = 1 x 10^{-6}; Sy=0.08; Eff. Porosity = 0.11; Tot. Porosity = 0.24

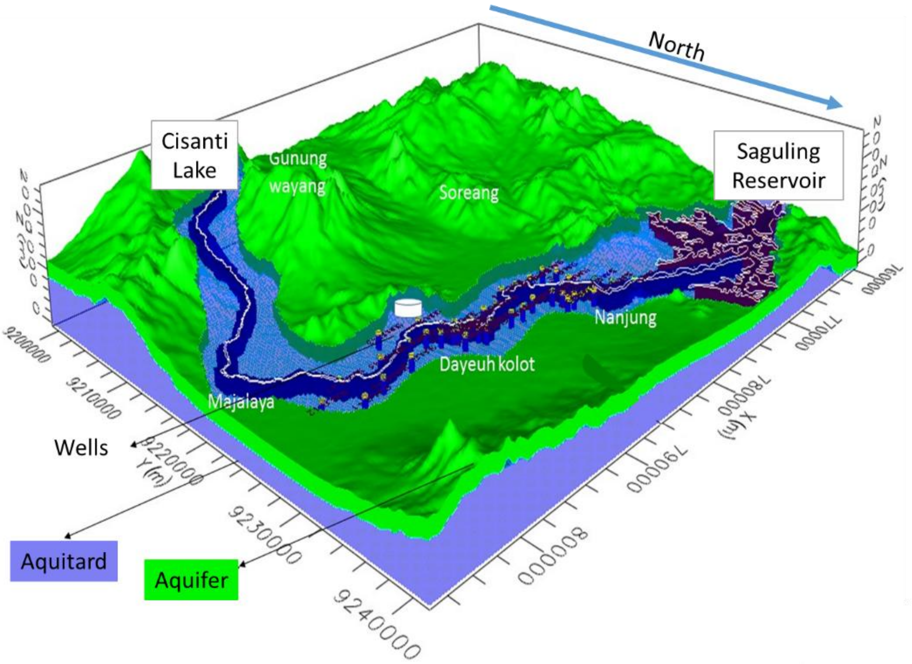

Figure 4. 3D Physical Model of Citarum River

5. Simulation Results

The groundwater simulation model shows that groundwater from hyporheic zone flows into the river with very low gradient, and it shows that the Citarum River generally is a gaining stream. Direct seepage along hyporheic zone from groundwater to Citarum River is only 186 l/s. It is very small compared to the total discharge of the river, it is concluded that the water at Citarum River mostly is from the run-off.

Based on solute transport modeling, it indicates that dissolved ions from the river can be dispersed to groundwater. The phenomena of solute transport at Citarum hyporheic zone is caused by dispersion mechanism due to high concentration gradient between surface water and groundwater. The dispersion mechanism causing TDS value at shallow groundwater at hyporheic zone can be elevated from 300 ppm to 500 ppm caused by pollution at Citarum River. This condition would be occurred mainly at Bojongsoang-Dayeuh Kolot and Nanjung area (**Figure 5**).

6. Conclusions

The study of groundwater and solute transport modeling at hyporheic zone of upper part of Citarum River can be concluded as follows:

- There is interaction between Citarum River and shallow groundwater; flows direction from groundwater to Citarum River, with very small hydraulic gradient (about 186 l/s).
- In a very small gradient between groundwater and river water, dispersion of contaminant from Citarum River to shallow groundwater may still be occurred. In this case pollution in river water also causing pollution in hyporheic zone.
- Based on simulation, TDS in hyporheic zone can be elevated from 300 ppm to 500 ppm caused by pollution in river water.

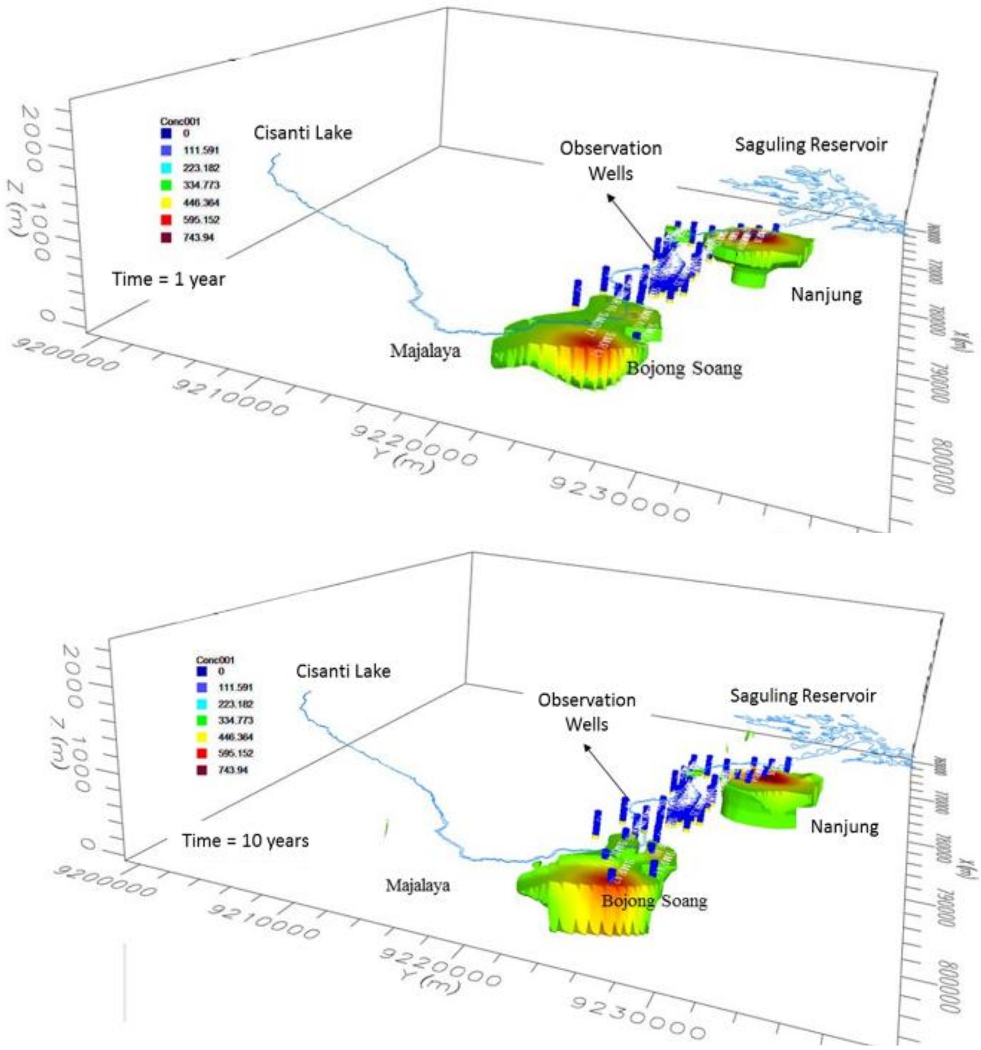

Figure 5. Hydrogeological modeling results of Citarum River (top: after 1 year, bottom: after 10 years)

7. References

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