Groundwater play in extensional regime: a case study in Cibunar Region, Garut, Indonesia

M Hanif 1,*, W W Parnadi 2
1Research Center for Geotechnology, National Research and Innovation Agency (BRIN), Bandung, Indonesia
2Geophysical Engineering Department, Institute Technology of Bandung, Bandung, Indonesia
*corresponding author: hanif.geotek@gmail.com

Abstract. The intermountain Cibunar area of the Garut basin periodically suffered from a drought and thus became a devastating hazard. Its fault structure as an impact of the extensional regime might affect the groundwater play as a transport or barrier system. The tectonic setting and its disruption of volcanic lithologies by faults make the area's hydrogeology very complex. The conducted electrical resistivity tomography coupled with gravity and magneto-telluric studies revealed the aquifer play on the zone is affected by the extensional regime. Tectonically, the drought Cibunar district is close to the top of the horst structure where the uplifted segments might contribute to the limited low resistivity aquifer zone and triggered the flow to the graben zone. The low and high resistivity on the region was related to an unconfined aquifer and unsaturated zone, while the medium zone remains unclear.

1. Introduction
Groundwater in the Cibunar Region, Garut, West Java, Indonesia, as well as the flowing water of Cimanuk stream is suffered from the drought and decreasing water flow in the dry season. This hazard caused a serious problem to the livestock and household activities of the local residents. Moreover, waste due to an increase in population and the growth of industrial activities around the Cimanuk stream could contaminate water reservoirs (called “embung” in local term), which built in 2018. Consequently, these vulnerable circumstances need a more sustainable solution, especially by exploring the unconfined aquifer around the area.

The area is geologically situated on the intermountain Garut basin (Figure 1a), which has an extensional regime [1]. The northern and middle parts of the basin are bordered by Mt. Malabar (2321 m), Mt. Papandayan (2622 m), Mt. Cikuray (2820 m), and Mt. Guntur (1838 m). The lithology of this area (Figure 1b) is dominated by Efflata of Papandayan volcanic (Qhp) which is constituted by volcanic ash, andesite and basalt boulder. Young volcanic deposit from Cikurai Mt. and Guntur Pangkalan Kendang (Qye and Qypu) consists of eflata and lava flow, mainly andesitic basalt, and undifferentiated volcanic rocks such as volcanic ash, tuff, lapilli, and breccia. The extensional normal faults generally have an important role on the groundwater system. Previous studies were performed on the relation between tectonic structure and groundwater play, which could influence its flow, recharge-discharge relation, and water-table elevations [2–4].
Electrical resistivity tomography (ERT) is a non-invasive geophysical tool and an indirect ground imaging method that can solve some hydrogeological issues. The groundwater feature could be recognized by the resistivity contrasts between saturated/unsaturated formations, such as observed in volcano-sedimentary deposits [5]. Numerous resistivity studies around this basin are mostly focused on the deeper geological scale due to its geothermal potential (e.g. Papandayan and Guntur). However, the near-surface and deep resistivity studies have never been studied to investigate the region’s groundwater play and drought factor. This study aims to understand the geologic control on the groundwater, which leads to solving the possible aquifer potential using the resistivity method.

Figure 1 a The Cibunar studied area (red box) overlaid in digital elevation model indicates the intermountain basin which is bordered with Cikurai, Galunggung, Papandayan, Masigit, and Guntur Mountains. b Three resistivity lines (red line) are situated around Young Volcanic formation (Qy and Qypu), Efflata Papandayan (Qhp), and Guntur Volcanic Rock (Qgpk). The lithology refers to Garut-Pameungpeuk regional geology map [6].

2. Method
Direct current (DC) resistivity method utilizes a current that is transmitted from a logger through two electrodes. The passage of this current into the ground creates a potential that is measured with two other electrodes [7]. Survey using this method was conducted in Cibunar district, Pakuhaji village by using Lippmann Earth resistivity meter with Wenner electrode configuration at 5 m spacing.

The preferences of this acquisition method and location are based on the geological analysis and drought assessment through the resident dug wells during periods of drought. The resistivity data were collected through 3 lines: 280 m long line 1 in N-S direction, 225 m long line 2 and 200 m long line 3, both in E-W direction as seen in figure 1b. The secondary data such as gravity and magneto-telluric data from published report were utilized to provide a comprehensive and detailed view of geology condition related to the groundwater.

The magneto-telluric (MT) method works based on geomagnetic and geoelectric field variation at earth’s surface in the frequency range of 10000-0.00001 Hz. Consequently, it could be used for exploration from near surface to thousands of meter depth. The MT profiles used in this study were obtained from a published paper [1]. The gravity method is also a non-invasive geophysical method that could map the subsurface density distribution, faults, sediment thickness, and groundwater potential. The Bouguer anomaly used in this study was obtained from a published paper [8]. By a deeper penetration and a wider range of MT and gravity method, this region’s groundwater play might be clearly understood to find a possible aquifer.
3. Results and Discussions

Two-dimensional resistivity models obtained for 3 lines shown in Figure 2 indicate the subsurface geological structure and might correspond to its groundwater play. On average, the low resistivity value (1-24.5 Ohm.m) is interpreted as the saturated groundwater reservoir, the medium resistivity range (24.5-56.1 Ohm.m) might correlate with the medium saturated zone, while the highest value zone (54.1-90 Ohm.m) is probably related to the unsaturated zone.

![Figure 2 a-c](image)

The low resistivity zone as a saturated water reservoir which has a thickness <20m lies in the depth range of resident dug wells. During drought, it might be expected that this low resistivity zone is an unconfined aquifer that has no impermeable trap to accumulate the groundwater. Besides, the volume is probably vulnerable to the decrease of rainfall rate. The high resistivity zone (red to purple) which seems to be a zone with unsaturated medium, might be interpreted as an impermeable rock dominated on the whole lines (30-40 m). Since a few low resistivity zone remains on the bottom of those profiles, the potential of a deeper confined aquifer might be expected. However, due to the limited penetration (~45 m), a clear confined aquifer could not be delineated.

The magneto-telluric (MT) profiles revealed a broader and deeper resistivity profiles on the region which are concluded as an extensional tectonic regime (Figure 3a) [1]. Both two profiles showed three regions of resistivity which were delineated with horst-graben and normal fault structures. The studied Cibunar area is located around the G03-G05 on the MT line (Figure 3a). Generally, the regional geological background will have no big difference in this distance range (~3 km). The lowest range of resistivity (<100 Ohm.m, red to yellow) with about 250 m thickness might be related to the sediments on the near surface, consistent with the resistivity tomography value range. The thickness indicated a high potential of groundwater on this depth.
Figure 3  a The Bouguer anomaly map on Garut basin and the magneto-telluric station locations. b The northern line resistivity profiles (blue stations)  c The southern line resistivity profile (red stations). The extensional regime, horst-graben structure, and faults distribution might affect the distribution of groundwater aquifer. These figures were modified from a published paper [1].

The Bouguer gravity anomaly indicated a lowering anomaly to the eastern part of the zone which means a thickening sediment deposition to the eastward and might have more probabilities on the aquifer accumulation. Moreover, the rapid decreasing change on the Bouguer anomaly indicates the fault structures that might exist intensively in the region. This analysis deducts two probabilities on the groundwater play based on the resistivity tomography results (Figure 2). Firstly, the medium zone might be interpreted as a normal fault structure or fracture that plays a conduit to the groundwater. The second alternative, the medium to the high anomaly, is a boulder of impermeable igneous rocks that separates the above groundwater play from the confined one. Consequently, deeper resistivity and geological studies need to be conducted to validate the vicinity of the confined aquifer and the fault role to the groundwater play in this zone.

4. Conclusions
Based on the geological study and electrical resistivity tomography results, the profiles have three distinguished resistivity ranges that illuminate subsurface lithology. The low, medium, and high resistivity values are expectedly correlated with the unconfined groundwater, weathered rock, and igneous rock, respectively. Given the groundwater shortage in the region, the citizens’ dug well groundwater source probably has no connected structure to the deeper confined aquifer. The integration with the magneto-telluric and gravity approach revealed the extensional tectonic regime controls the groundwater play in the Cibunar area especially on the horst structure which the prolific aquifer might accumulate in the graben zone. Further research should explore the confined aquifer potential by using resistivity sounding and well bore-based methods.

Acknowledgement
The authors wish to thank Tanoto Foundation and Kemenristek-BRIN (formerly Kemenristekdikti) for the funding under TSRA 2012 and PKM-P grant. Mr. Ilham Togi Sihombing and Social Service Division - Geophysical Engineering Student Association HIMATG TERRA ITB are thanked for the ‘Kampung Kita’ initiation and field work.
References

[1] Handayani L, Kamtono K and Wardhana D D 2013 Extensional Tectonic Regime of Garut Basin based on Magnetotelluric Analysis *Indones. J. Geosci.* 8 127–33

[2] Apaydin A 2010 Relation of tectonic structure to groundwater flow in the Beypazari region, NW Anatolia, Turkey *Hydrogeol. J.*

[3] Melchiorre E B, Criss R E and Davisson M L 1999 Relationship between seismicity and subsurface fluids, central Coast Ranges, California *J. Geophys. Res. Solid Earth*

[4] Delinom R M and Suriadarma A 2010 Groundwater Flow System of Bandung Basin Based on Hydraulic Head, Subsurface Temperature, and Stable Isotopes *J. Ris. Geol. dan Pertamb.* 19 55

[5] Toulier A, Baud B, de Montety V, Lachassagne P, Leonardi V, Pistre S, Dautria J-M, Hendrayana H, Miftakhul Fajar M H, Satrya Muhammad A, Beon O and Jourde H 2019 Multidisciplinary study with quantitative analysis of isotopic data for the assessment of recharge and functioning of volcanic aquifers: Case of Bromo-Tengger volcano, Indonesia *J. Hydrol. Reg. Stud.* 26 100634

[6] Alzwar M, Akbar N and Bachri S 1992 Regional Geology Map of Garut and Pamengpeuk, Java *Cent. Geol. Res. Dev.*

[7] Knödel K, Lange G, Voigt H-J, Seidel K and Lange G 2007 Direct Current Resistivity Methods Environmental Geology

[8] Untung M and Sato Y 1978 Gravity and geological studies in Jawa *Indones. Geol. Surv. Bandung Geol. Surv. Japan, Tokyo*