SARI

Air tanah pada sistem akuifer vulkanik memainkan peran signifikan dalam pemenuhan kebutuhan air bersih bagi sebagian besar masyarakat di kawasan Cekungan Air Tanah (CAT) Yogyakarta-Sleman. Hal ini mendorong pentingnya studi komprehensif mengenai karakteristik hidrogeologi dan delineasi zona imbuhan air tanah sebagai landasan konservasi air tanah yang berkelanjutan. Namun, penentuan zona imbuhan air tanah saat ini masih bergantung pada indikator hipotetik seperti tekuk lereng, topografi, dan geologi, sehingga belum mampu mengidentifikasi sumber imbuhan secara rinci pada sistem akuifer vulkanik yang kompleks. Penelitian ini bertujuan menentukan batas zona imbuhan air tanah, memahami proses evolusi hidrogeokimia, mengestimasi imbuhan air tanah, serta menentukan model konseptual hidrogeologi. Analisis dalam penelitian ini dilakukan melalui pendekatan multidisipliner dengan mengintegrasikan data isotop stabil (δD dan $\delta^{18}O$), hidrogeokimia, serta metode *Water Table Fluctuation* (WTF) dan *Chloride Mass Balance* (CMB) untuk mengidentifikasi sumber serta proses imbuhan air tanah. Selain itu, pemodelan hidrostratigrafi berbasis data log bor dan geolistrik 2D digunakan untuk memodelkan sistem akuifer secara lebih detail. Hasil penelitian menunjukkan bahwa sistem akuifer CAT Yogyakarta-Sleman terbagi menjadi *upper aquifer* (akuifer bebas) dan *lower aquifer* (akuifer semi-tertekan hingga tertekan). Air tanah pada sistem *upper aquifer* memiliki fasies dominan Ca-Mg-HCO_3, sedangkan *lower aquifer* didominasi oleh fasies *mixed* Ca-Na-HCO_3, Na-HCO_3, *mixed* Ca-Mg-Cl, dan Na-Cl-SO_4. Evolusi air tanah dari zona imbuhan ke zona lepasan ditandai oleh peningkatan *Total Dissolved Solids* (TDS) akibat interaksi air dan batuan. Proses ini melibatkan berbagai peristiwa geokimia, seperti pelapukan mineral silikat dan pertukaran ion yang mengubah dominasi ion HCO_3 menjadi SO_4 dan Cl sepanjang aliran air tanah. Sementara itu, komposisi isotop stabil menunjukkan pengaruh topografi lereng selatan Gunung Merapi, di mana kandungan isotop berat pada air hujan menurun (*depleted*) seiring peningkatan elevasi. Zona imbuhan efektif berdasarkan pelacak isotop berada pada elevasi 453–1.473 mdpl, mencakup 9,63% dari luas CAT, yang berasosiasi dengan satuan geomorfologi kaki Gunung Merapi. Secara hidrostratigrafi, imbuhan *upper aquifer* terjadi pada elevasi 453–1.113 mdpl, sedangkan *lower aquifer* terimbuhkan pada 567–1.473 mdpl. Sistem aliran air tanah yang teridentifikasi terdiri dari aliran lokal pada *upper aquifer*, serta aliran intermediet dan regional pada *lower aquifer*. Estimasi kuantitas imbuhan berkisar 140–1.505 mm/tahun (WTF) dan 102–1.969 mm/tahun (CMB), dengan imbuhan tertinggi di kawasan utara sementara kawasan urban menunjukkan pengaruh fenomena *urban recharge* yang ditandai dengan kenaikan tren muka air tanah berdasarkan uji Mann-Kendall. Penelitian ini memberikan pemahaman baru tentang zona imbuhan, evolusi hidrogeokimia, dan estimasi imbuhan air tanah sebagai dasar konservasi berkelanjutan di CAT Yogyakarta-Sleman, serta berkontribusi dalam pengembangan metode identifikasi zona imbuhan berbasis isotop dan hidrogeokimia pada akuifer vulkanik yang berpotensi diterapkan di wilayah tropis lainnya.

Kata Kunci: Akuifer vulkanik; CAT Yogyakarta-Sleman; Evolusi hidrogeokimia; Imbuhan Air Tanah; Pelacak isotop

ABSTRACT

Groundwater in volcanic aquifer systems plays a significant role in meeting the clean water needs of the majority of the population in the Yogyakarta-Sleman Groundwater Basin (GWB). This highlights the importance of a comprehensive study of hydrogeological characteristics and delineation of groundwater recharge zones as a foundation for sustainable groundwater conservation. However, the determination of groundwater recharge zones still relies on hypothetical indicators, such as slope curvature, topography, and geology, which are insufficient to identify detailed recharge sources in complex volcanic aquifer systems. This study aimed to define the boundaries of groundwater recharge zones, understand the process of hydrogeochemical evolution, estimate groundwater recharge, and develop conceptual models and groundwater flow systems. The analysis was carried out using a multidisciplinary approach, integrating stable isotope data (δD and δ^{18}O), hydrogeochemistry, Water Table Fluctuation (WTF), and Chloride Mass Balance (CMB) methods to identify sources and processes of groundwater recharge. Additionally, hydrostratigraphic modelling based on borehole logs and 2D geoelectrical resistivity data was used to model the aquifer system in more detail. The results show that the Yogyakarta-Sleman GWB aquifer system is divided into an upper aquifer (unconfined aquifer) and a lower aquifer (semi-confined and confined aquifers). The groundwater in the upper aquifer has dominant Ca-Mg-HCO_3 and mixed Ca-Mg-Cl facies, whereas the lower aquifer is dominated by mixed Ca-Na-HCO_3, Na-HCO_3, and Na-Cl-SO_4 facies. The evolution of groundwater from recharge to discharge zones is marked by an increase in Total Dissolved Solids (TDS) due to water-rock interactions. This process involves various geochemical events, such as silicate mineral weathering and ion exchange, which change the dominance of HCO_3 ions to SO_4 and Cl ions along the groundwater flow. Meanwhile, the stable isotope composition shows the influence of the topography of the southern slopes of Mount Merapi, where the heavy isotope compositions in rainfall were depleted with increasing elevation. Based on isotopic tracers, the effective recharge zone is located at an elevation of 453–1,473 meters above sea level (masl), covering 9.63% of the GWB area, and is associated with the geomorphological unit of the Mount Merapi foothills. Hydrostratigraphically, recharge to the upper aquifer occurs at elevations of 453–1,113 masl, whereas recharge to the lower aquifer occurs at elevations of 567–1,473 masl. The identified groundwater flow systems comprised local flow in the upper aquifer and intermediate and regional flows in the lower aquifers. The estimated recharge quantity ranged from 140 to 1,505 mm/year (WTF) and 102–1,969 mm/year (CMB), with the highest recharge in the northern region of the basin. Urban areas are influenced by urban recharge phenomena, marked by a rising groundwater table trend based on the Mann-Kendall test. This study provides new insights into recharge zones, hydrogeochemical evolution, and groundwater recharge estimation as a foundation for sustainable groundwater conservation in the Yogyakarta-Sleman Groundwater Basin. It also contributes to the development of isotope and hydrogeochemistry-based methods for identifying recharge zones in volcanic aquifers, with potential applications in other tropical regions.

Keywords: *Volcanic aquifer; Yogyakarta-Sleman GWB; Hydrogeochemical evolution; Groundwater recharge; Isotopes tracer*