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Distribution Pattern and Estimation of Groundwater Flow Direction Using pH in Unconfined Aquifer Greater Bandung Area, Purwakarta Regency, and Subang Regency Using Principal Component Analysis

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Abstract. The Greater Bandung area, Purwakarta Regency, and Subang Regency have considerable potential as a source of groundwater because of their volcanic deposits. Nonetheless, there are also concerns about groundwater contamination in the region. Investigating the characteristics of the groundwater in this area is very interesting because the local people depend heavily on agricultural activities for their livelihoods. This study uses multivariable statistical analysis techniques, especially the principal component analysis method, using Orange Data Mining software. The study which focused on examining the physical parameters of groundwater, particularly its pH, managed to collect 674 data points, consisting of 58 primary data and 616 secondary data. In the northern region, comprising Bandung City, Cimahi City, West Bandung Regency, Subang Regency, and Purwakarta Regency, the groundwater flow is from south to north, and its average pH is 6.7. Conversely, in the southern area, encompassing Bandung Regency, the groundwater flow is also from south to north, but its average pH is 6.1. The acidity of the southern area's groundwater is attributed to the volcanic activity of Mount Wayang-Windu, which is a component of Mount Malabar.

Keywords: *Greater Bandung Area; volcanic hydrogeology; groundwater contamination; multivariate statistical analysis; principal component analysis; livelihood.*

1 Introduction

Greater Bandung Area, Purwakarta, and Subang areas are volcanic deposit areas originating from two main volcanoes, Mount Tangkuban Perahu in the north and Mount Malabar in the south. Volcanic deposits exhibit considerable potential as groundwater reservoirs, although they also pose a risk of contamination. Investigating the groundwater characteristics in these areas is of significant interest due to the escalating population growth reported by the Indonesian statistical center. Moreover, with approximately 80% of the local population heavily reliant on agriculture, the increasing threat of groundwater contamination necessitates a comprehensive examination of its characteristics.

In this area there has been no research on pH parameter, so this research focuses on evaluating the properties of groundwater through pH parameters. Groundwater is taken from water bodies in the form of springs in the study area. The research area has an area of 2,607 km^2 which is located at 761061.84 – 805653.89 Easting and 9269596.42 – 9192221.21 Northing with the position of South Latitude in UTM 48S zone (Figure 1).

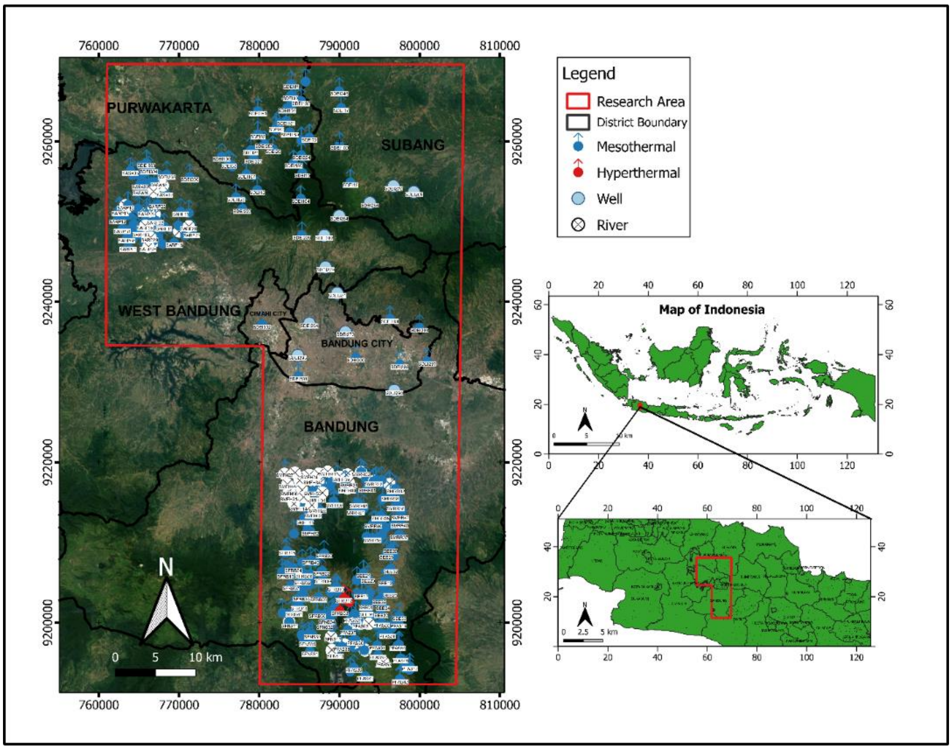

Figure 1 Area study

2 Research Method

The method employed in this study is principal component analysis (PCA) using Orange Data Mining software. A total of 674 data points were analyzed, including 58 primary data entries labeled as "P" in the data tabulation. Additionally, the dataset comprised 616 secondary observations, which consisted of 305 data points from supervisor Irawan (2020) and 311 data points from Susanto (2022).

Principal Component Analysis (PCA) is a widely employed technique for dimension reduction, particularly when dealing with extensive datasets characterized by high-dimensional features, facilitating data visualization. PCA utilizes statistical methods to linearly transform the data into a new coordinate system, thereby enabling the representation and visualization of data variations using a reduced number of dimensions. An important consideration during PCA analysis is to focus on the data variance. Specifically, the aim is to identify the component with the highest variance, which is retained, while discarding the remaining components with lower variances (Irawan et al., 2009).

3 Discussion

3.1 Geological Setting

The research site was divided into two distinct regions. The northern region encompasses Bandung City, Cimahi City, West Bandung Regency, Subang Regency, and Purwakarta Regency, which are indicated on the regional geological maps of the Bandung sheet (Silitonga, 1973) and the Cianjur sheet (Sudjatmiko, 1972). In accordance with the Bandung sheet (Silitonga, 1973), the northern area exhibits a stratigraphic sequence ranging from old to young formations, namely the Tertiary Citalang Formation, followed by old volcanic deposits, young volcanic deposits, and Quaternary Lake deposits.

Conversely, the Cianjur sheet (Sudjatmiko, 1972) indicates that the northern region comprises the Jatiluhur Formation and the Cantayan Formation, both of which are Tertiary in age, along with Quaternary old volcanic deposits.

The southern area, as depicted on the geological maps of Garut and Pameungpeuk (Alzwar et al., 1992), primarily consists of Quaternary volcanic rock units.

3.2 pH

The findings obtained from the principal component analysis (PCA) examination of the pH parameter distribution (Figure 2.a) reveal the presence of a distinct anomaly represented by a single data point located at the extreme left. This anomaly can be attributed to the inclusion of data from hot springs (hyperthermal) within volcanic craters, which exhibit exceptionally low pH values. Analysis of the constituent lithology and water body types (Figure 2.b) demonstrates an average pH value of 6.467, with the lowest recorded pH value of 1.46 and the highest pH value of 8.67. Notably, the lowest pH value is observed in the southern region of the study area, specifically at the site with the code SEE37. This data corresponds to the hot springs found within the volcanic crater of Mount Wayang-Windu. The geological characteristics of this area are consistent with other spring data, indicating that these springs originate from Quaternary volcanic rocks associated with ongoing volcanic activity.

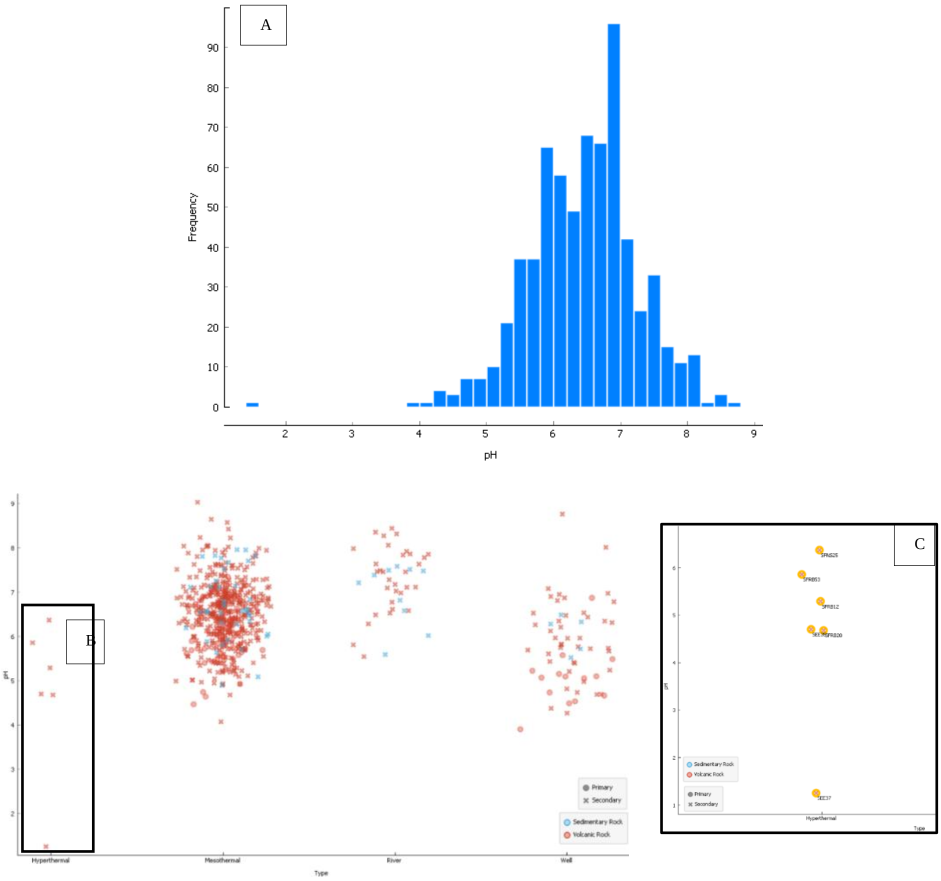

Figure 2.a pH distribution, **Figure 2.b** pH distribution based on lithology and water body type, and **Figure 2.c** Hot spring data.

The analysis of the pH distribution in the northern and southern regions (Figure 3.a) indicates distinct patterns. In the northern region, the pH values exhibit a relatively normal range, centered around 6.7. This suggests that the groundwater, influenced by sedimentary rock lithology, experiences a decrease in acidity levels. Conversely, the southern region demonstrates a relatively acidic pH range, with values hovering around 6. This observation suggests that the groundwater in this area is still impacted by volcanic activity, resulting in higher levels of acidity.

Further support for these findings is illustrated in Figure 3.c and Figure 3.d, which depict the flow of groundwater from acidic pH towards more basic pH conditions. The geological cross-sections displayed on the regional geological map provide additional insight.

The observed pH distribution patterns in the southern and northern regions provide valuable insights into the geological and hydrochemical characteristics of the study area. The average pH value of 6.1 in the southern region indicates an acidic nature of the groundwater, which can be attributed to the persistent volcanic activity of Mount Wayang-Windu. The ongoing volcanic eruptions release gases and minerals that react with the water, resulting in an increase in acidity. This volcanic influence contributes to the lower pH values observed in the groundwater, creating an environment that is more prone to acidic conditions.

3.3 Groundwater Flow

In contrast, the northern region displays a relatively less acidic environment, as evidenced by the average pH value of 6.7. The differences in pH between the southern and northern areas can be explained by variations in the underlying geological formations and volcanic activities. The northern region, characterized by its proximity to Mount Tangkuban Perahu, may experience a lesser degree of volcanic influence compared to the southern region. This difference in volcanic impact can be attributed to factors such as volcanic vent locations, lava flows, and the extent of volcanic gas emissions. As a result, the northern region exhibits a pH distribution that reflects a more neutral or slightly alkaline groundwater environment.

In the southern part of the research area, the groundwater flow initiates in a southward direction, originating from Mount Wayang-Windu and proceeding towards the north. In contrast, the northern region experiences groundwater flow originating from Mount Tangkuban Perahu, moving in a northward direction towards the south.

The consistent and unidirectional flow of groundwater from the south to the north in both the southern and northern areas hold significant implications for the hydrological dynamics and potential contaminant transport within these regions. This prevailing flow pattern suggests the presence of underlying geological and topographical factors that exert a dominant influence on the movement of groundwater. Understanding the direction of groundwater flow is crucial for assessing the vulnerability of aquifers, identifying potential sources of contamination, and designing effective management strategies for the sustainable utilization and protection of groundwater resources.

In the southern area, where the groundwater flow originates from the south and moves towards the north, this hydrological pattern may be attributed to several factors. One prominent influence is the volcanic activity associated with Mount Wayang-Windu, which continues to contribute to the hydrogeological characteristics of the region. The volcanic nature of the area can significantly impact the groundwater chemistry, resulting in relatively higher levels of acidity and potential mineralization. Furthermore, the geological structure and permeability of the subsurface layers, influenced by volcanic formations, may play a role in directing the groundwater flow path and establishing preferential flow channels.

Similarly, in the northern area, the consistent south-to-north groundwater flow can be linked to the geological framework of the region. The presence of Mount Tangkuban Perahu, a significant volcanic structure, may contribute to the hydrological patterns observed. Volcanic formations often exhibit distinct permeability properties, which can influence the movement and distribution of groundwater. Understanding the groundwater flow direction in this area is vital for managing water resources, particularly in terms of locating suitable extraction points, assessing potential contamination risks, and ensuring the sustainable supply of water for various sectors.

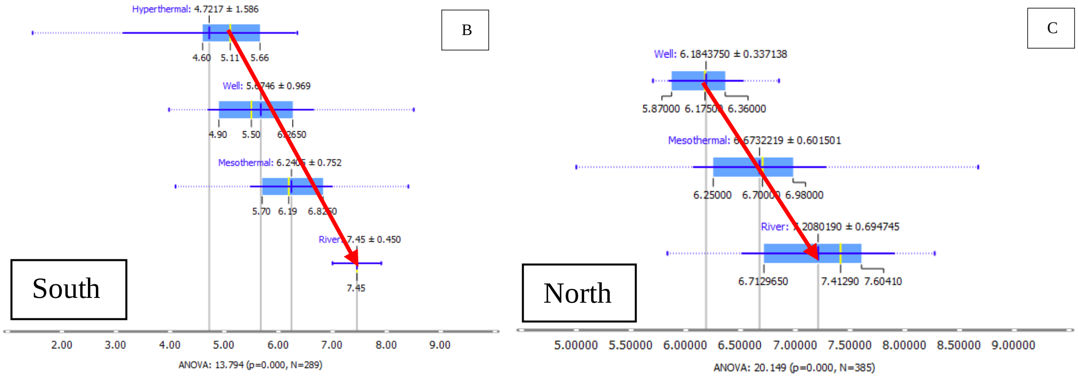

Figure 3.a pH distribution in the south and north, **Figure 3.b** pH distribution in the southern area, and **Figure 3.c** pH distribution in the northern area

4 Conclusions

In conclusion, this research yields the following key findings:

1. Understanding the pH distribution and its variation between the southern and northern regions is crucial for assessing the overall water quality and potential impacts on ecological systems and human health. The acidity observed in the southern region necessitates careful monitoring and management strategies to mitigate the potential adverse effects on aquatic ecosystems and groundwater-dependent activities such as agriculture. Additionally, the contrasting pH conditions highlight the need for tailored approaches in water treatment and resource management based on the specific hydrochemical characteristics of each region.

2. By comprehending the consistent south-to-north groundwater flow in both the southern and northern areas, researchers, policymakers, and water resource managers can make informed decisions regarding land use planning, pollution prevention measures, and groundwater management strategies. Moreover, these findings highlight the interconnectedness of hydrological processes and geological factors, emphasizing the need for an integrated approach to managing groundwater resources that considers both natural and anthropogenic influences on aquifer systems.

Further research and monitoring efforts are warranted to delve deeper into the complex interactions between volcanic activities, geological formations, and hydrochemical processes in order to enhance our understanding of the groundwater dynamics and to develop sustainable strategies for water resource management in volcanic regions.

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