Assessment of characteristics, water quality and groundwater vulnerability in Pakis District, East Java Province, Indonesia

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Abstract: Groundwater is a very important natural resource to support the activities of the residents of Pakis District, Malang Regency. On the other hand, increased activity puts pressure on groundwater quality. Agricultural intensification, urbanisation, and industrialisation can be sources of pollutants. Hydrological factors, topography, lithology, and surrounding rainfall are triggers for contamination of groundwater. The main objective of this research is to determine the characteristics, quality of groundwater, and its susceptibility to pollution. To complete this research, geoelectric measurements were carried out at 43 points spread throughout the study area and sampling of 18 shallow wells in agricultural, residential, and industrial areas for chemical analysis. All data obtained were analysed to create a map of the spatial distribution of groundwater vulnerability. The results show that the groundwater in the study location is in the transition zone and flows through the volcanic rock layers. The level of groundwater pollution is in the uncontaminated status to heavily polluted with pollutants in the form of heavy metal manganese and Escherichia coli bacteria. The spatial distribution of groundwater intrinsic vulnerability shows low, moderate, and high levels of vulnerability, respectively 32.99%, 60.87%, and 6.14% of the research area. Groundwater specific vulnerability associated with land use factors shows that 26.25% are negligible, 42.46% are low, and 31.29% are moderate. From this it can be concluded that the study area has been polluted both geogenically and anthropogenically, therefore, special actions must be taken to restore the quality of groundwater.

Keywords: geoelectric, groundwater, intrinsic vulnerability, pollution, quality of groundwater, specific vulnerability

INTRODUCTION

Groundwater has now become a very important water resource to meet clean water needs. Domestic, agricultural, and industrial activities are some of the sectors that need clean water [ALLEY et al. 1999; BISWAS et al. 2009; MACHIWAL et al. 2018; UNESCO 2018; ZERTSER 2000]. These activities also produce waste which harms groundwater quality [SALMAN et al. 2019].

The hydrogeological characteristics of the surrounding environment affect the level of groundwater vulnerability to pollution [TODD 1980; VERBA, ZAPOROZEC 1994; WIDYASTUTI et al. 2006]. Hydrogeological characteristics consisting of groundwater level depth, rainfall, topography, and rock lithology are called intrinsic factors. Meanwhile, land use and contaminant types are specific factors [RIBEIRO et al. 2017].

Until now, there is no consensus on the method of assessing the vulnerability of groundwater to pollution [ARAUZO 2017; FOSTER et al. 2007]. The LU-IV method introduced by ARAUZO [2017] has several advantages over the currently widely used DRASTIC and GOD methods [ARAUZO 2017; SALMAN et al. 2019]. This procedure not only assesses the intrinsic vulnerability but also the specifics of groundwater.

Several studies show that groundwater vulnerability has occurred in the Pakis District area. Pakis District will have a potential deficit of groundwater in 2030 [IMAN et al. 2011; PUTRI, PERDINAN 2018] due to its very poor carrying capacity [RIVAD
Until now, there have been no studies related to groundwater vulnerability assessment in the Pakis District area. The objectives of this study are: (a) to identify the characteristics of groundwater, (b) to investigate the source of groundwater contamination, (c) to assess the vulnerability and quality of groundwater in the Pakis District, Malang Regency.

Groundwater vulnerability assessment is an important step in several years to understand and evaluate pollution to aquifer layers.

MATERIAL AND METHODS

STUDY AREA

The study location is located in Pakis District, Malang Regency, East Java Province, Indonesia. Located at coordinates 112.4018–112.4507 E longitude and 7.56.21–7.5956 S latitude (Fig. 1). An area with an area of 53.62 km², the land use is dominated by agricultural areas (71%), settlements (27%), and industry (2%). The study location has a tropical climate and rock lithology which is in the poor sheet influenced by volcanic or volcanic sedimentary rocks.

SAMPLING AND ANALYSIS

The study data were obtained from secondary and primary data. Primary data is in the form of rock lithology data obtained from measurements using the geoelectric method at 43 points scattered throughout the study location (Fig. 2). Using the Kentada Resistivitimeter RM 103 geoelectric tool, identify rock layers based on differences in resistivity values up to a depth of 60 m.

Groundwater quality data obtained from measurements of 18 well samples either directly on-site or chemical analysis in the laboratory. Sampling in agricultural, residential, and industrial areas (Fig. 3). The temperature, pH, and conductivity parameters were measured directly using the Horiba U50 water quality device. Parameters iron (Fe²⁺), manganese (Mn²⁺), sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), carbonates (CO₃²⁻), bicarbonates (HCO₃⁻), chloride (Cl⁻), sulphates (SO₄²⁻) and nitrates (NO₃⁻) were analysed in a chemical laboratory, Faculty of Mathematics and Natural Sciences Universitas Brawijaya. The microbiological parameters of the Escherichia coli bacteria were analysed using MPN method in the microbiology laboratory, Faculty of Medicine Universitas Brawijaya.

Fig. 1. The area of Pakis District; source: own elaboration

Fig. 2. Geoelectrical measurement points; source: own elaboration

Fig. 3. Water quality sampling points; source: own elaboration
IDENTIFICATION OF GROUNDWATER CHARACTERISTICS

Lithology and aquifer layers

Identification of rock layers using the Schlumberger configuration to a depth of 60 m. The electrode length (m), current value (I), and voltage value (V) will be obtained during the measurement process. Then the resistance value is obtained by dividing the voltage value by the current (1). The geometry factor of the Schlumberger configuration (K) is obtained from the calculation of the distance between the current and potential electrodes (2). The apparent resistivity (ρa) is obtained by multiplying the value of the geometric factor and the resistance (3) [SUHENDRA 2016].

\[
R = \frac{V}{I} \quad (1) \\
K = n(n+1)\pi a \quad (2) \\
\rho_a = K \cdot R \quad (3)
\]

You will get the apparent resistivity ρa value (Ω·m) for each depth (m). Interpretation is carried out to determine the type of rock based on the resistivity value.

Groundwater hydrochemistry

Groundwater chemical phase analysis using the computer program GW Chart version 1.30 (www.water.usgs.gov, accessed in 2020), groundwater chemical phase analysis using the Piper diagram. Piper diagram can identify sources of dissolved elements in groundwater, changes in groundwater properties specific areas, and their relation to geochemical problems. Chemical elements include: sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), carbonates (CO₃²⁻), bicarbonates (HCO₃⁻), chlorides (Cl⁻), and sulphate (SO₄²⁻).

GROUNDWATER POLLUTION INDEX

The groundwater pollution index is obtained from the comparison of the value of each parameter of water quality to the water quality standard. The quality standard used is the Regulation of the Minister of Health of the Republic of Indonesia [Peraturan … Nomor 492/menkes/per/iv/2010]. The price of the pollution index for designation (j) can be calculated using the Equation:

\[
P_{ij} = \sqrt{\left(\frac{C_i}{L_i}\right)_M^2 + \left(\frac{C_i}{L_i}\right)_R^2} \quad (4)
\]

where: \(P_{ij}\) = the pollution index (Tab. 1), \(C_i\) = pollutant concentration, \(L_i\) = value of water quality standards for each parameter, \(M\) = minimum value, \(R\) = average value.

The weights of each environmental parameter are shown by SALMAN et al. [2019] (Tab. 2).

Table 1. Water quality pollution index (\(P_{ij}\))

<table>
<thead>
<tr>
<th>(P_{ij}) value range</th>
<th>Quality status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ≤ (P_{ij}) ≤ 1.0</td>
<td>negligible</td>
</tr>
<tr>
<td>1.0 ≤ (P_{ij}) ≤ 5.0</td>
<td>lightly polluted</td>
</tr>
<tr>
<td>5.0 ≤ (P_{ij}) ≤ 10</td>
<td>moderately polluted</td>
</tr>
<tr>
<td>(P_{ij}) &gt; 10</td>
<td>severely polluted</td>
</tr>
</tbody>
</table>


Table 2. Ranges and ratings for risks associated with environmental parameters related to groundwater vulnerability

<table>
<thead>
<tr>
<th>Litology of the vadose zone (L)</th>
<th>rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcretes, karst limestone, gravels</td>
<td>10</td>
</tr>
<tr>
<td>Chalky limestone calcarenites</td>
<td>9</td>
</tr>
<tr>
<td>Alluvial and fluvo-glacial sands, recent volcanic lavas</td>
<td>7–8</td>
</tr>
<tr>
<td>Aeolian sands, volcanic tuffs, igneous/metamorphic formations and older volcanic formulations, sandstones, conglomerates, peat</td>
<td>5–6</td>
</tr>
<tr>
<td>Alluvial silts, loess glacial till, loam, mudstones, shales</td>
<td>3–4</td>
</tr>
<tr>
<td>Clays, residual soils</td>
<td>1–2</td>
</tr>
</tbody>
</table>

Depth to the water table (D)

Ranges (m) | rating
---|---
All depths (for calcretes, karst limestone, chalky limestones calcarenites, recent volcanic lavas) | 10
<0; 5> | 9
(5; 10> | 8
(10; 20> | 6
(20; 50> | 4
>50 | 2
None | 1

Topography (T)

Slope (%) | rating
---|---
<0; 2> | 10
(2; 3> | 9
(3; 4> | 8
(4; 5> | 7
(5; 6> | 6
(6; 9> | 5
(9; 12> | 4
(12; 15> | 3
(15; 18> | 2
>18 | 1

Annual precipitation (P)

Ranges (mm) | rating
---|---
>900 | 10
(800; 900> | 9
(700; 800> | 8
(600; 700> | 7
(500; 600> | 6
(400; 500> | 5
(300; 400> | 4
(200; 300> | 3
(100; 200> | 2
<0; 100> | 1
GROUNDWATER VULNERABILITY ASSESSMENT

The LU-IV procedure is divided into two stages, namely intrinsic susceptibility assessment (stage 1) and specific assessment (stage 2). This groundwater vulnerability assessment uses ArcGIS 10.4 for desktop.

Groundwater intrinsic vulnerability (index IV) According to ARAUZO [2017] intrinsic vulnerability is obtained using a simple algorithm:

$IV = \frac{\sum_{j=1}^{n} P_{rj}}{n}$

where: $P_{rj}$ = the weight of each selected environmental parameter, $n$ = the number of environmental parameters. The selected environmental parameters include rainfall ($P$), topography ($T$), groundwater level depth ($D$), and rock lithology ($L$) in the unsaturated zone. The weights of each environmental parameter are shown by ARAUZO [2017].

The intrinsic vulnerability has five status categories, including: negligible, low, moderate, high, and very vulnerable are shown in Table 3.

Rainfall data were obtained from four rain stations closest to the research location from the PUPR office in the SDA sector of East Java Province. Rainy period from 2009 to 2018. The data is tested for consistency using the RAPS method [SRI HARTO 1993] which shows that the data can be accepted with 90% confidence.

Groundwater specific vulnerability

The specific vulnerability is calculated by overlaying the intrinsic reclassification map with the land use map. Based on the procedure [ARAUZO 2017], they reclassify the intrinsic vulnerability map to a value of 1 for non-vulnerable status (0) to low vulnerable (4), and a value of 0 for moderately vulnerable status (5) to very vulnerable (10).

Land use maps were obtained from the Geospatial Information Agency (BIG) with land uses including irrigated agricultural areas (31.29%), rainfed land (38.26%), urban areas (19.97%), and shrubland (2.59%). The weights for each land use are shown in Table 3. The overlay results of the two results in mapping specific vulnerability zones.

RESULTS AND DISCUSSION

GROUNDWATER CHARACTERISTICS

Groundwater is water that occupies and flows through rock lithology cavities in unsaturated layers [BISRI 2012]. Rock layers with medium to coarse grains are good for draining and storing water. The lithology of the study location is influenced by three volcanic rock formations, namely gendis volcanic rock formations on the north side (Qpg), Malang tuff sedimentary rock (Qvtm), and buring volcanic rock (Qpb). The constituent rocks include clay, tuff, sand, breccia, and lava. The tuff and sand layers have medium to coarse grain sizes that provide excellent aquifer layers. Meanwhile, the breccia and lava layers are compact rock layers that are very hard. The presence of aquifer layers was identified on the east, south, and west sides of the study site. Meanwhile, in the north and center of the research location, there was no shallow aquifer layer. The distribution of the aquifer layer is shown in Figure 4.

<table>
<thead>
<tr>
<th>Intrinsic range</th>
<th>Index status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–2</td>
<td>negligible</td>
</tr>
<tr>
<td>3–4</td>
<td>low</td>
</tr>
<tr>
<td>5–6</td>
<td>moderate</td>
</tr>
<tr>
<td>7–8</td>
<td>high</td>
</tr>
<tr>
<td>9–10</td>
<td>very vulnerable</td>
</tr>
</tbody>
</table>

Source: ARAUZO [2017] and SALMAN et al. [2019].
Based on the analysis of the Piper diagram (Fig. 5), the chemical phase of groundwater in Pakis District is dominated by magnesium cations (Mg\(^{2+}\)) and sulphate anions (SO\(_4^{2-}\)). Groundwater flows in the transition zone of the groundwater drainage system with the Mg–Ca–Na cations type and Cl–SO\(_4\) anions type. Passing through the space between volcanic rocks that are easily weathered and contributing minerals to Ca, K, and S [DEVNITA 2012; PURWANTO et al. 2018].

### GROUNDWATER POLLUTION INDEX

The quality of groundwater in the Pakis District is negligible until high contaminated (Tab. 4). Contamination occurs due to concentrations of heavy metal Mn and *E. coli* bacteria that exceed the quality standard for drinking water. Mn minerals are very abundant in nature, in rock layers in the form of manganese ore and ferrous manganese [POST 1999] which are then dissolved by groundwater to form brown or blackish deposits of manganese oxide. Contamination caused by rock minerals is called geogenic contamination. *E. coli* bacterial contamination was identified in wells that were close to the septic tank building and had poor sanitation. The content of *E. coli* bacteria from good observations reached 900 per 100 cm\(^3\). *E. coli* contamination due to domestic waste is called anthropogenic contamination.

### GROUNDWATER VULNERABILITY TO POLLUTION

Groundwater intrinsic vulnerability assessment considers natural factors of the groundwater system [GOGU, DASSARGUES 2000], including hydrological conditions, topography, and rock lithology [ARAUZO 2017].

Precipitation data from four rain stations shows that the research location has a very high intensity, namely >2000 mm·y\(^{-1}\). Reclassification of the precipitation map that the research location is very homogeneous (Fig. 6). High precipitation is an indication that more water is filling groundwater and is

![Piper phase diagram of groundwater in Pakis District; source: own study](image)

**Fig. 5.** Piper phase diagram of groundwater in Pakis District; source: own study

### Table 4. Groundwater pollution index (\(P_{ij}\)) in Pakis District in investigated dug wells

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample code</th>
<th>(0&lt;P_{ij}\leq 1)</th>
<th>(1&lt;P_{ij}\leq 5)</th>
<th>(5&lt;P_{ij}\leq 10)</th>
<th>(P_{ij}&gt;10)</th>
<th>Pollution status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jl. Industri Gang 1 RT 3 RW 2, Desa Mangliawan</td>
<td>S01</td>
<td>4.855</td>
<td></td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Wendit Barat, RT 4 RW 3, Desa Mangliawan</td>
<td>S02</td>
<td></td>
<td>6.820</td>
<td></td>
<td></td>
<td>moderate</td>
</tr>
<tr>
<td>Desa saptorenggo, RT 21 RW 3</td>
<td>S03</td>
<td></td>
<td></td>
<td>11.311</td>
<td></td>
<td>high</td>
</tr>
<tr>
<td>Dusun Genitri, RT 1 RW 2, Desa Tirtomoyo</td>
<td>S04</td>
<td>0.731</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
</tr>
<tr>
<td>Jl. Raya Bamban Desa Saptorenggo</td>
<td>S07</td>
<td></td>
<td>3.411</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Jl. Ampeldento No 89, Desa Ampeldento</td>
<td>S11</td>
<td></td>
<td>2.412</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Bonangan Desa Sumberkradenan</td>
<td>S12</td>
<td></td>
<td>2.477</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>RT 02 RW 03 Desa Kedungrejo</td>
<td>S13</td>
<td></td>
<td>2.925</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>RT 02 RW 01 Desa Banjarejo</td>
<td>S14</td>
<td></td>
<td>4.497</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Klethak, RT 13 RW 4 Desa Pucangsongo</td>
<td>S15</td>
<td>0.818</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
</tr>
<tr>
<td>RT 6 RW 8 Desa Sukoanyar</td>
<td>S16</td>
<td></td>
<td>2.938</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Perum Simpang Wisnuwardhana IV No 16</td>
<td>S17</td>
<td></td>
<td>2.482</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Gagak Asinan, Desa Sumber Pasir</td>
<td>S19</td>
<td>0.816</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
</tr>
<tr>
<td>Dsn Ngranggen Desa Sumber Pasir</td>
<td>S20</td>
<td></td>
<td>2.477</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Gentong, Desa Tirtomoyo</td>
<td>S23</td>
<td></td>
<td>2.950</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Padas Pecah, Desa Pakis Kembar</td>
<td>S24</td>
<td></td>
<td>2.942</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Krajan RT 1 RW 1 Desa Sumber Kradenan</td>
<td>S25</td>
<td></td>
<td>4.476</td>
<td></td>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Dsn Trajeng Desa Pakis Jajar</td>
<td>S26</td>
<td></td>
<td>4.338</td>
<td></td>
<td></td>
<td>low</td>
</tr>
</tbody>
</table>

Source: own study.
increasingly susceptible to pollution. Apart from being a solvent, rainwater is also a diluent.

Land slope related to surface water flow. The flatter, the more water stagnates and increases the infiltration and percolation of water into the soil. Based on topographic data from DEMNAS maps, the slope of the study sites varied greatly from 0 to 18%. Based on the weight, it shows that the slope is divided into five classes (Fig. 7). Weight 10 is for the slope 0 to 2%; weight 9 is for the slope 2 to 3%; weight 5 is for the slope 5 to 6%; weight 3 is for the slope 12 – 15%; and weight 1 is for the slope more than 18%.

Shallow groundwater is very vulnerable to contamination. Soil thickness affects the rate of flow of contaminants reaching groundwater so that it affects the level of pollution [SALMAN et al. 2019; THIRUMALAIVASAN et al. 2003]. The depth of the groundwater level at the study sites varied from 15 to 60 m. Weighted groundwater level is divided into three classes (Fig. 8). Weight 6 is for the depth 10–20 m; weight 4 is for the depth 20–50 m; and weight 2 is for the depth >50 m.

Dissolved pollutants flow through rock layers in the unsaturated zone before contact with groundwater. Rock type affects the rate of contaminant infiltration to contaminate groundwater [ALLER et al. 1987; SALMAN et al. 2019]. Rocks with fine grains are impermeable to water and vice versa. The unsaturated zone layer is dominated by layers of clay, tuff, and sandy tuff. Based on the weight, the clay layer is less susceptible to contamination than the tuff and sandy tuff layers (Fig. 9). Weight 1 is for clay layers, weight 5 is for tuff layers; and weight 6 is for sandy tuff layers.

Based on the calculation of the intrinsic vulnerability index of the four environmental factors (IV index), it shows that 32.99% are low vulnerable, 60.87% moderate vulnerable and 6.14% of high vulnerable from the study area (Fig. 10). The low vulnerability zones include areas that have deeper groundwater depths and steep slope of land. The high vulnerability zones include areas that have shallow groundwater depths and flat land areas. The study area was dominated by moderate vulnerability.
The next stage is to assess the specific vulnerability of groundwater by adding land-use factors. The study areas are consists of 38.26% of moor land areas or field areas, 31.29% of rice areas, 19.97% of settlements or urban areas, and 2.59% of shrubs areas. Based on the weights, the level of vulnerability associated with land use is divided into four classes. Weight 10 is for rice areas, weight 7 is for urban areas, weight 5 is for woody crops or field land, weight 3 is for shrubs areas, and weight 1 is for forest or natural areas. Rice areas and urban areas are more susceptible to pollution than fields and shrubs (Fig. 11).

The specific vulnerability of groundwater to pollution is obtained by overlaying the spatial distribution map of land use with a reclassification of the groundwater intrinsic vulnerability map (Fig. 12). A value of 0 for a moderate to high vulnerable condition, and a value of 1 for negligible to low vulnerable condition.

Fig. 9. Map of spatial distribution of area classified acc. to unsaturated zone litological index; source: own study

Fig. 10. Map of the intrinsic groundwater vulnerability; source: own study

Fig. 11. Map of spatial distribution of area classified acc. to land use index; source: own study

Fig. 12. Map of reclassification of intrinsic spatial distribution; source: own study
The overlay results show that the Pakis District area consists of 26.25% in a negligible, 42.46% in low vulnerable, and 31.29% in moderately vulnerable status (Fig. 13). The negligible zones include forest and shrubs area, the low vulnerable zones include moor land or fields areas, and moderate vulnerability zones include rice areas and urban areas. The study area was dominated by low vulnerable zone due to the vast dry agricultural fields.

In the negligible zone, groundwater pollution can still occur due to significant leakage of aquifer layers in certain locations [FOSTER et al. 2007; SISWOYO 2018]. Aquifer leaks due to domestic pollution in the study location due to leakage of septic tank buildings and damage to sanitation around the wells.

CONCLUSIONS

1. Groundwater in the study location is in a transition zone that flows through a volcanic aquifer layer in the form of a sandy tuff layer. The chemical phase of groundwater is dominated by Mg cations and SO4 anions.
2. Pollution of groundwater quality is caused by the geogenic waste of heavy metal Mn and anthropogenic waste of coli bacteria.
3. Based on the LU-IV method, the intrinsic vulnerability of groundwater is in a low to high vulnerable status. Meanwhile, the specific vulnerability associated with land use factors is in the negligible to moderate vulnerability status. The sanitary conditions around the wells act as a trigger agent for groundwater pollution, so it is advisable to improve sanitation to prevent groundwater pollution.

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