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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; Zektser 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; Vrba, Zaporožec 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 [Riyadi

2018]. 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 km^2, 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.

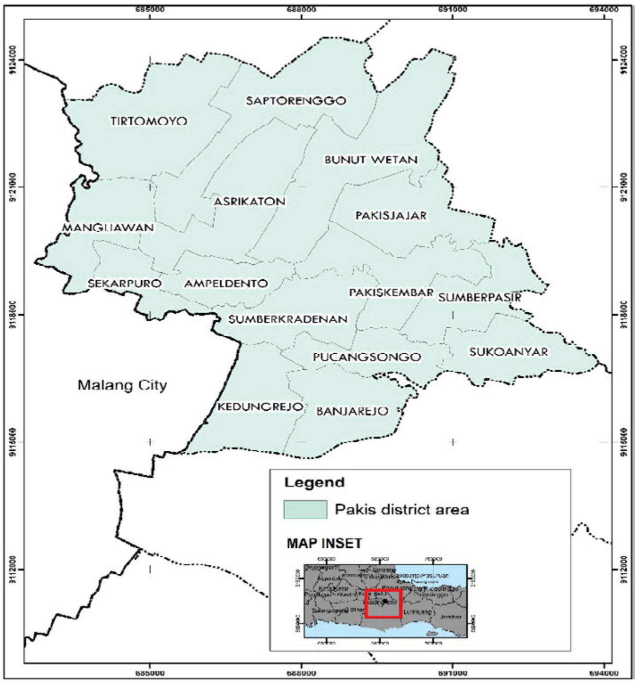

Fig. 1. The area of Pakis District; source: own elaboration

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 (Fe^{2+}), manganese (Mn^{2+}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonates $(CO_3)^{2-}$, bicarbonates (HCO_3^-), chloride (Cl^-), sulphates (SO_4^{2-}) and nitrates (NO_3^-) 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.

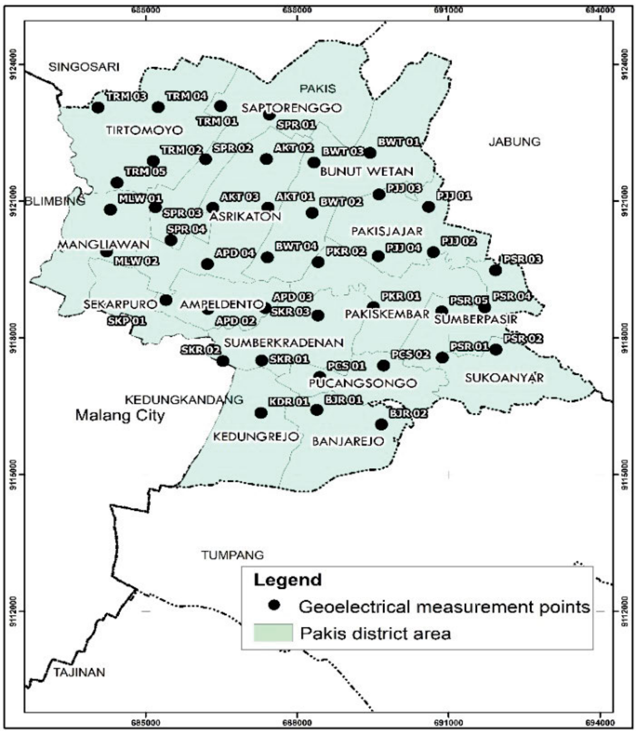

Fig. 2. Geoelectrical measurement points; source: own elaboration

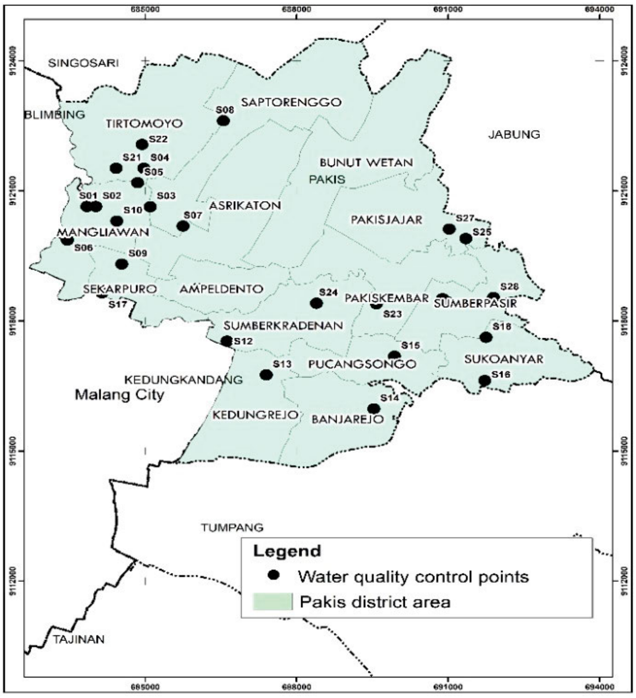

Fig. 3. Water quality sampling points; source: own elaboration

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].

$$R = \frac{V}{I} \tag{1}$$

$$K = n(n+1)\pi a \tag{2}$$

$$\rho a = K \cdot R \tag{3}$$

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 (Ca^{2+}), magnesium (Mg^{2+}), carbonates $(CO_3)^{2-}$, bicarbonates (HCO_3^-), chlorides (Cl^-), and sulphate (SO_4^{2-}).

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:

$$P_{ij} = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}} \tag{4}$$

where: P_{ij} = the pollution index (Tab. 1), C_i = pollutant concentration, L_{ij} = 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})

P_{ij} value range	Quality status
$0 \le P_{ij} \le 1.0$	negligible
$1.0 \le P_{ij} \le 5.0$	lightly polluted
$5.0 \le P_{ij} \le 10$	moderately polluted
$P_{ij} > 10$	severely polluted

Source: Keputusan … No. 115/2003.

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

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

cont Tab. 2

Land use	
Types	rating
Irrigated land (horticultural crops)	10
Irrigated land (herbaceous forage crops)	9
Urban areas	7
Irrigated land (woody crops)	7
Rainfed land (herbaceous crops)	6
Rainfed land (woody crops)	5
Meadows and pastures	5
Shrubland, unproductive land	3
Forest and natural areas	1

Source: Arauzo [2017], modified.

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:

$$IV = \frac{\sum_{j=1}^{n} Prj}{n} \tag{5}$$

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.

Table 3. Intrinsic vulnerability index

Intrinsic range	Index status
1–2	negligible
3–4	low
5–6	moderate
7–8	high
9–10	very vulnerable

Source: Arauzo [2017] and Salman et al. [2019].

Topographic data is generated from DEMNAS maps issued by the Geospatial Information Agency (Ind. Badan Informasi Geospasial – BIG) with a data resolution of 8 m. The depth of the groundwater level is obtained by measuring directly in the community's wells, using a meter. The lithology of rocks in the unsaturated zone is obtained from geoelectric measurement data. The depth of the layer starts from the ground surface to the boundary of the aquifer layer. Using the Spatial Analyst Tools menu in the Arc GIS application, a mapping of intrinsic vulnerability zones can be made.

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 burring 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.

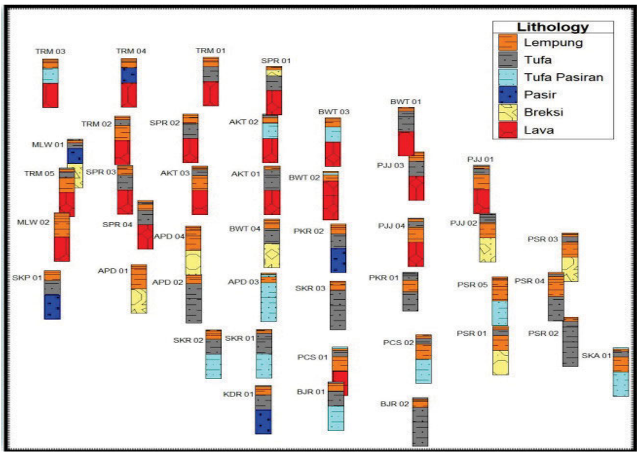

Fig. 4. Distribution of rock lithology in Pakis District; source: own study

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].

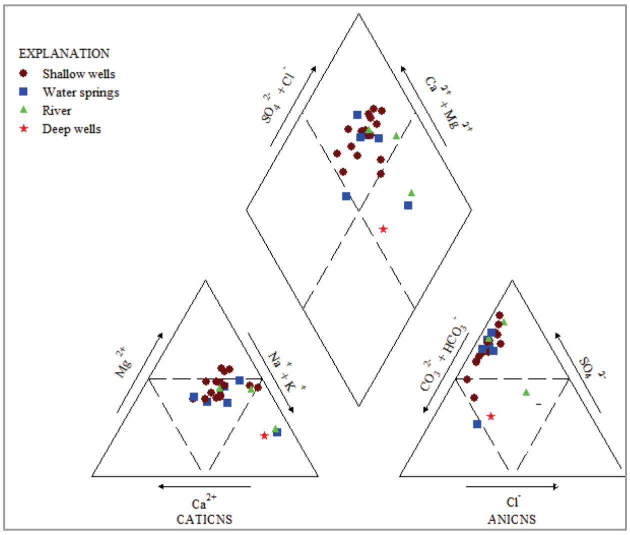

Fig. 5. Piper phase diagram of groundwater in Pakis District; source: own study

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

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

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

Source: own study.

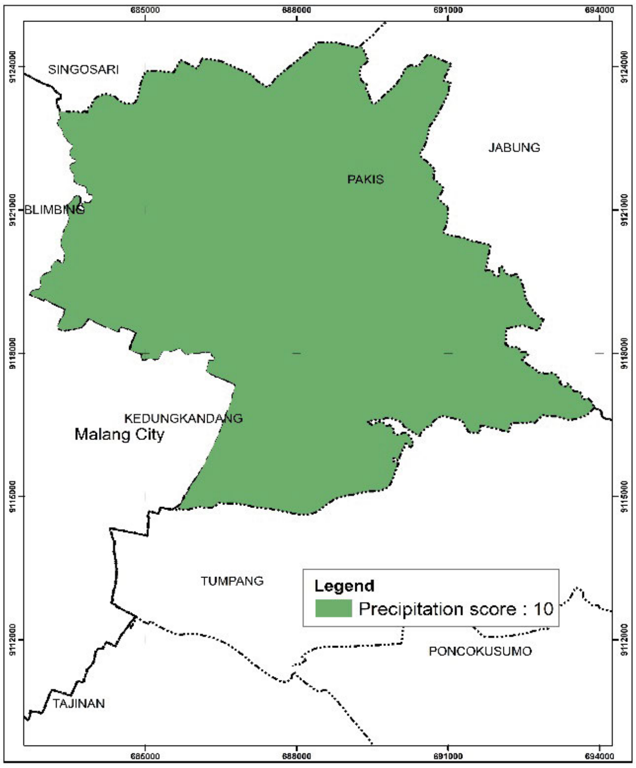

Fig. 6. Map of precipitation index distribution; source: own study

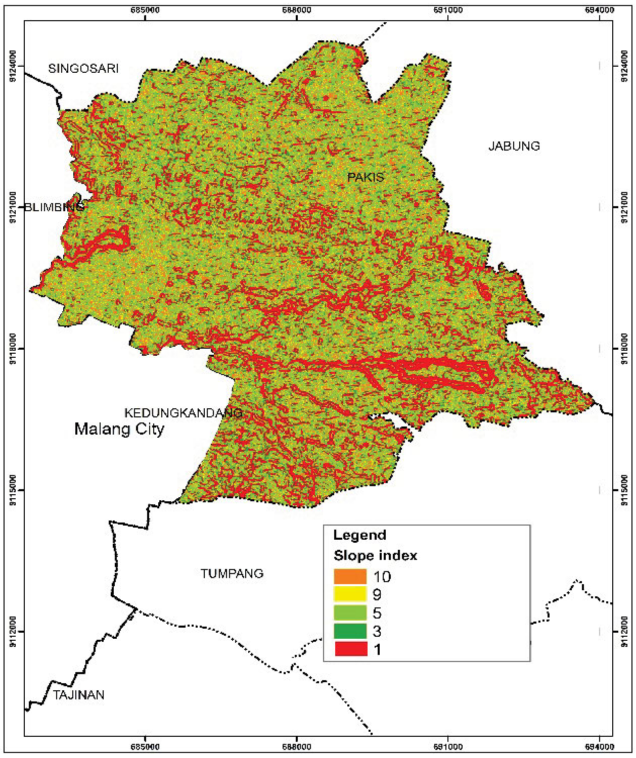

Fig. 7. Map of spatial distribution of area classified acc. to slope index; source: own study

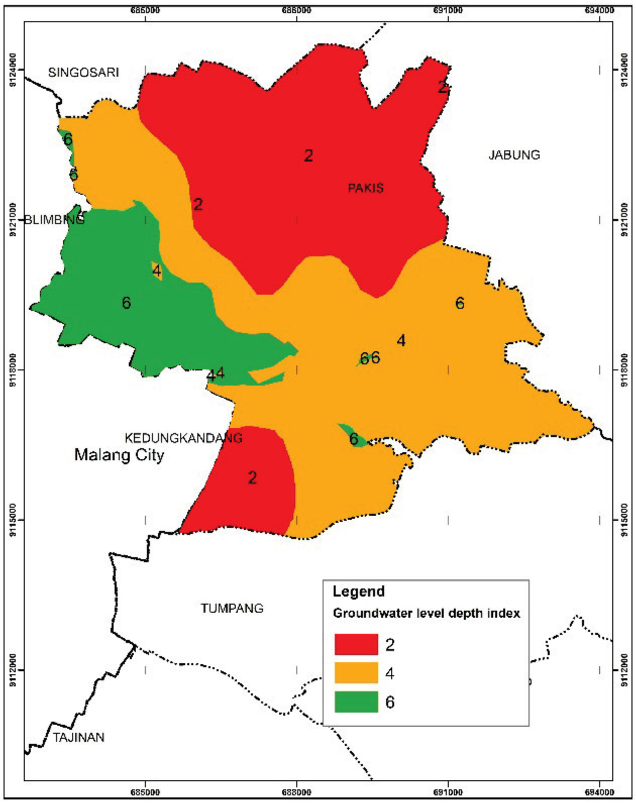

Fig. 8. Map of spatial distribution of area classified acc. to groundwater depth level index; source: own study

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 moderated vulnerability.

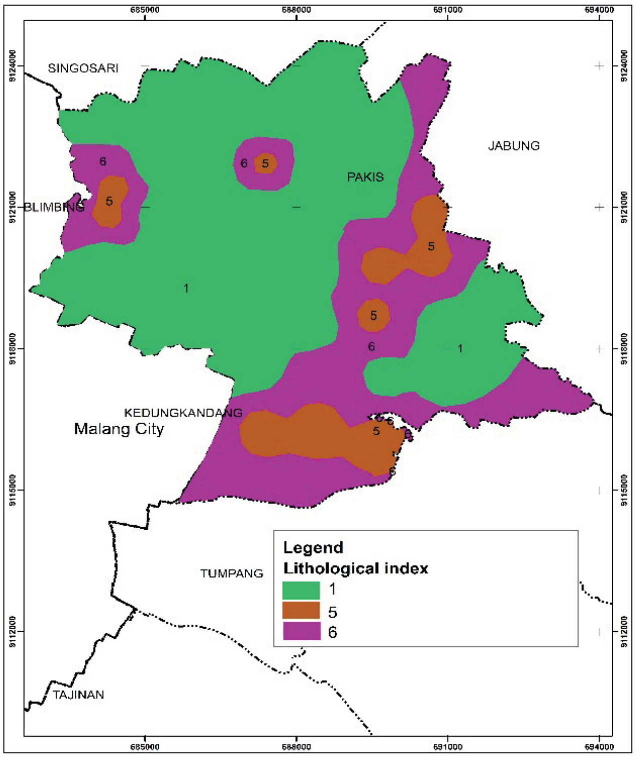

Fig. 9. Map of spatial distribution of area classified acc. to unsaturated zone litological index; source: own study

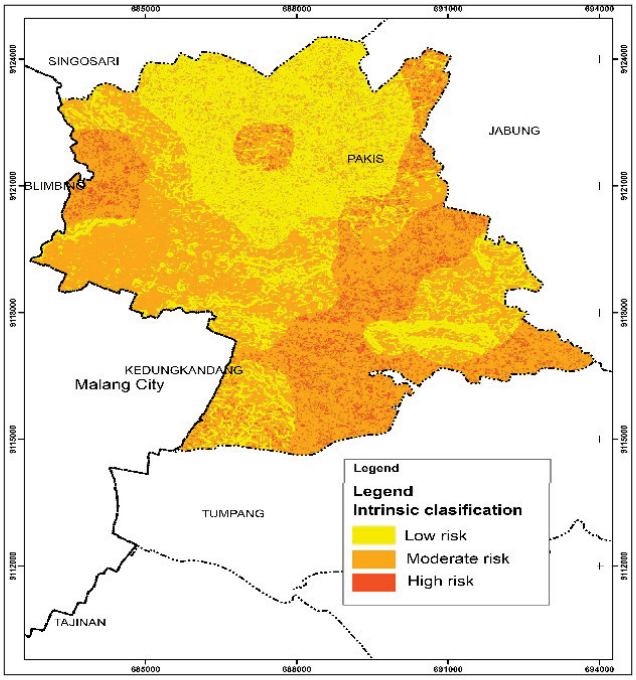

Fig. 10. Map of the intrinsic groundwater vulnerability; source: own study

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.

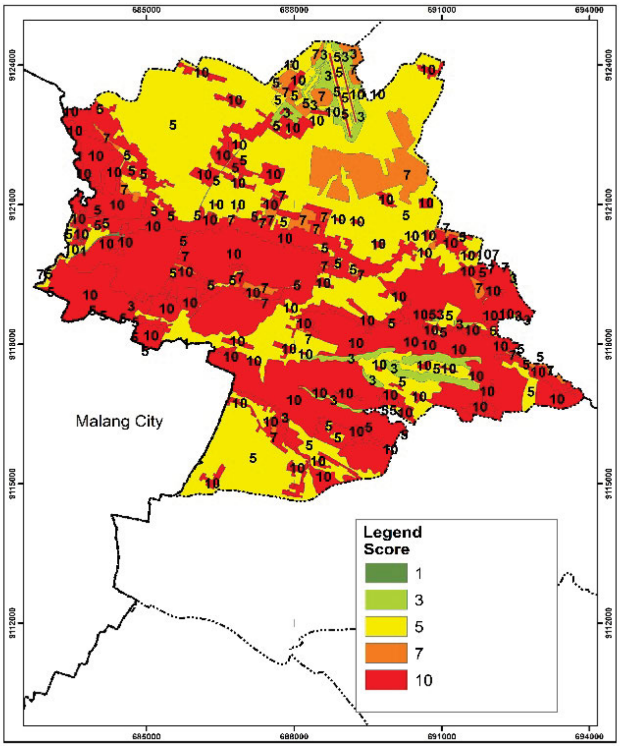

Fig. 11. Map of spatial distribution of area classified acc. to land use index; source: own study

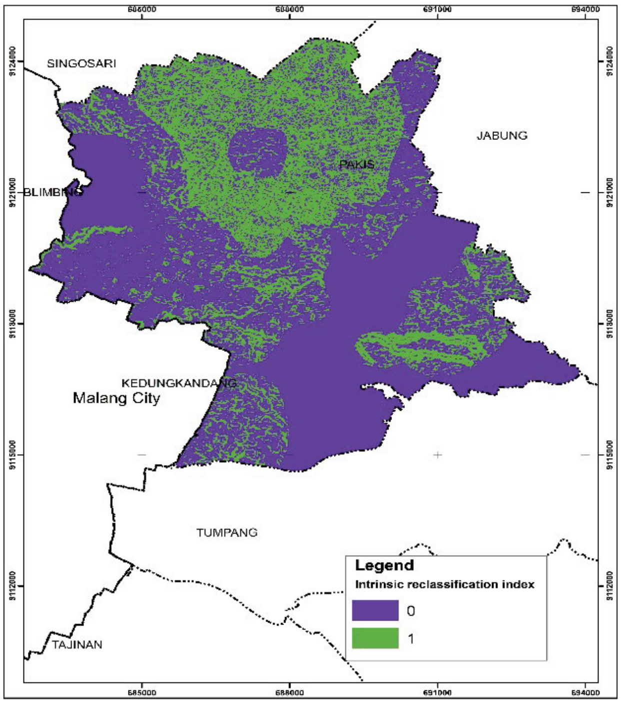

Fig. 12. Map of reclassification of intrinsic spatial distribution; source: own study

The overlay results show that the Pakis District area consist of 26.25% is in a negligible, 42.46% is in low vulnerable, and 31.29% is in moderately vulnerable status (Fig. 13). The negligible zones includes forest and shrubs area, the low vulnerable zones includes moor land or fields areas, and moderate vulnerability zones includes rice areas and urban areas. The study area was dominated by low vulnerable zone due to the vast dry agricultural fields.

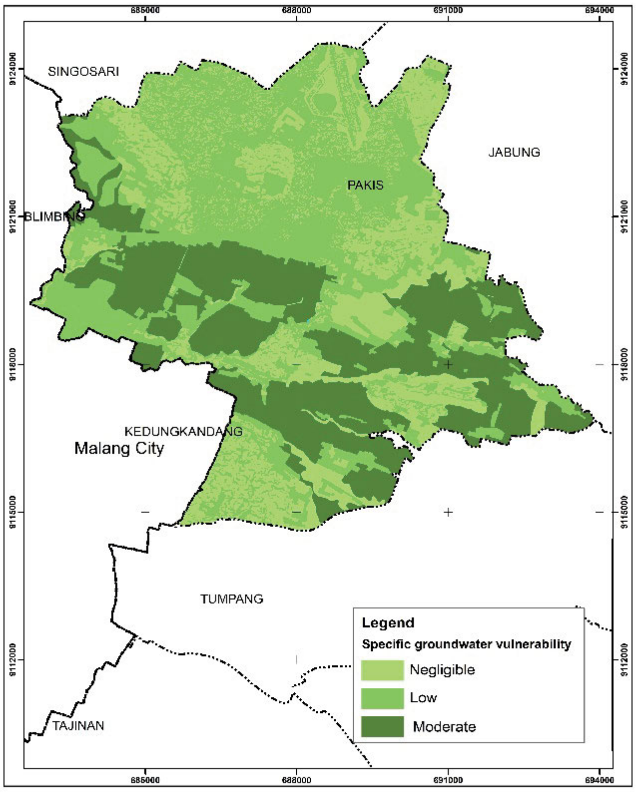

Fig. 13. Map of the specific groundwater vulnerability; source: own study

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 SO_4 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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