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Determination of groundwater quality index for irrigation and its suitability for agricultural crops in Jombang Regency, East Java, Indonesia

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Abstract

The objective of this study was to determinate groundwater quality index for irrigation and its suitability for agricultural crops in the development area of groundwater potential for irrigation in Jombang regency. This study was based on 25 groundwater samples from bored wells at the confined aquifer by using IWQI model proposed by Meireles *et al.* (2010). Results revealed the IWQI value of the groundwater samples in the study area were found to be in the range 57.1–95.8, indicating the groundwater quality laid between moderate restriction and no restriction for irrigation. The agricultural land located in the areas with moderate water usage restrictions was suggested to be planted with crops that are moderately tolerant to salt, meanwhile in the areas with low water usage restrictions types of crop that are moderately sensitive and moderately tolerant to salts were suggested, and all crops tolerant to salt could be planted in the areas with no water usage restrictions.

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Introduction

Jombang regency is one of the areas in East Java Province of Indonesia where the potential for groundwater has been developed for irrigation puposes (Siswoyo *et al.*, 2016[a], 2016[b]). The cost of utilization of groundwater for irrigation is relatively more expensive when compared with surface water, because the utilization of groundwater is done by using a pump that requires fuel and farmers are required to bear the cost of operating the pump. Therefore the farmers' income should be increased by choosing the type of crops cultivated.

Types of agricultural crops cultivated should have high economic value (Haryono *et al.*, 2009). However, at the moment in these locations there is no guidance on the direction of the suitability of the groundwater quality for irrigating agricultural crops. It makes farmers do not have a description of the types of agricultural crops which can be cultivated on their land so they referring to the crop types that have been cultivated in general in the region.

The models of Irrigation Water Quality Index (IWQI) has now been developed extensively by researchers such as IWQI model proposed by Meireles *et al.* (2010). This model reflects soil salinity and sodicity risks and water toxicity to plants.

The IWQI model is based on parameters i.e.: electrical conductivity (EC), concentration of sodium (Na^+), concentration of chloride (Cl^-), concentration of bicarbonate (HCO_3^-), and adjusted sodium adsorbtion ratio (SAR°). Based on this model, water use restrictions for soil and plants can be recommended (Meireles *et al.*, 2010). The model has been used by other researchers in Iraq (Al-Mussawi, 2014; Khalaf and Hassan, 2013) and in Egypt (Omran *et al.,* 2014), however it has not been used in Indonesia and in the study area in particular.

Based on the description as stated above, it would require a study to determine the index of the quality of groundwater for irrigation and its suitability with the type of agricultural crops in the study area. Through this study is expected to be designed.

Zonation of groundwater quality index for irrigation and its suitability with agricultural crops, which can be used as an alternative solution for the farmers to choose the type of crops cultivated on the groundwater irrigated land so that resulting in better productivity with high economic value.

The objective of this study was to determine groundwater quality index for irrigation and its suitability for agricultural crops in the development area of groundwater potential for irrigation in Jombang regency using the applied model of IWQI proposed by Meireles *et al.* (2010). This study is a continuation of previous studies (Siswoyo *et al.*, 2016[a], 2016[b]).

Materials and methods

Description of the study area

The study area was located in Jombang regency, East Java Province, Indonesia which has the same description as in the previous studies (Siswoyo *et al.*, 2016[a], 2016[b]). In this present study, the study area was restricted only in the development area of groundwater potential for irrigation in Jombang regency, which covers 8 districts i.e.: Mojowarno, Mojoagung, Diwek, Jogoroto, Sumobito, Jombang, Peterongan and Kesamben district. Map of the study area is presented in Fig. 1.

Data collection

Twenty five groundwater samples were collected from bore wells with variations in depth of 61–127 m BGL at confined aquifer.

The geographical position of groundwater samples was determined using Global Positioning System (GPS) Garmin 60. Digital Topographical Map Indonesia scale 1:25,000 (sheets: 1508-323, 1508-324, 1508-332, 1508-341, 1508-342, 1508-333, 1508-334, 1508-343, 1508-344, 1508-612, 1508-621, and 1508-622) (published by Coordinating Agency of National Surveying and Mapping) were used as the base maps to delineate the limits of the study area. The parameters analyzed from each groundwater sample were EC, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^- (Siswoyo *et al.*, 2016[a]).

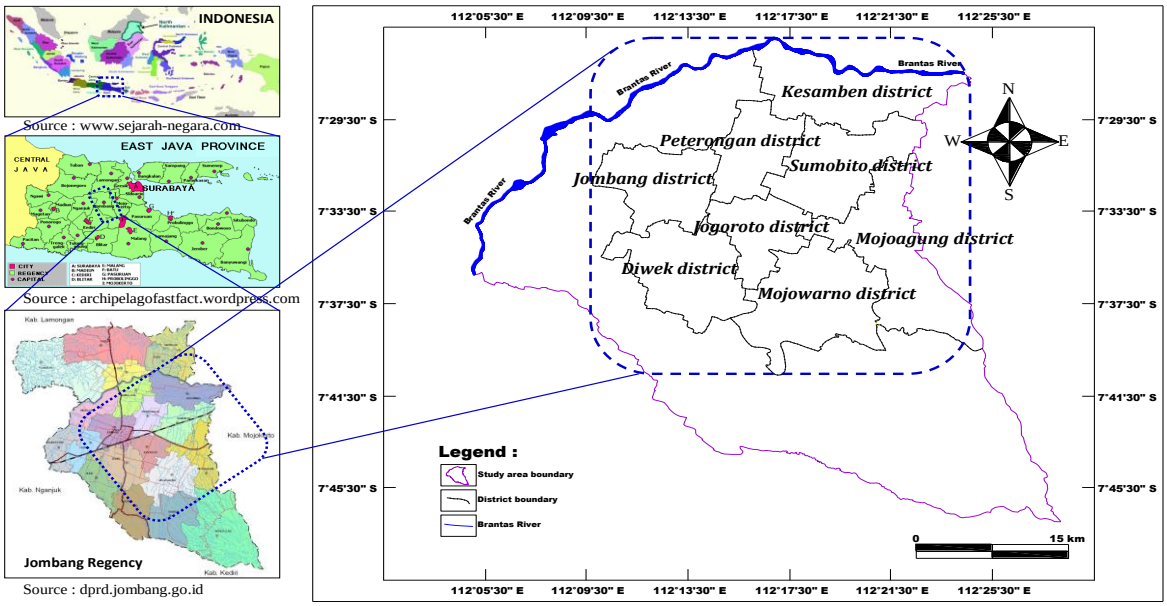

Fig. 1. Map of the study area.

Analysis proceedures

The groundwater quality index for irrigation and its suitability for agricultural crops were analyzed with the following stages:

1. Identifying the parameters of water quality for irrigation such as EC, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^-. The EC in µS/cm unit and concentration of ions in meq/l units. The value of these parameters have been obtained in previous studies (Siswoyo *et al.*, 2016[a]).
2. Calculating the adjusting sodium adsorption ratio (SAR) value according to the procedures of Lesch and Suarez (2009), based on the consentration of ions Na^+, Ca^{2+}, and Mg^{2+}.
3. Calculating the IWQI value based on the equations in the model of Meireles *et al.* (2010). Limit values of the parameters for calculating the value of the measured water quality for IWQI were determined in agreement with Ayers and Westcot (1994), Al-Mussawi (2014), Khalaf and Hassan (2013), and Omran *et al.* (2014).
4. Determining irrigation water usage restrictions based on the value IWQI and suitability of the use of irrigation water to the soil and plants according to the table of water quality index characteristics proposed by Meireles *et al.* (2010).
5. Analyzing suitability of groundwater quality to types of crops based on water use restrictions dan recommendation for plant (Meireles *et al.*, 2010) and relatively salt tolerant agricultural crops (Ayers and Westcot, 1994) considering the types of agricultural crops of high economic value (recommended in the Criteria Development and Management of Groundwater Irrigation) (Haryono *et al.*, 2009) and those with cultural techniques commonly used by farmers , socially, economically acceptable and has been cultivated in the study area (Badan Pusat Statistik Kabupaten Jombang, 2014[a], 2014[b], 2014[c]).
6. Mapping the spatial distribution of groundwater quality index in the study area based on Kriging method. Kriging is a geostatistical gridding method that produces visually appealing maps from irregularly spaced data (Golden Software, Inc., 2002).

Results and discussion

Groundwater quality index for irrigation

The groundwater quality index for irrigation expressed in IWQI value of groundwater samples are given in Table 1. The IWQI value of the groundwater samples were found to be in the range 57.1–95.8, indicating that groundwater samples were in category of moderate restriction (MR) to no restriction (NR) of water use for irrigation.

Table 1. IWQI value for groundwater samples in the study area.

No.	Sample ID	GPS Observation		IWQI	Water use restriction
		Latitude, S	Longitude, E		
1	SDJB 583	7°39'30.9"	112°17'07.0"	62.9	Moderate restriction (MR)
2	SDJB 475	7°38'32.3"	112°17'17.1"	65.2	Moderate restriction (MR)
3	SDJB 544	7°37'36.2"	112°17'58.7"	64.7	Moderate restriction (MR)
4	SDJB 476	7°36'07.9"	112°19'30.8"	80.8	Low restriction (LR)
5	SDJB 446	7°36'54.4"	112°17'05.7"	66.8	Moderate restriction (MR)
6	SDJB 425	7°36'34.1"	112°16'52.8"	67.5	Moderate restriction (MR)
7	SMJB 382	7°34'29.5"	112°20'0.8"	63.6	Moderate restriction (MR)
8	SDJB 195	7°33'50.3"	112°20'23.05'	78.2	Low restriction (LR)
9	SDJB 196	7°33'20.5"	112°20'30.7"	78.6	Low restriction (LR)
10	SMJB 395	7°34'59.3"	112°15'36.4"	68.0	Moderate restriction (MR)
11	SDJB 452	7°34'46.6"	112°17'59.4"	80.7	Low restriction (LR)
12	SMJB 383	7°33'22.6"	112°16'15.4"	71.0	Low restriction (LR)
13	SMJB 300	7°32'16.0"	112°20'20.5"	79.7	Low restriction (LR)
14	SDJB 584	7°32'14.2"	112°20'06.4"	77.8	Low restriction (LR)
15	SDJB 204	7°30'20.7"	112°22'16.0"	81.3	Low restriction (LR)
16	SDJB 455	7°32'48.6"	112°18'40.0"	79.7	Low restriction (LR)
17	SDJB 454	7°32'39.6"	112°17'16.9"	60.2	Moderate restriction (MR)
18	SDJB 490	7°30'11.8"	112°20'18.2"	78.9	Low restriction (LR)
19	SMJB 317	7°29'33.6"	112°21'43.9"	84.5	Low restriction (LR)
20	SMJB 393	7°29'54.6"	112°18'30.8"	95.8	No restriction (NR)
21	SMJB 389	7°31'24.2"	112°13'09.6"	74.8	Low restriction (LR)
22	SDJB 067	7°32'36.9"	112°16'41.9"	64.3	Moderate restriction (MR)
23	SMJB 379	7°30'17.1"	112°17'58.7"	57.1	Moderate restriction (MR)
24	SMJB 380	7°29'27.8"	112°17'58.8"	69.0	Moderate restriction (MR)
25	SMJB 387	7°28'56.1"	112°20'02.2"	65.1	Moderate restriction (MR)

Based on the IWQI value, there were 12 groundwater samples (48%) in the range of 55–70 were MR i.e. sample numbers 1, 2, 3, 5, 6, 7, 10, 17, 22, 23, 24, and 25. Twelve groundwater samples (48%) in the range of 70–85 were low restrictions for use (LR) i.e. sample numbers 4, 8, 9, 11, 12, 13, 14, 15, 16, 18, 19, and 21. There was an only one groundwater sample (4%) in the range of 85–100 with no restrictions for use (NR), the sample number 20.

Based on this study, it was found that in the development area of groundwater potential for irrigation in Jombang regency is dominated by rock formation of laharic deposits (volcanic pabble-sand, tuff, clay, and plant remains and archeological artefacts) and alluvium (pabble, gravel, sand, clay, and mud) (Siswoyo *et al.*, 2016[a]), the groundwater has a water quality index of >55 with category MR to NR.

Water use restrictions

The groundwater quality with MR may be used in soils with moderate to high permeability values, probably due to moderate leaching of salt, and this could be recommended for plants with moderate tolerance to salt. Groundwater resources for irrigation with LR are recommended for applying in irrigated soil with light texture or moderate permeability in order to wash excessive salts away and to avoid salinity risk for sensitive plants. Groundwater with NR may be used for the majority of soils with less probability of causing salinity and sodicity problems, and therefore no toxicity risk for most plants (Meireles *et al.,* 2010).

The groundwater with MR having the IWQI values between 55–70 is suggested that crops with moderately tolerant to tolerant to salt. The groundwater with LR having the IWQI values between 70–85 is suggested that crop species with moderately sensitive, moderately tolerant, and tolerant to salt. The groundwater with NR having the IWQI values between 85–100 is suggested that crops of all level salt tolerance. The types of crops based on category of salt tolerance has been provided (Ayers and Westcot, 1994).

To provide the direction for crop suit abilities grown in agricutural land in the study area, the type of crops should have high economic values (Haryono *et al.*, 2009), socially, economically, acceptable and commonly cultivated by farmers in the study area (Badan Pusat Statistik Kabupaten Jombang, 2014[a], 2014[b], 2014[c]).

Recommendation for agricultural crops

Based on those aspects ((Haryono *et al.*, 2009; Badan Pusat Statistik Kabupaten Jombang, 2014[a], 2014[b], 2014[c]) and on the category of salt tolerance (Ayers and Westcot, 1994) the type of crops that can be suggested are as follows:

1. The type of sensitive crops to salt that can be suggested in the study area are bean *(Phaseolus vulgaris),* welsh onion *(Allium cepa var. fistulosum),* shallot *(Allium cepa var. ascalonicum).*
2. The types of moderately sensitive crops to salt that can be suggested in the study area are maize *(Zea mays),* groundnut *(Arachis hypogaea),* sugarcane *(Saccharum officinarum),* cabbage *(Brassica oleraceae var. capitata),* cauliflower *(Brassica oleracea var. botrytis),* sweet corn *(Zea mays convar),* cucumber *(Cucumis sativus),* eggplant *(Solanum melongena),* muskmelon *(Cucumis melo),* potato *(Solanum tuberosum),* spinach *(Spinacia oleracea),* sweet potato *(Ipomoea batatas),* tomato *(Lycopersicon esculentum),* green pak choy *(Brassica rapa var. chinensis),* and watermelon *(Citrullus lanatus).*
3. The type of moderately tolerant crops to salt that can be suggested in the study area is soybean *(Glycine max).*
4. There is no type of tolerant crops to salt that can be adapted for agricultural land in the study area.

Based on the catagories and criteria stated by Ayers and Westcot (1994), Haryono *et al.* (2009), and Badan Pusat Statistik Kabupaten Jombang (2014[a], 2014[b], 2014[c]), the category of crops suggested for cultivated agricultural land in the study area are as follows:

1. The areas with moderate water usage restrictions (MR) can be planted with types of crops with category of moderately tolerant to salt.
2. The areas with low water usage restrictions (LR) can be planted with types of crops with categories of moderately sensitive and moderately tolerant to salt.
3. The areas with no water usage restrictions (NR) can be planted with types of crops with categories of sensitive, moderately sensitive, and moderately telerant to salt.

The spatial distribution map of groundwater quality index for irrigation in the study area are depicted in Fig. 2.

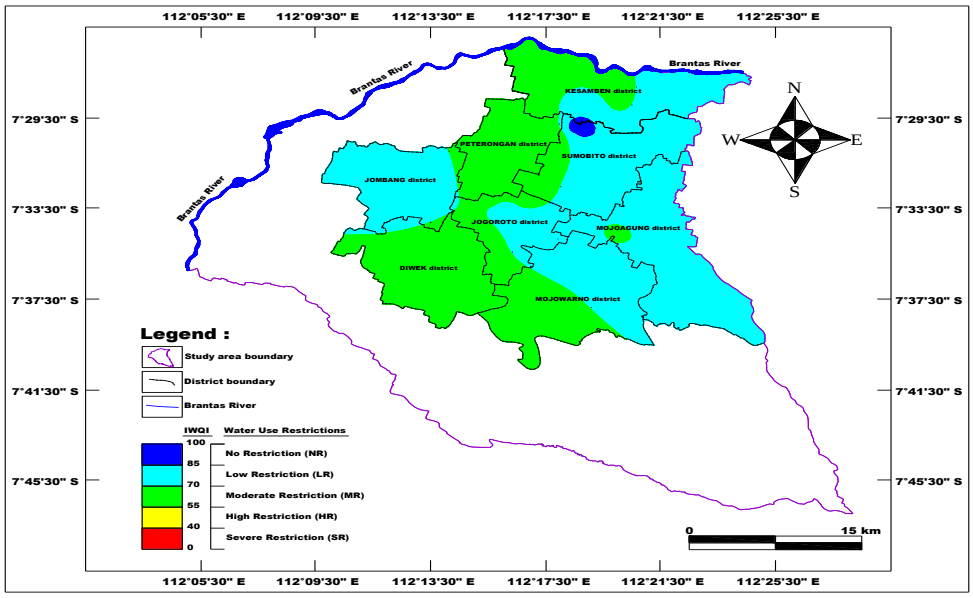

Fig. 2. Spatial distribution of groundwater quality index for irrigation in the study area.

Conclusion

The groundwater quality index in the study area were found to be in the range of 57.1–95.8, indicating of groundwater with moderately restriction (MR) to no restriction (NR) for irrigation. The spatial distribution map of IWQI for groundwater in the study area showed that low water usage restrictions (LR) dominate the eastern and north-western parts of study area, while the rest are the areas with moderately restrictions (MR) and no restriction (NR) for irrigation. The agricultural land located in areas with moderate water usage restrictions (MR) are suggested to be planted with moderately tolerant crops to salt. Meanwhile moderately sensitive and moderately tolerant crops to salt are suggested to be planted in the areas with low wate usage restrictions (LR). Crops with all levels of tolerance to salt could be planted in the areas with no water usage restriction (NR).

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