Chemical Characteristics of Groundwater and its Suitability for Irrigation purpose in Jombang Regency, East Java, Indonesia

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***Abstract*—** *The utilization of groundwater in the agricultural sector in Jombang regency is to meet the needs of irrigation water in sub-optimal land and to supply water for irrigation in the dry season on land that has been irrigated by surface water. The existence and potential of groundwater as a source of irrigation water should be available, not only in the quantity but also with the quality is good. The objectives of this study were to identify chemical characteristics of groundwater and to assess of groundwater quality for irrigation purpose. Twenty five groundwater samples were collected in the study area from bore wells ranging in depth between 61 – 127 m BGL on the confined aquifer. Chemical chracteristics of groundwater samples were analyzed using Piper trilinear diagram based on major ionic concentrations. Base on this analysis, discovered 6 water types of groundwater samples i.e.* Ca^{2+}–HCO_3^- *type, mixed* Ca^{2+}–Mg^{2+}–SO_4^{2-} *type, mixed* Na^+–Ca^{2+}–HCO_3^- *type,* Ca^{2+}–SO_4^{2-} *type,* Na^+–SO_4^{2-} *type, and* Na^+–HCO_3^- *type. To define the quality of groundwater for irrigation, groundwater samples were analyzed by using* $EC_{25^\circ C}$*, SAR, and RSC values. The classification of irrigation water base on* $EC_{25^\circ C}$ *and SAR show that most of groundwater samples into C2-S1 class indicating low sodium and medium salinity hazard. On the basis of RSC all groundwater samples are safe for irrigation purpose. All water type of groundwater samples in the study area are suitable for irrigation purpose.*

Keywords*— *Chemical characteristics, groundwater, irrigation, Jombang regency.

I. INTRODUCTION

The essential role of groundwater in the agricultural sector is to meet the needs of irrigation water in an area where surface water cannot be used either as a result of location factors (spatial) as well as seasonal factors (temporal). Jombang regency, East Java Province, Indonesia has aspects of groundwater potential is quite large because it was in part Brantas Groundwater basin [2], that most of its territory consisting of aquifers earning moderate to high productive [16] is one regional development potential of groundwater for irrigation. Utilization of groundwater in the agricultural sector in Jombang regency is to meet the needs of irrigation water in sub-optimal land and to supply water for irrigation in the dry season on land that has been irrigated by surface water.

The existence and potential of groundwater as a source of irrigation water should be available, not only in the quantity should be sufficient but also with the quality is good. For successful irrigated agriculture, the quality of groundwater is as important as the fertility of soil [21]. Suitability of water for irrigation is based on its salinity, sodicity, and toxicity [12]. Assessment and classification of groundwater based on its quality can be done by analyzing their chemical characteristics. Variations in ion chemistry of groundwater are used to identify geochemical processes that control the groundwater quality [22].

Relative to the importance of the suitability of the quality of groundwater for irrigation purposes, it would require a study of the chemical characteristics of groundwater and its suitability for irrigation in Jombang regency. The quality of groundwater suitable for irrigation purposes will be able to be a good input in an agricultural business. With a good input then agricultural productivity can be improved in the long term, which is one of the fundamental principles of sustainable agriculture.

Many researchers used chemical characteristics of groundwater to evaluate the groundwater quality for irrigation such as Sigh and Khare [21], Reddy [17], Venkateswaran and Vediappan [24], Golekar et al. [6], Hagras [8], Khan et al. [12], Barick and B.K. Ratha [3], Kanwar and Khanna [11]. The objectives of this study were to identify chemical characteristics of groundwater and to assess of its suitability for irrigation purpose in development area of groundwater potential for irrigation in Jombang regency, East Java, Indonesia.

II. DESCRIPTION OF THE STUDY AREA

The study area falls in Jombang regency, East Java Province, Indonesia. The study area is located between latitudes 7˚26'3.84"–7˚46'58.08" S dan longitudes 112˚5'4.92"–112˚28'11.28" E. The total region of the study area covers 803.06 km^2 and covers 16 districts in Jombang regency. Map of the study area is given in Figure 1.

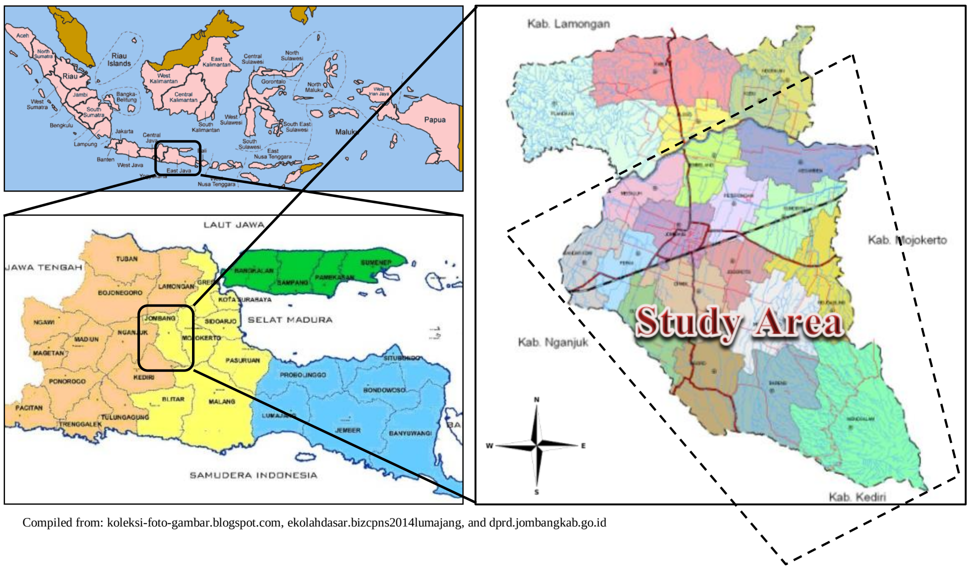

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FIG. 1 MAP OF THE STUDY AREA

The study area is bounded from Wonosalam district as recharge area where the presence of Mount Argowayang (South East section of Jombang regency) to North West on exploitation area of groundwater, to natural hydraulic boundary where the presence of Brantas river. The rocks units of the development area of groundwater potential for irrigation in Jombang regency to be dominated by laharic deposits (volcanic pabble-sand, tuff, clay and plant remains and archeological artefacts) and alluvium (pabble, gravel, sand, clay, and mud) [19]. Aquifer condition of the study area was confined aquifer.

III. MATERIALS AND METHODS

Twenty five groundwater samples were collected from bore wells ranging in depth between 61 – 127 m BGL. Groundwater samples were collected during dry season period of September – November, 2015. Samples were collected dan preservated based on the Indonesia National Standard (SNI 6989.58:2008) Section 58: Method of groundwater sampling [14]. The geographical position of groundwater samples was determined with the help of Global Positioning System (GPS). Groundwater samples location of the study area are given in Figure 2.

In this study, analysis of groundwater parameters based on temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), major cation concentrations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), and major anion concentrations (Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}). Groundwater parameters such as temperature, pH, TDS, and EC were measured on the sites by using thermometer (Digital Thermometer TP 3001), pHmeter (Pen type pHmeter PH-009(I)), TDSmeter (TDS testers 139), and ECmeter (Senz μSiemen digital conductivity tester). The groundwater samples were analyzed in the laboratory in Department of Chemistry, State University of Surabaya, Surabaya, Indonesia for the major ionic concentrations such as Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, and HCO_3^{-}. The concentrations of Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} were estimated using atomic absorption spectrophotometer (AAnalyst 100, Perkin Elmer). Chloride concentration was measured using argentometric titration method. Concentrations of SO_4^{2-} and HCO_3^{-} were analyzed using acid titrimetric method. The carbonate (CO_3^{2-}) concentration was calculated from the value of the HCO_3^{-} concentration based on distribution of species diagram for the CO_2–HCO_3^{-}–CO_3^{2-} system in water [13] using GW_Chart software [26].

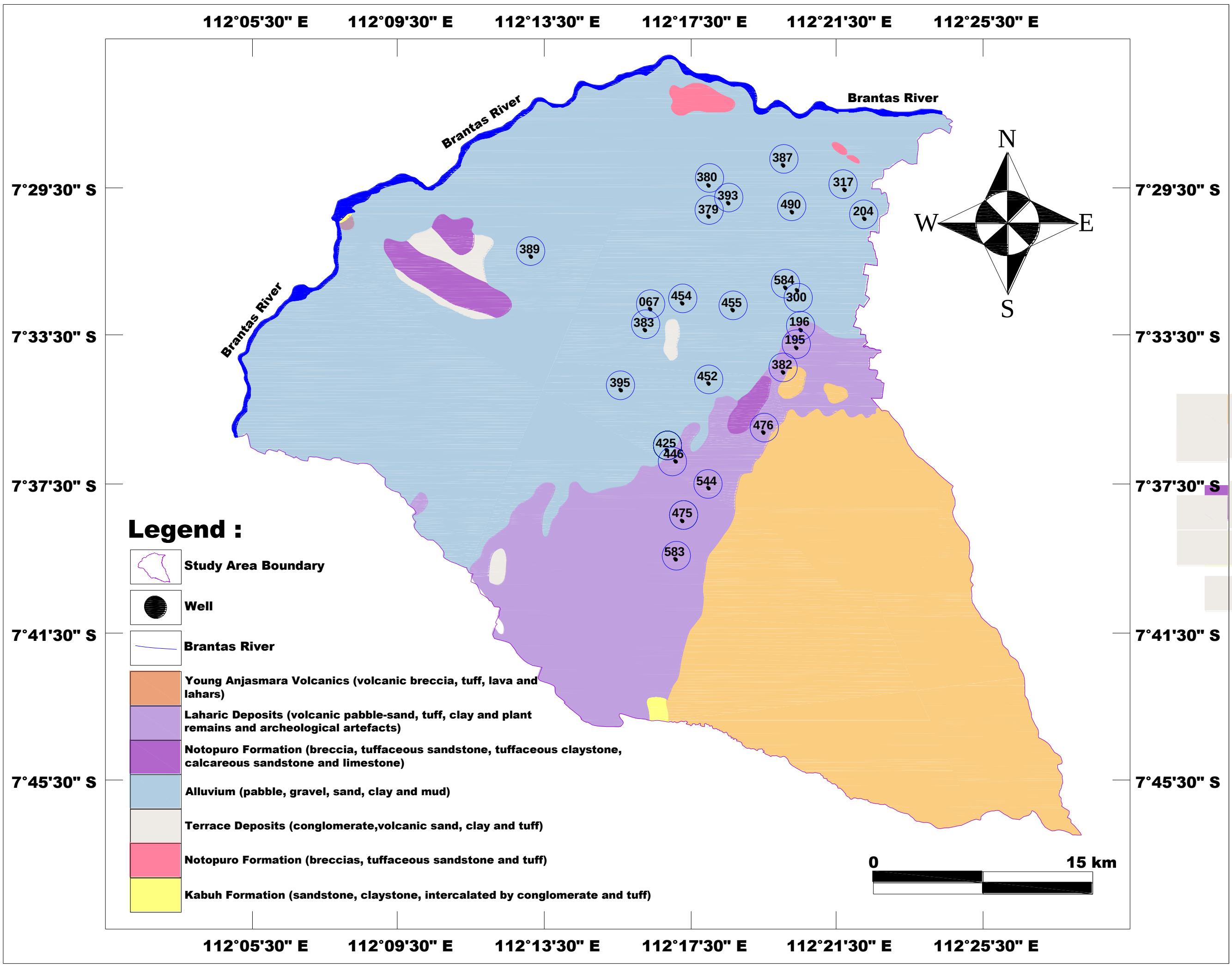

FIG. 2 GROUNDWATER SAMPLES LOCATION MAP OF THE STUDY AREA

Chemical characteristics of groundwater samples were analyzed using Piper trilinear diagram [15] based on major ionic concentrations. Piper trilinear diagram is a graphic procedure in the geochemical interpretation of water analysis. The suitability of the groundwater for irrigation purpose has been qualified according to irrigation indices sodium adsorption ratio (SAR), electrical conductivity ($EC_{25^\circ C}$), and residual sodium carbonate (RSC):

1. Sodium Adsorption Ratio (SAR) [25] :

$$SAR = \frac{Na^{+}}{\sqrt{\frac{\left(Ca^{2+} + Mg^{2+}\right)}{2}}} \quad (1)$$

where the ionic concentrations are expressed in meq/L

2. Electrical conductivity at temperature 25˚C ($EC_{25^\circ C}$) [9] :

$$EC_{25^\circ C} = EC_t - 0.02 \times (T - 25) \times EC_t \quad (2)$$

where EC_t is EC at temperature T of the sample

3. Residual sodium carbonate (RSC) [25] :

$$RSC = \left(CO_3^{2-} + HCO_3^{-}\right) - \left(Ca^{2+} + Mg^{2+}\right) \quad (3)$$

where the ionic concentrations are expressed in meq/L

The suitability of the groundwater for irrigation purpose based on indices SAR and $EC_{25^\circ C}$ plotted in the diagram for the classification of irrigation waters [18],[25].

IV. RESULTS AND DISCUSSION

The content of chemical elements contained in the water will greatly influence the suitability of the water is used as irrigation water in agriculture [10]. The pH value is an expression of the intensity of the acid or alkali in water. Electrical conductivity is commonly used for indicating the total concentration of the ionized constituents of a natural water. Total dissolved solids is a measure of the total quantity of dissolved matter carried by a water. The cations such as Na^+, K^+, Ca^{2+}, and Mg^{2+} are the cations or basic constituents ordinaliry present in significant concentrations in irrigations waters. The anions such as HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^- are the more important anions found in irrigation water [25].

The results of physicochemical analysis of groundwater samples are given in Table 1. The temperature of the groundwater samples were found to be in the range 26.0–31.0˚C. The pH values are in the range of 7.3 to 9.3 indicating groundwater in study area is alkaline in nature. The concentration of TDS range from 132 to 407 ppm indicating groundwater in study area are fresh water. The value of EC varied from 226 to 662 μS/cm indicating groundwater in study area is which indicate excellent to good quality water for irrigation [23]. Sodium concentration varies from 3.82 ppm to 56.29 ppm, potassium from 3.79 ppm to 13.12 ppm, calcium from 3.11 ppm to 51.38 ppm, and magnesium from 0.004 ppm to 25.70 ppm. The bicarbonate concentration in the groundwater samples of the study area ranges from 2.01 ppm to 79.88 ppm. The concentration of SO_4^{2-} was within the range of 0.004 to 63.35 ppm. The chloride concentration varied from 0.19 to 4.85 ppm.

TABLE 1
PHYSICHOCHEMICAL ANALYSIS RESULTS OF GROUNDWATER SAMPLES OF THE STUDY AREA

No.	Sample ID	t	pH	TDS	EC	Major Cations (ppm)				Major Anions (ppm)		
		(˚C)		(ppm)	(μS/cm)	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
1	SDJB 583	26.0	7.9	170	295	22.49	3.99	19.64	5.97	3.38	39.65	49.64
2	SDJB 475	27.0	7.5	246	421	23.81	5.47	25.05	8.70	2.99	38.42	24.11
3	SDJB 544	28.0	7.6	211	368	22.59	8.24	17.45	7.90	2.56	25.07	31.49
4	SDJB 476	26.7	7.4	218	379	23.41	7.52	17.87	11.45	3.02	20.80	64.80
5	SDJB 446	28.0	7.4	253	431	24.11	5.01	32.31	11.57	3.43	61.78	10.56
6	SDJB 425	27.0	7.4	275	480	18.65	4.18	42.26	11.03	3.60	38.69	10.24
7	SMJB 382	27.7	7.3	407	662	41.35	10.74	40.81	10.61	0.23	0.03	3.35
8	SDJB 195	27.2	7.4	325	553	24.26	5.97	28.97	11.26	3.40	63.35	79.88
9	SDJB 196	27.2	7.5	296	505	29.05	8.49	32.89	17.47	3.52	62.70	70.61
10	SMJB 395	27.2	7.4	385	620	17.30	7.18	51.38	7.92	0.27	0.03	3.01
11	SDJB 452	26.9	7.5	249	425	22.82	7.04	18.06	14.05	3.43	31.34	64.82
12	SMJB 383	27.8	7.7	273	453	3.82	8.96	28.58	8.06	0.31	0.03	4.61
13	SMJB 300	27.8	7.4	305	517	24.94	5.97	20.99	14.85	3.46	43.84	65.74
14	SDJB 584	27.4	8.4	178	314	49.46	5.23	10.98	1.78	2.54	40.36	48.61
15	SDJB 204	30.3	8.3	204	348	17.38	5.67	9.56	2.60	3.30	41.19	70.35
16	SDJB 455	27.5	7.7	212	385	27.75	7.84	13.23	8.38	4.85	37.58	65.62
17	SDJB 454	28.0	7.8	245	423	27.75	13.12	26.81	8.90	2.91	40.84	59.09
18	SDJB 490	28.,3	8.4	203	345	56.29	4.93	5.22	0.50	3.35	43.54	25.66
19	SMJB 317	28.6	7.9	235	402	45.99	12.57	15.62	6.51	0.52	0.004	3.57
20	SMJB 393	28.3	8.1	220	375	49.66	6.07	11.42	3.24	2.90	43.89	64.51
21	SMJB 389	31.0	9.3	132	226	45.11	3.79	3.11	0.004	2.96	41.36	65.94
22	SDJB 067	28.5	7.8	276	464	24.63	11.81	15.35	25.70	3.29	37.95	27.96
23	SMJB 379	28.4	7.9	223	401	45.10	10.59	13.16	5.44	2.45	25.07	55.96
24	SMJB 380	27.9	8.5	344	567	13.35	4.91	19.41	6.94	0.19	0.03	2.01
25	SMJB 387	28.6	8.3	220	373	42.55	11.70	16.52	1.36	0.39	0.04	2.34

For classification of chemical characteristics of groundwater samples in study area, data of major ionic concentrations were plotted on Piper trilinear diagram [15]. In the Piper trilinear diagram, the cation and anion fields are combined to show a single point in a diamond-shaped field that shows the overall chemical properties of the groundwater samples. On the cation triangle, the cations type classified into 3 areas i.e. area A = Magnesium type, B = Sodium and potassium type, C = Calcium type, and D = no dominant type. The anion triangle also classified into 3 areas i.e. area E = Sulphate type, F = Chloride type, G = Bicarbonate type, and H = no dominant type. The diamond-shaped field of Piper trilinear diagram was used to classify groundwater characteristics, if the samples fall into zone 1 = alkaline earth exceeding alkalies, 2 = alkalies exceeding alkaline earth, 3 = weak acids exceeding strong acids, and 4 = strong acids exceeding weak acids. Water type can be diagnostic i.e.:

zone a = Ca^{2+}–SO_4^{2-} type, b = Na^{+}–SO_4^{2-} type, c = Na^{+}–HCO_3^{-} type, d = Ca^{2+}–HCO_3^{-} type, e = mixed Ca^{2+}–Mg^{2+}–SO_4^{2-} type, and f = mixed Na^{+}–Ca^{2+}–HCO_3^{-} type [1],[4],[7],[20],[22],[27]. Major ionic concentrations of groundwater samples were plotted on Piper trilinear diagram showen in Figur 3.

The plot of Piper trilinear diagram in cation triangel shows that 13 of samples (52%) fall in area of no dominant cation type, 9 of samples (36%) fall in area of sodium type, and 3 of samples (12%) fall in area of calcium type. In anion triangel, discovered predominates anion 15 of samples (60%) fall in area of bicarbonate type, 6 of samples (24%) fall in area of sulphate type, and 4 of samples (16%) fall in area of no dominant anion type. Characterization of corresponding zone of diamond shaped field shows that 16 samples (64%) fall under zone-1, 9 samples (36%) fall under zone-2, 15 samples (60%) fall under zone-3, and 10 samples (40%) fall under zone-4. Figure 2 also shows that in study area discovered 6 water types, i.e.: 8 of groundwater samples (32%) are Ca^{2+}–HCO_3^{-} type, 6 of groundwater samples (24%) are mixed Ca^{2+}–Mg^{2+}–SO_4^{2-} type, 6 of groundwater samples (24%) are mixed Na^{+}–Ca^{2+}–HCO_3^{-} type, 2 of groundwater samples (8%) are Ca^{2+}–SO_4^{2-} type, 2 of groundwater samples (8%) are Na^{+}–SO_4^{2-} type, and 1 of groundwater sample (4%) is Na^{+}–HCO_3^{-} type. Chemical characteristics of groundwater samples are given in Table 2.

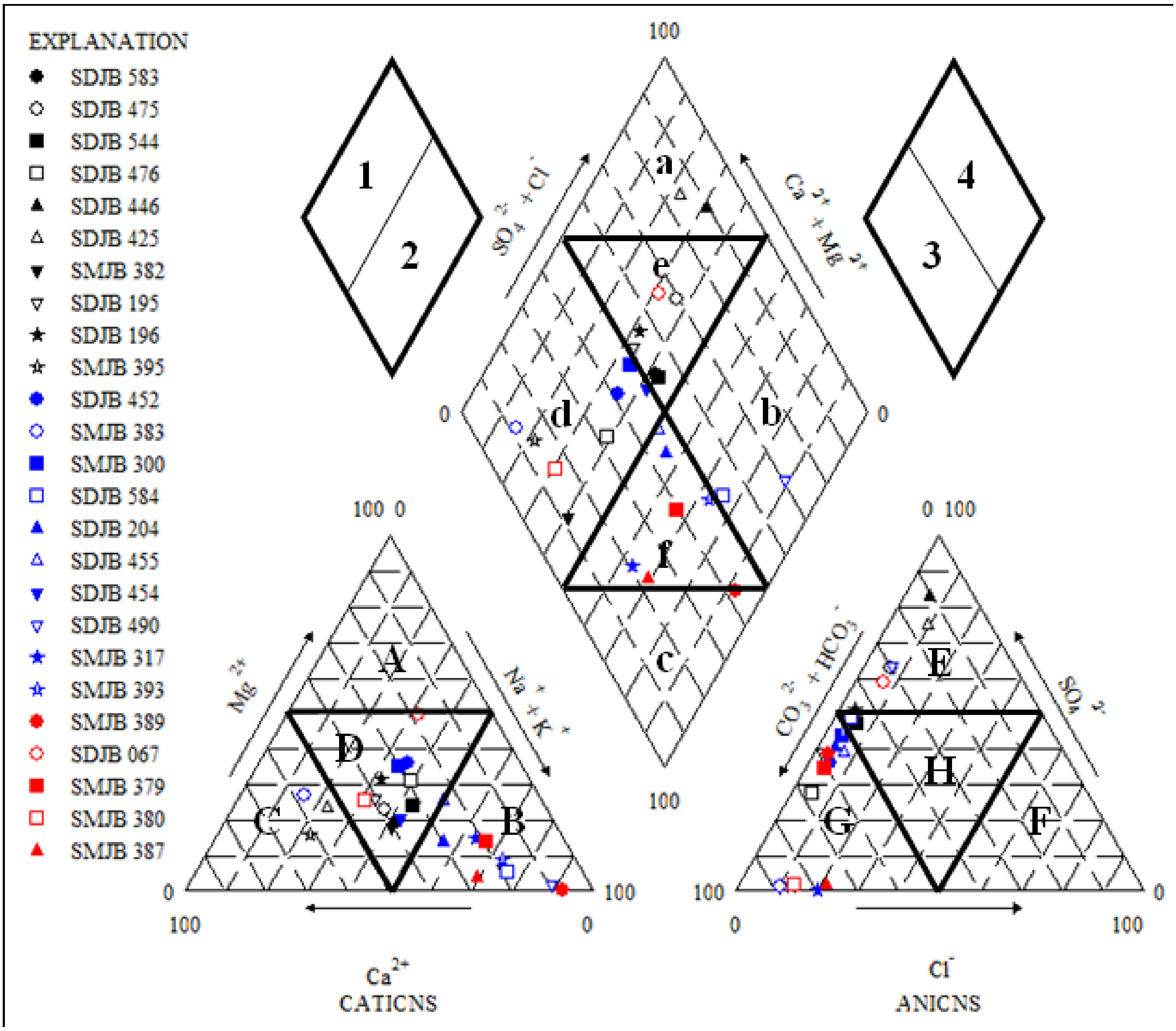

FIG. 3 PIPER TRILINEAR DIAGRAM FOR GROUNDWATER SAMPLES

TABLE 2
CHEMICAL CHARACTERISTICS OF GROUNDWATER SAMPLES

No.	Sample ID	Plotting in triangles		Plotting in diamond		Water type
		Cation type	Anion type	Cation zone	Anion zone	
1	SDJB 583	No dominant	No dominant	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
2	SDJB 475	No dominant	Sulphate	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
3	SDJB 544	No dominant	No dominant	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
4	SDJB 476	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
5	SDJB 446	No dominant	Sulphate	1	4	Ca^{2+}–SO_4^{2-}
6	SDJB 425	Calcium	Sulphate	1	4	Ca^{2+}–SO_4^{2-}
7	SMJB 382	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
8	SDJB 195	No dominant	No dominant	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
9	SDJB 196	No dominant	Sulphate	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
10	SMJB 395	Calcium	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
11	SDJB 452	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
12	SMJB 383	Calcium	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
13	SMJB 300	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
14	SDJB 584	Sodium	No dominant	2	4	Na^+–SO_4^{2-}
15	SDJB 204	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-
16	SDJB 455	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-
17	SDJB 454	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
18	SDJB 490	Sodium	Sulphate	2	4	Na^+–SO_4^{2-}
19	SMJB 317	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-
20	SMJB 393	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-
21	SMJB 389	Sodium	Bicarbonate	2	3	Na^+–HCO_3^-
22	SDJB 067	No dominant	Sulphate	1	4	mixed Ca^{2+}–Mg^{2+}–SO_4^{2-}
23	SMJB 379	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-
24	SMJB 380	No dominant	Bicarbonate	1	3	Ca^{2+}–HCO_3^-
25	SMJB 387	Sodium	Bicarbonate	2	3	mixed Na^+–Ca^{2+}–HCO_3^-

The Classification of irrigation water in study area based on electrical conductivity ($EC_{25^\circ C}$) and on SAR using the diagram for the classification of irrigation waters [18],[25] and RSC values. Based on $EC_{25^\circ C}$, SAR, and RSC values the suitability of groundwater samples for irrigation are given in Table 3. The SAR and $EC_{25^\circ C}$ values of water samples of the study area were plotted in the diagram for the classification of irrigation waters in Figure 4.

From Table 3 and Figure 4, the values of $EC_{25^\circ C}$ varied from 198.88 to 626.25 μS/cm indicating groundwater samples of low to medium salinity hazard [25] or excellent to good quality water for irrigation [23]. The SAR values in the groundwater samples of the study area ranges from 0.16 to 7.03 indicating low sodium hazard [25]. Classification of groundwater quality base on $EC_{25^\circ C}$ and SAR values shows that 24 samples (96%) fall under C2-C1 water class and 1 sample (4%) fall under C1-S1 water class. The water class of C2-S1 indicates medium-salinity and low-sodium water and C1-S1 indicates low-salinity water and low-sodium water. Medium-salinity water can be used if a moderate amount of leaching accurs. Low-sodium water can be used for irrigation on almost all soil with little danger of the development of harmful levels of excangable sodium. Low-salinty water can be used for irrigation with most crops on most soil, with little likelihood that a salinity problem will develop [25].

The sodium hazard involved in the use of a water for irrigation is determined by the absolute and relative concentrations of cations. The SAR value is a ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange with soil [25]. SAR value of irrigation water direct relation to the adsorption of sodium by soil [23]. If groundwater used for irrigation is high in sodium and low in calsium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles [24]. The sodium content is high in irrigation water can also cause the pH to be very high and would poison the plant [10]. The water class of C2-S1 and C1-S1 are good waters for irrigation purpose [24].

TABLE 3
QUALITY CLASSIFICATIONS OF GROUNDWATER SAMPLES

No.	Sample ID	$EC_{25^\circ C}$ (µS/cm)	SAR $(meq/l)^{0,5}$	Water class	RSC (meq/l)	Water class
1	SDJB 583	289.10	1.14	C2-S1	-0.65	Safe
2	SDJB 475	403.78	1.04	C2-S1	-1.57	Safe
3	SDJB 544	345.92	1.13	C2-S1	-1.00	Safe
4	SDJB 476	366.11	1.06	C2-S1	-0.77	Safe
5	SDJB 446	405.14	0.93	C2-S1	-2.39	Safe
6	SDJB 425	460.80	0.66	C2-S1	-2.85	Safe
7	SMJB 382	626.25	1.49	C2-S1	-2.85	Safe
8	SDJB 195	528.67	0.97	C2-S1	-1.06	Safe
9	SDJB 196	482.78	1.02	C2-S1	-1.92	Safe
10	SMJB 395	592.72	0.59	C2-S1	-3.17	Safe
11	SDJB 452	408.85	0.98	C2-S1	-0.99	Safe
12	SMJB 383	427.63	0.16	C2-S1	-2.01	Safe
13	SMJB 300	488.05	1.02	C2-S1	-1.19	Safe
14	SDJB 584	298.93	3.65	C2-S1	0.12	Safe
15	SDJB 204	311.11	1.29	C2-S1	0.48	Safe
16	SDJB 455	365.75	1.47	C2-S1	-0.27	Safe
17	SDJB 454	397.62	1.19	C2-S1	-1.10	Safe
18	SDJB 490	322.23	6.31	C2-S1	0.13	Safe
19	SMJB 317	373.06	2.47	C2-S1	-1.26	Safe
20	SMJB 393	350.25	3.34	C2-S1	0.23	Safe
21	SMJB 389	198.88	7.03	C1-S1	1.13	Safe
22	SDJB 067	431.52	0.89	C2-S1	-2.42	Safe
23	SMJB 379	373.73	2.64	C2-S1	-0.18	Safe
24	SMJB 380	534.11	0.66	C2-S1	-1.51	Safe
25	SMJB 387	346.14	2.71	C2-S1	-0.90	Safe

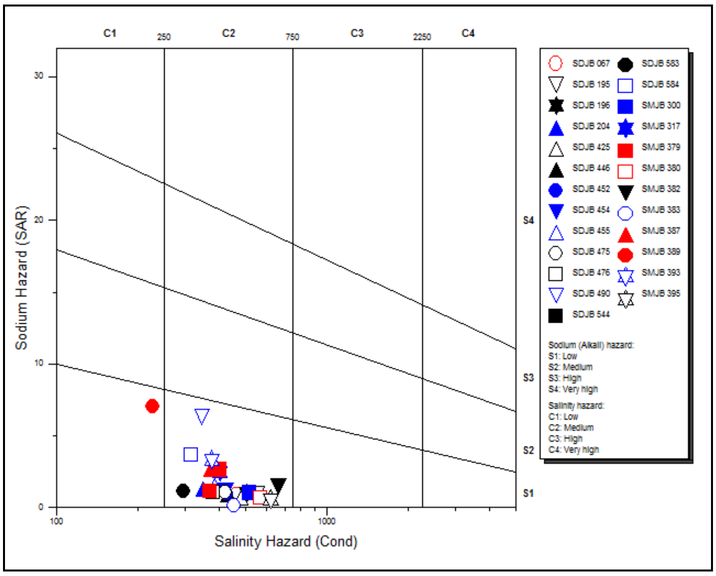

FIG. 4 DIAGRAM FOR THE CLASSIFICATION OF IRRIGATION WATERS

Residual sodium carbonate is a concept used to classify water quality for irrigation, which states that the concentration of bicarbonate ions can cause precipitates Ca^{2+} dan Mg^{2+} ions as carbonate, to increases ion Na^{+} in the soil [5],[10]. The waters with RSC value more than 2.5 meq/l are not suitable for irrigation purpose, RSC value from 1.25 to 2.5 meq/l are marginal, and those containing less than 1.25 meq/l are probably safe [18],[25]. In this study, the groundwater samples show RSC values of –3.17 to 1.13 meq/l. The values of RSC of all groundwater samples (100%) shows less than 1.25 meq/l. These values are groundwater quality all samples are safe for irrigation purpose.

V. CONCLUSION

In the development area of groundwater potential for irrigation in Jombang regency is dominated by geological formations of laharic deposits (volcanic pabble-sand, tuff, clay and plant remains and archeological artefacts) and alluvium (pabble, gravel, sand, clay, and mud). In the study area, discovered 6 water types i.e. Ca^{2+}–HCO_3^- type (32% of samples), mixed Ca^{2+}–Mg^{2+}–SO_4^{2-} (24% of samples), mixed Na^+–Ca^{2+}–HCO_3^- type (24% of samples), Ca^{2+}–SO_4^{2-} type (8% of samples), Na^+–SO_4^{2-} type (8% of samples), and Na^+–HCO_3^- type (4% of samples). The suitability of all groundwater samples for irrigation based on $EC_{25^\circ C}$ and SAR were good for irrigation purpose, than based on RSC values all groundwater samples in the study area were safe for irrigation. All water type of groundwater samples in study area are suitable for irrigation purpose.

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