Hydrogeochemical Analysis of Unconfined Groundwater in the Surrounding Salt Farming Areas of Pademawu, Madura, Indonesia

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INTRODUCTION

Groundwater is an unlimited significant natural resource on earth (Avtar et al. 2019). The limitation of surface water bodies has prompted the use of groundwater for consumption in dry and semi-arid areas (Mallick et al. 2018). Groundwater has been used for drinking in around one-third of the globe (Abu-alnaeem et al. 2018). Thus, the quality and quantity of groundwater are essential factors in modern water resource management.

The global issue related to groundwater availability is seawater intrusion due to sea level rise and excessive groundwater extraction (Javadi et al. 2022). Groundwater in the coastal area is prone to natural salinization and anthropogenic pressures. Seawater intrusion has become the primary issue in the use of safe groundwater (Gopinath et al. 2018). Groundwater quality is a significant factor in assessing the feasibility of groundwater utilization for household consumption and irrigation. A geochemical study could improve our understanding of seasonal and spatial quality alteration and geochemical processes in groundwater (Sivakarun et al. 2020).

The natural chemical state of groundwater relies on regional geological settings and geographical management. However, increases in pollutant concentration in groundwater sources by ionic variation could deteriorate the water quality. The ionic variation on groundwater is caused by water–rock interactions and redox reactions during water percolation via aquifer (Yetiş et al. 2019). Many interrelated processes control the groundwater’s chemical quality, which must be evaluated prior to managing groundwater resources (Subba Rao et al. 2020). The chemical composition of groundwater is determined by several factors, such as rainfall intensity, infiltration, groundwater flow patterns, rock characteristics, and aquifer arrangement (Duraisamy et al. 2019). Pollution within groundwater aquifers near the ocean is caused by two amalgamated processes: seawater intrusion and infiltration from precipitation (rainfall intensity and other anthropogenic factors). Salinization impacts coastal areas and isles depending on relief, climate, and aquifer lithology (Aris et al. 2012).

Seawater intrusion and infiltration polluting the groundwater have become a significant issue among coastal communities. The demand for clean water in the coastal area has increased because the water for consumption tends to be salty (Gopinath et al. 2018). This case has also occurred in the Pademawu Subdistrict, Madura, Indonesia. The concentrated salt production over

ABSTRACT

The Pademawu coast has rapidly transformed into salt ponds, causing seawater intrusion and pollution. This study aims to examine the quality of groundwater in the surrounding settlement area of Pademawu and assess its eligibility for daily use. The psychochemical parameters of groundwater are measured in situ. Groundwater samples from several stations are analyzed in the laboratory and used to collect several chemical compounds, including Ca2+, Mg2+, Na+, K+, HCO3−, Cl−, SO42−, Fe2+, Mn2+, F−, NO3−, NO2−, and CaCO3. The detected concentrations are then used to calculate TH, sodium adsorption ratio (SAR), %Na, PI, KR, and MH. Hydrochemical calculation and interpretation are also performed. The groundwater characteristics are determined according to TDS, conductivity, and water quality index (WQI). Results showed that the groundwater facies are predominated by Ca-HCO3 water in the northern and middle study areas and Na-Cl (37%) in the salt farming area. The groundwater is categorized as SAR (C2S1) in the north and SAR (C4S2) in the south. The primary groundwater consists of Na+ and Cl− (dominant cation and anion) originating from salt farming. The TDS in the salt farming area ranges from 1000 mg/L to 3000 mg/L (slightly saline). The WQI ranges from 39.0 to 735.4, which encompasses excellent water, good water, very poor water, and unsuitable for consumption. Salt farming infiltration toward unconfined aquifers is the primary factor causing groundwater pollution. Mitigation efforts to minimize scattered infiltration must be applied in the Pademawu Subdistrict by modifying the system between salt farming and settlement areas.
Seawater intrusion and groundwater pollution are the most severe environmental issues in coastal areas (Javadi et al. 2012). In addition to intrusion and excessive groundwater exploration, the influence of salt framing on groundwater may exacerbate water quality for consumption (Selvakumar et al. 2017). Many studies related to groundwater quality and hydrogeochemistry in the coastal area were conducted (Adimalla et al. 2018; Abu-alnæem et al. 2018; Chotpanarat et al. 2020; Haji et al. 2020; Huizer et al. 2018; He et al. 2019; Liu et al. 2019; Yuan et al. 2020; Aris et al. 2012); however, reports regarding the impacts of conventional salt farming on unconfined aquifer in the coastal area are limited. In addition, studies on groundwater pollution only focused on identifying saline water intrusion and agriculture waste pollution (Barlow and Reichard 2010; Alfarrah and Walraevens 2018; Manivannan and Elango 2019). Salt farming infiltration in Pademawu or even in Indonesia has never been assessed. Therefore, the hydrochemical characteristics of groundwater and its feasibility for consumption and irrigation warrant an investigation. This study analyzes the psychochemical state of groundwater sampled from several settlement artesian wells in the Pademawu Subdistrict and assess the quality of groundwater for daily consumption. Only a few studies employed hydrogeochemical analysis to identify groundwater pollution in the salt farming area; hence, this aspect should be investigated. The current work aims to determine the physical and chemical characteristics of the groundwater in the surrounding settlement area of Pademawu to identify the impacts of salt ponds on groundwater quality.

2. MATERIALS AND METHODS

2.1 Study site

The study area is situated in Pademawu Subdistrict, Pamekasan Regency, East Java, Indonesia (Figure 1) and is directly adjacent to Larangan Subdistrict in the north, Tlanakan and Pamekasan Subdistricts in the west, and Galis Subdistrict in the east. In the south direction, it faces the Madura Strait. The area of Pademawu reaches 7,219 Ha, of which 62.26% is an agriculture area, 15.04% is an aquaculture area, and the remaining is used for settlement, trading, industry, and others. In addition to the land use in Pademawu, its salt farming area is the largest in Pamekasan Regency.

The land elevation of Pademawu Subdistrict tends to be uniform and less than 10 meters on average. It is categorized as an alluvial plain/coastal area with 0–50 meter elevation above sea level (BPS 2018). In terms of geography, the study area is positioned between 7.24°–7.66° south and 113.43°–113.6° east. The rainy season occurs from October to April, and the dry season occurs from May to September. Furthermore, the maximum temperature is around 28°C–30°C. The geological setting in the southern area of Pademawu Subdistrict is composed of three rock formations: alluvial deposit (Qa) consisting of gravel, pebble, sand, clay, and silt; Pamekasan formation (Qpp) consisting of conglomerate, sandstone, claystone, and limestone; and Madura formation (Tpm) that is located in the north, characterized by good quality water resource, and composed of coralline and dolomitic limestone (Figure 1). In addition to geological formation, the northern study area is directly bordered by Ngayrong formation (Tmtn) composed of sandstone and claystone and the intercalation of marl and limestone (Situmorang et al. 1992).

According to Poespowardoyo (1986) (in the hydrogeological map sheet VII Surabaya [Java]), the lithology of the study area is composed of alluvium deposits in the form of clay–sand amalgamation and organic matters (coralline limestone) with low-to-medium permeability. The aquifer type in the southern study area is categorized as poorly productive in terms of local importance (Figure 1). Owing to low-to-very-low transmissivity, limited shallow groundwater resources can be obtained locally, especially in valleys or the weathered zones of solid rocks. The aquifer type in the northern study area is categorized as extensive and moderately productive (aquifers of low-to-moderate transmissivity, groundwater table varies from above to under land surface, and generally less than 5 l/s yield of wells) (Poespowardoyo 1986).

The lithology-arranged aquifer system layer in the study area is determined by geological-based mapping, geological and regional hydrogeological map interpretation, and drilling data (shallow drilled well logs established by the Indonesia Regional Utility Company [PDAM] and the Groundwater Development Project [PPAT] of Pamekasan

![Figure 1. Geological map of the study area.](image-url)
Regency). Several log wells are situated within the study area (three points) (Figure 2). According to the correlated data from the drilled wells, the study area has two aquifer systems: unconfined aquifer and confined aquifer. The latter is observed in the northern study area and is composed of approximately 80 meters of an impermeable layer consisting of coralline limestone and dolomite limestone. In addition to this impermeable layer, claystone (ranging from 90 meters to 100 meters in depth) can be found in several locations in Pademawu.

In the southern study area close to the coastal zone, the aquifer system is classified as an unconfined aquifer composed of claystone impermeable layers with a depth range of 50 meters. Lime–sandstone and limestone aquifers are also observed. However, the south area is generally composed of sandstone and geologically appertained to the Pamekasan formation (Qpp), which consisted of sandstone and limestone.

2.2 Field survey and hydrogeochemical analysis

Groundwater samples were collected from the 52 observation stations separated by the shallow habitation well (unconfined aquifer) and several industrial wells, and their physical and chemical parameters were mapped and measured. The physical parameters consisted of surface soil depth, conductivity, pH, and temperature and were surveyed using a handy water checker named multi-parameter water quality meter model WM-22EP and a global positioning system for the recording of coordinates. For accurate measurement, the instrument was calibrated using 2 points of standard solution with tenfold different concentrations encompassing the target concentration (Rajib et al. 2019).

Twenty-four groundwater samples were analyzed in the Environmental Engineering Laboratory, Bandung Institute of Technology. A standard method for water and wastewater examination was employed to analyze the water chemical compounds (Bridgewater et al. 2017). The analyzed chemical parameters were Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$, HCO$_3^-$, Cl$^-$, SO$_4^{2-}$, Fe$^{2+}$, Mn$^{2+}$, F$^-$, NO$_3^-$, NO$_2^-$, and CaCO$_3$. Charge balance error was calculated as follows to verify the quality of the analysis results (Freeze and Cherry 1979):

$$CBE = \frac{\sum Zm_c - \sum Zm_a}{\sum Zm_c + \sum Zm_a} \times 10$$  (1)

Where: $Z$ = Ion valency; $m_c$ = Cation motility; $m_a$ = Anion motility;

The analyzed physicochemical parameters were then compared with the standard established by World Health Organization (2008) regarding water resources for consumption and society’s health (Table 1). The primary hydrochemical facies were identified using a trilinear piper diagram (Piper 1944) provided by Aquachem software v4.0. Moreover, a Wilcox salinity diagram was used to determine any kinds of hydrogeochemical activities on groundwater and its feasibility for irrigation. Each type of groundwater has a different total dissolve solid (TDS) value depending on the number of dissolved ion concentrations. Krishna Kumar et al. (2015) classified TDS as follows:

TDS 0–1,000 mg/L = freshwater
TDS 1,000–10,000 mg/L = brackish water
TDS 10,000–100,000 mg/L = saline water

According to Muchamad et al. (2017), the characteristics of groundwater could also be distinguished using conductivity values as follows:

Conductivity <1,500 µS/cm = freshwater
Conductivity 1,500–5,000 µS/cm = semi-brackish water
Conductivity 5,000–15,000 µS/cm = brackish water
Conductivity 15,000–50,000 µS/cm = saline water

Ion variation could determine the toxicity or feasibility of groundwater. Cl$^-$, B$^{3+}$, and Na$^+$ are toxic elements commonly found in irrigation systems. Plants are sensitive to these elements even at extremely low concentrations. The water quality for irrigation is generally assessed by several key factors such as sodium adsorption ratio (SAR), suspended sodium percentage (SSP), residual sodium carbonate (RSC), and electric conductivity (EC). Several additional indices are also essential to categorize groundwater quality for irrigation, such as magnesium adsorption ratio (MAR), Kelly’s ratio (KR), total hardness (TH), permeability index (PI), and residual sodium bicarbonate (RSBC) (Raihan and Alam 2008). The unit used for the whole ions was meq/L.

The TH of groundwater was calculated using the following equation (Hem 1985):

$$TH = (Ca^{2+} + Mg^{2+}) \times 50$$  (2)

TH was classified into four categories: soft (<75 mg/L), moderately hard (75–150 mg/L), hard (150–300 mg/L) and very hard (>300 mg/L) (Sawyer 1967). The relative activity of Na$^+$ ions during exchange was determined by SAR (Todd

| Parameter | WHO standard | Score (av) | Score relative (Wt) |
|-----------|--------------|------------|---------------------|
| pH        | 8.5          | 3          | 0.103               |
| TDS (mg/L)| 500          | 5          | 0.179               |
| Cl$^-$ (mg/L) | 250   | 5          | 0.179               |
| SO$_4^{2-}$ (mg/L) | 250 | 5          | 0.179               |
| Na$^+$ (mg/L) | 200   | 4          | 0.143               |
| K$^+$ (mg/L) | 12       | 2          | 0.071               |
| HCO$_3^-$ (mg/L) | 120  | 1          | 0.036               |
| Ca$^{2+}$ (mg/L) | 75    | 3          | 0.107               |
| Mg$^{2+}$ (mg/L) | 50    | 3          | 0.107               |

FIGURE 2. Borehole cross-section of the study area referenced from PDAM P2AT Pamekasan Regency and modified by the authors.
was classified into five categories (Table 2). The first stage to calculate WQI was to define SI for every chemical parameter. Thus, WQI could be calculated by summing the SI value of each parameter as follows:

\[
\text{SI} = Wi \times qi
\]

\[
\text{WQI} = \sum SI_i
\]

Where SIi is the sub-index from each parameter, and q is the rating according to parameter concentrations. WQI was classified into five categories (Table 2). WQI can be used as a basis for land use planning and water resource management (Dwivedi and Pathak 2007; Saeedi et al. 2010; Yidana and Yidana 2010).

3. RESULTS

3.1 Physiochemical characteristics of groundwater

Figure 3 shows the spatial distribution of groundwater's physiochemical parameters. All analyzed parameters were still under the allowed standard. The groundwater classification based on EC, TDS, TH, %Na, SAR, and PI is shown in Table 3. pH, EC, and TDS are the physical parameters sampled directly in the field. The pH value ranged from 6.7 to 7.8, and <7 pH was identified in the surrounding coastal area. By contrast, alkaline water was observed in the north and middle study areas. The average EC was 6466.8 µS/cm, exceeding the standard established by WHO. Similarly, TDS exceeded the standard set by WHO and the Ministry of Health (>1500 mg/L). The variation of TDS is related to the conductivity values in the northern study area and coastal area, with an average of 1000 µS/cm. Overall, 67% of the groundwater samples had physicochemical parameters below the standard.

According to conductivity classification (Klassen et al. 2014), most groundwater samples in the study area were predominated by fresh and slightly brackish water with an equal value of 41%. The remaining categories were 13% brackish water and 5% saline water. The conductivity ranged 653–35400 µS/cm, indicating that that groundwater is contaminated by salt due to infiltration from the salt pond and surrounding shallow aquifer. Despite the salinization issue, the groundwater quality based on conductivity values was good and permissible (Table 3).

In addition to conductivity, the TDS value showed linearity and ranged 1000–3000 mg/L (slightly saline) (Table 3). A high conductivity is associated with a high TDS concentration. The TDS values ranged from 17.7 to 3728 mg/L. According to groundwater classification based on TDS (Krishna et al. 2015), freshwater was found in the north, and brackish water was predominant in the surrounding salt ponds. The variability of TDS relies on the environmental condition of groundwater flow path and the lithology or rock formation where groundwater exists (aquifers) (Putranto et al. 2019). The high TDS value observed in several stations might be caused by the nature of the study area, that is, the presence of salt farming areas could induce a high TDS value in the coastal area.

The analyzed groundwater consisted of Ca\(^{2+}\), Mg\(^{2+}\), CaCO\(_3\), Na\(^+\), K\(^+\), HCO\(_3\)^{−}, Cl\(^−\), and SO\(_4^{2−}\). Except for Na\(^+\) and HCO\(_3^{−}\), the values of these parameters generally did not exceed the standard established by WHO (Table 3). Around 12.5% of Ca concentration in several stations showed a higher value than the standard (more than 200 mg/L), and the overall average was 123 mg/L. Even though the average Na concentration was more than 200 mg/L, its value was below the standard in several stations near the coastal area (<100 mg/L). Meanwhile, 21% of HCO\(_3^{−}\) in the groundwater met the standard, and this compound was scattered evenly in the north study area. Moreover, >50% of groundwater samples exceeded 300 mg/L. By contrast, the K value exceeded the standard in several stations and reached 162.9 mg/L. The same state was observed for Cl\(^−\), SO\(_4^{2−}\), and Mg\(^{2+}\), whose sufficiently high concentrations were observed in several stations of the coastal area and salt ponds. Nevertheless, their overall average was below the standard.

Approximately 92% of the groundwater samples’ TH was categorized as very hard, and only 4% were labeled as soft (Table 3). The very hard category predominated...
FIGURE 3. Spatial distribution of groundwater's physiochemical parameters in Pademawu. (a) pH, (b) EC, (c) TDS, (d) Ca, (e) Mg, (f) Na, (g) CaCO$_3$, (h) K, (i.) HCO$_3$, (j) Cl, and (k) SO$_4$. 

the northern study area and coastal area. Different from TH, the %Na, calculated by summing Na$^+$, Ca$^{2+}$, K$^+$, and Mg$^{2+}$ concentrations, showed that 25% of the groundwater sample was categorized as 60%-80%Na (doubtful for daily use). By contrast, the overall stations in the northern area showed an excellent water quality (%Na <20) (Table 3). In calculating the chemical parameters of groundwater, the dominant anion and cation must be determined. In terms of dominant anion, 42% of the groundwater samples consisted of anion HCO$_3^-$ > SO$_4^{2-}$ > Cl$^-$ and 30% anion HCO$_3^-$ > Cl$^-$ > SO$_4^{2-}$. The remaining 21% and 7% were attributed to anion Cl$^-$ > SO$_4^{2-}$ > HCO$_3^-$ and Cl$^-$ > HCO$_3^-$ > SO$_4^{2-}$, respectively (Figure 3). Overall, the anion concentration was composed of HCO$_3^-$ (72%), followed by SO$_4^{2-}$ and Cl$^-$. According to the graph in Figure 4, Na$^+$ and Cl$^-$ were the dominant cation and anion, respectively, indicating that saltwater played a significant role in reflecting the state of groundwater in the coastal area. The high Cl$^-$ and Na$^+$ concentrations in several locations could be caused by either seawater and salt deposits infiltrating the groundwater or domestic industrial wastes (Sajil Kumar et al. 2014).

According to WQI assessment, the study area was categorized as having excellent water quality ranging from 39 to 736.4 (67%). The other categories, such as good and very poor water quality, covered only 13% and 17% of the samples. However, 17% of groundwater samples were categorized as unsuitable for drinking purposes.
3.2 Hydrogeochemical analysis of groundwater

The dominant groundwater facies in the study area were Ca-HCO₃, Ca-Mg-Cl, Ca-Cl, and Na-Cl (Figure 5). These facies were determined according to the order of dominant cation and anion. The hydrochemical facies were predominated by Ca-HCO₃ (50%), Na-Cl (37%), Ca-Cl (8%), and mixed facies of Ca-Mg-Cl (5%). Groundwater facies CaHCO₃ predominated the northern study area, which is composed of deposit materials of Madura formation (coralline and dolomitic limestone). Lithology states play a significant role in determining the type of groundwater facies. Moreover, the primary components of limestone were Ca⁺ and HCO₃⁻, explaining why general facies contain these elements in the north area.

In contrast to the groundwater facies in the north area, Na-Cl were the dominant facies in the coastal zone and surrounding salt ponds, mainly in the seawater (Figure 5). Several groundwater samples in the coastal area showed different facies such as Ca-Cl and Ca-Mg-Cl. The arranging materials (alluvial deposits and amalgamation of sandstone, claystone, and limestone) trigger the unspecific dominant element within the groundwater near the coast. The spatial distribution of hydrogeochemical facies was predominated by NaCl in the study area and mixed Ca-Mg-Cl facies in the coastal area overlaid by a salt farming area. Groundwater facies were gradually altered toward the north and became CaHCO₃ facies. In the middle study area, Ca-Cl facies were observed and found to be associated with CaHCO₃ (Figure 6).

In addition to hydrochemical facies, SAR was analyzed in the 24 groundwater samples. The average SAR ranged from 0.17 to 3.63. In general, a high SAR was observed near the coast. The highest SAR of 20.35 was found in the northern study area. According to the Todd (1980) classification of these ratios, 75% of the groundwater samples were classified as "no problem" with SAR of <6, 16% were labeled as "increasing problem" with SAR of 6–9, and 9% were identified as "severe problem" with SAR of >9. Overall, the groundwater in the study area is suitable for irrigation with very good quality (Table 3). The US regional salinity

### TABLE 3. Groundwater classification based on hydrogeochemical analysis

| Parameter | Range         | Category | Southern | Middle | Northern |
|-----------|---------------|----------|----------|--------|----------|
| EC        | <250          | Excellent| -        | -      | -        |
|           | 250–750       | Good     | -        | -      | 33%      |
|           | 750–2000      | Permissible| 17%   | 4%    | 13%      |
|           | 2000–3000     | Doubtful | 8%      | 4%    | -        |
|           | >3000         | Unsuitable| 8%    | 13%   | -        |
|           | <1000         | Fresh    | 13%     | 8%    | 46%      |
|           | 1000–3000     | Slightly Saline| 17% | 8%    | -        |
| TDS       | 3000–10,000   | Moderately saline| 4%  | 4%    | -        |
|           | 10,000–35,000 | High saline | -     | -     | -        |
|           | >35,000       | Brine    | -       | -     | -        |
| TH as CaCO₂ (mg/L) | <20 | Excellent | - | 4% | 42% |
|           | 20–40         | Good     | -       | -     | -        |
|           | 40–60         | Permissible| 8%   | 13%   | 4%       |
|           | 60–80         | Doubtful | 17%     | 4%    | -        |
| Na% (SSP) | <6            | No problem| 13%   | 17%   | 46%      |
|           | 6–9           | Increasing problem| 13% | 4%    | -        |
|           | >9            | Severe problem| 8%   | -     | -        |
| SAR       | <60           | Suitable for irrigation| 4%  | 17%   | 42%      |
|           | >60           | Unsuitable for irrigation| 4%  | 4%    | -        |
| PI        | <1.25         | Excellent| 29%     | 13%   | 42%      |
|           | 1.25–2.5      | Good     | -       | 8%    | -        |
|           | >2.5          | Fair     | 4%      | -     | 4%       |
| RSBC (meq/L) | <50        | Not dangerous/feasible| 29% | 21%   | 46%      |
|           | >50           | Dangerous/not feasible| 4%  | -     | -        |
| MAR (meq/L) | <1           | Not feasible for irrigation| 8%  | 4%    | 29%      |
|           | >1            | Feasible for irrigation| 25% | 17%   | 17%      |

FIGURE 4. Major ionic concentration of groundwater in meq/L

FIGURE 5. Piper trilinear diagram showing the hydrogeochemical facies of the groundwater
laboratory has developed a diagram for categorizing irrigation water (Wilcox 1955) into 16 classes by referring to SAR. SAR established that dangerous Na+ and EC can be used for indexing the danger level of salinity. In the present work, 38% of the groundwater samples were categorized as SAR C2S1, 29% were SAR C4S2, and 25.5% were SAR C3S1. The two other samples were C4S1 and C3S2 (Figure 7).

PI was used to ease the water flow in a media. Approximately 61% of the water samples were categorized as “suitable for irrigation” category, and the remaining 38% were unsuitable (Bhardwaj and Singh 2011). PI results revealed that the groundwater has a good quality for irrigation with a maximum of 60% permeability. However, nine groundwater samples showed awful conditions for irrigation use.

RSBC is the amount of alkaline bicarbonate and carbonate on sediment dominated by Ca2+ and Mg2+, which influence groundwater suitability for irrigation. A perfect silting of Ca2+ and Mg2+ occurs when the amount of HCO3- and CO32- exceeds the concentration of Ca2+ and Mg2+ (Bhardwaj and Singh 2011). The average RSBC was ~1.4 (<1.25) (excellent), and the two other stations showed good and fair categories with RSBC of 1.25–2.5 and >2.5, respectively. These categories were also observed in the northern study area.

The suitability of groundwater could also be examined using MAR because around 2% of continental crust is based on masses and magnesium is the 8th most abundant element. This finding also explains why magnesium is predominant in the human body. Given that the magnesium ion is associated with soil aggregation and fragility, MAR can be used to determine the groundwater’s suitability for irrigation (Adimalla et al. 2020). The results showed that 83% of the groundwater samples were in the “not dangerous” category (MAR <50), and the remaining 17% were in the “dangerous” class. KR was also used to examine the groundwater’s feasibility for irrigation. Approximately 71% of the groundwater samples in the surrounding coastal area were feasible for irrigation with KR <1, and the remaining 29% showed non-feasibility (KR > 1). Thus, groundwater in coastal regions is not recommended for irrigation use.

4. DISCUSSION

4.1 Identification of saltwater contamination zone

The groundwater salinity in the study area was evaluated according to the tabulation of Ca2+ + Mg2+ concentration against Cl− in units of mmol/L. Overall, 29% of the groundwater samples were classified as saline water, which was mainly observed in the coastal area and the middle of Pademawu. As many as three samples near the coast were categorized as freshwater. Approximately 71% of the groundwater samples were classified as freshwater, which was mainly observed in the northern study area (Figure 8). Moreover, no samples were classified as brine water—the correlation between Ca2+ + Mg2+ against Cl− indicated the positive ion correlation with a regression value of 0.7359. Ca2+ and Mg2+ were of geogenic origin through rock water interactions. Meanwhile, Na and Cl were sourced from anthropogenic activities, such as agricultural, domestic, and industrial wastes (Mukate et al. 2020). This finding can be attributed to the dilution of limestone availability in geological formations (Sajil Kumar et al. 2014) where ion enrichments are sourced from mineral dissolutions, such as dolomite, apatite, and saltwater infiltration occurs within groundwater. This result is also correlated with the geological settings, that is, the limestone and dolomitic limestone formations in the middle and north parts of the study area should be considered (Situmorang et al. 1992).

TDS and Cl− showed a positive correlation with R2 of 0.3305 (Figure 9a). The high level of TDS in the study area is related to salt washing from the soil, resulting in elevated Cl− concentration. Another reason is the saltwater infiltration in the coastal zone. The regression of TDS against
total anion and cation also showed a positive correlation with R2 values of 0.2793 and 0.3238, respectively (Figure 9b). Groundwater anion in the study area consisted of Cl\(^-\) and HCO₃\(^-\). The high concentration of Cl\(^-\) may be caused by the leaching of saline residues in the soil because of climatic conditions and anthropogenic activities (Kale et al. 2010; Subba Rao et al. 2020). In addition to Cl\(^-\) anion predomination, the TDS value could also interpret the state of groundwater. A high concentration of TDS is influenced by domestic wastes, septic tanks, agricultural waste, and recharging rainwater (Wagh et al. 2016; Mukate et al. 2020). Generally, high Cl\(^-\) and TDS concentrations are triggered by the presence of salt ponds in Pademawu.

The groundwater samples’ TH was generally in the “very hard” category. This phenomenon can be attributed to several factors, such as the rock’s chemical compositions. Lithology-arranged aquifer in the coastal area is clay and sand containing high CaCO₃. The chemical mineralogy elements of clay mineral and coastal lithology reacting with seawater could dissolve CaCO₃ within the clay and sand minerals (Chidambaram et al. 2011). Moreover, the calcium content of groundwater is sourced from detrital minerals, such as plagioclase, feldspar, pyroxene, amphibole, garnet, limestone, dolomite, gypsum anhydrate, and clay, found in the coastal sediment (Sheik Mujabar and Chandrasekar 2013).

The high Na\(^+\) concentration of groundwater reflects its association with Cl\(^-\), resulting in the formation of saline water. Ion exchange could induce a high Na\(^+\) concentration (Subba Rao et al. 2020). Furthermore, the amalgamated influence of dilution, SO\(_4^{2-}\) reduction, anthropogenic activities, saltwater, and mineral vaporization could promote ion exchange. Meanwhile, the increasing Cl\(^-\) concentration of groundwater aquifers indicates seawater intrusion. Cl\(^-\) is possibly yielded from domestic waste pollution and salt washing residues (Jанардхана Рату et al. 2011).

### 4.2 Hydrogeochemical facies

The groundwater facies of Ca-HCO₃ were found in Pamekasan formation lithology (Qpp) and Madura formation, which were composed of conglomerate, sandstone, claystone, and limestone. By contrast, the facies Na-Cl and Ca-Cl and the mixed Ca-Mg-Cl consisted of alluvial deposits (Qa). Facies Ca-HCO₃ reflected groundwater interaction with limestone and dolomite limestone (Setiawan et al. 2010). This type of groundwater has similar chemical compositions to rainwater (Siftianida et al. 2017).

HCO₃\(^-\) in water is generally sourced from shallow and young groundwater. The primary source of ion HCO₃\(^-\) within the groundwater is CO₂ dissolved in the rainwater; once it infiltrates the surface soil, CO₂ will dissolve additional CO₂ (Muchamad et al. 2017). An increase in temperature or a decrease in pressure causes CO₂ reduction and dissolution in the water. Organic material decomposition and SO₄ release CO₂ during dissolution. Water-amalgamated CO₃\(^2-\) minerals are dissolved by CO₂ while passing the soils and rocks, resulting in HCO₃\(^-\) release (Ramesh et al. 2013). Water containing Ca (HCO₃\(^-\)) is uncontaminated groundwater, meaning that it is the original one.

Na-Cl facies are related to seawater-containing Na-Cl polluting aquifer. The hydrochemical evolution of Ca-HCO₃ is altered to Na-HCO₃ facies and eventually results in Na-Cl facies. Na-Cl facies are related to rocks in the form of alluvial deposits (Qa) situated in the coastal area and salt agriculture. Furthermore, Na-Cl facies are also influenced by the distance from facies sources to the sea and salt pond area. Ca-HCO₃ facies reflect the origin of groundwater situated in shallower regions and indicate that the dominant water has interacted with limestone and dolomitic limestone (Setiawan et al. 2010).

In general, Ca\(^{2+}\) and Mg\(^{2+}\) maintain their stability within groundwater. Excessive Mg\(^{2+}\) in the groundwater will influence its quality by making it alkaline. This process can hamper the agriculture system and reduce the yield (Szabolcs 1964). SAR C2SI category was found in the northern study area that is sufficiently far away from the coastal area. This category shows that the groundwater has low salinity and a moderately harmful sodium alkalinity. The cohort of SAR C4S2 was identified in the coastal area (very high salinity and less harmful sodium alkalinity). By contrast, the group of C3SI (high salinity and less harmful sodium alkalinity) was found in the mixed zone between the coastal area and the northern study area.

The other remnant samples were categorized as C4SI and C3S2 with very high and high salinity status and less and moderate sodium alkalinity, respectively. According to the Wilcox classification, the salinity concentration of groundwater is highly degraded from the coastal area with very high salinity and gradually declines toward the north. The salinity state is related to the high concentration of Na\(^+\) elements and low calcium. If this kind of groundwater is used for irrigation, then the complex cation will be saturated by Na\(^+\), demolishing the soil structure due to clay particle dispersion. Moreover, the groundwater showing a high Na\(^+\) proportion with HCO₃\(^-\) and Cl\(^-\) or SO₄\(^2-\) is called alkaline water and saline water, respectively (Todd 1980).

Groundwater chemistry analysis is commonly used to distinguish water quality for drinking and irrigation. WQI is a significant index to identify water quality and its sustainability for consumption. The WQI calculation for the study area ranged from 39 to 736, and the groundwater samples were categorized into four types: excellent water, good water, very poor water, and unsuitable water for consumption. In general, 67% of the groundwater samples in the Pademawu Subdistrict were labeled as excellent water, 13% were good water, and 4% were very poor water. Moreover, 17% of the groundwater samples in the settlement area of Pademawu surrounded by salt ponds were categorized as unsuitable water for consumption (Figure 10). The artesian wells that are sufficiently close to salt ponds produce unsuitable water for drinking. By contrast, the middle and northern Pademawu have excellent-to-very good water.
The very poor and unsuitable WQI categories in the coastal area of Pademawu are induced by salt mineral dissolution triggered by gypsum mineral lithology. Furthermore, the high values of EC, Cl\(^-\), Na\(^+\), and Ca\(^{2+}\) indicated the amalgamated interactions between water and rocks and the declining water quality in the study area. According to the assessed parameters (pH, TDS, Cl\(^-\), HCO\(_3\)^-, \(\text{SO}_4^{2-}\), \(\text{NO}_3^-\), Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\), and K\(^+\)), the overall groundwater sample did not exceed the standard established by WHO and the Ministry of Health. However, several stations showed high values, resulting in an elevated WQI for the area approximately 1 km from salt ponds and coastline.

In contrast with that in the coastal area, the groundwater sample in the northern study area was categorized as excellent WQI, reflecting that distance from the salt-sourced area is significant in determining groundwater quality. PI was also used to determine how the content of Na\(^+\), Mg\(^{2+}\), Ca\(^{2+}\), and HCO\(_3^-\) influences the soil permeability and water quality for irrigation. According to the PI values, 62% of the groundwater samples were suitable for irrigation. However, nine stations in the northern study area showed an unsuitable water quality for irrigation due to limestone-arranged lithology predomination with Mg\(^{2+}\), Na\(^+\), and Ca\(^{2+}\) enrichment.

RSC analysis showed that 84% of the groundwater samples were in the excellent category. Enrichment with CO\(_3^{2-}\) and HCO\(_3^-\) causes the formation of Ca\(^{2+}\) and Mg\(^{2+}\) deposits in the groundwater. RSC is used to distinguish the influence of CO\(_3^{2-}\) and HCO\(_3^-\) on yields (Aravinthasamy et al. 2021). RSC < 1.25 indicates that groundwater resources can be utilized for irrigation. KR is also used to determine the groundwater’s feasibility for irrigation. The high KR indicated that 71% of the groundwater samples were suitable for irrigation, and the high Na\(^+\) percentage could be reduced from feldspar weathering.

The feasibility of groundwater for irrigation could also be determined by MAR. Approximately 84% of the groundwater samples were suitable for irrigation with MAR < 50 meq/L. Magnesium is limited in plants, so a high concentration of Mg could support plant growth. Magnesium enhancement in plants could be boosted by applying Epsom salt and dolomitic limestone in soils, resulting in magnesium balance in plants.

In addition to using physicochemical parameters to determine groundwater quality, they could also classify the characteristics of groundwater. The groundwater with a savorless feature was identified in the far away area from the coastal zone based on conductivity values. The slightly brackish, saline groundwater was gradually observed in the middle up to the coastal area of Pademawu. Conductivity is a measure of the solution's ability to conduct electricity. When a large amount of dissolved salts are ionized,
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AUTHORS’ CONTRIBUTIONS

W. A. G: conception and design of study, sample acquisition, within the salt pond area. J. W: supervision, analysis, drafting the manuscript, review, and editing. M. A. M: supervision and design of study. All authors have read and approved the final version of the manuscript.

COMPETING INTERESTS

The authors declare that there is no conflict or competing interests regarding the publication of this manuscript.

REFERENCES

Abu-alnaceem MF, Yusoff I, Ng TF, Alias Y, Raksmsy M. 2018. Assessment of groundwater salinity and quality in Gaza coastal aquifer, Gaza Strip, Palestine: An integrated statistical, geostatistical and hydrogeochemical approaches study. Science of The Total Environment. 615:972–989. doi:10.1016/j.scitotenv.2017.09.320. https://linkinghub.elsevier.com/retrieve/pii/S0048969717326712.

Adimalla N, Dhakate R, Kasarla A, Taloor AK. 2020. Appraisal of groundwater quality for drinking and irrigation purposes in Central Telangana, India. Groundwater for Sustainable Development. 10:100334. doi:10.1016/j.gsd.2020.100334. https://linkinghub.elsevier.com/retrieve/pii/S2352801X19303470.

Adimalla N, Li P, Venkatayogi S. 2018. Hydrogeochemical Evaluation of Groundwater Quality for Drinking and Irrigation Purposes and Integrated Interpretation with Water Quality Index Studies. Environmental Processes. 5(2):363–383. doi:10.1007/s40710-018-0297-4. http://link.springer.com/10.1007/s40710-018-0297-4.

Alfarrah N, Walraevens K. 2018. Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions. Water. 10(2):143. doi:10.3390/w10020143. http://www.mdpi.com/2073-4441/10/2/143.

Aravinthasamy P, Karunandhir D, Subramani T, Roy PD. 2021. Demarcation of groundwater quality domains using GIS for best agricultural practices in the drought-prone Shamuganadhi River basin of South India. Environmental Science and Pollution Research. 28(15):18423–18435. doi:10.1007/s11356-020-08518-5. https://link.springer.com/10.1007/s11356-020-08518-5.

Aris AZ, Praveena SM, Abdullah MH. 2012. The Influence of Seawater on the Chemical Composition of Groundwater in a Small Island: The Example of Manukan Island, East Malaysia. Journal of Coastal Research. 279:64–75. doi:10.2112/JCOASTRES-D-10-00020.1. http://www.bioone.org/doi/abs/10.2112/JCOASTRES-D-10-00020.1.

Avtar R, Tripathi S, Aggarwal AK. 2019. Assessment of Energy–Population–Urbanization Nexus with Changing Energy Industry Scenario in India. Land. 8(8):124. doi:10.3390/land8080124. https://www.mdpi.com/2073-445X/8/8/124.

Barlow PM, Reichard EG. 2010. Saltwater intrusion in coastal regions of North America. Hydrogeology Journal. 18(1):247–260. doi:10.1007/s10040-009-0514-3. http://link.springer.com/10.1007/s10040-009-0514-3.

Bhardwaj V, Singh DS. 2011. Surface and groundwater quality characterization of Deoria District, Ganga Plain, India. Environmental Earth Sciences. 63(2):383–395. doi:10.1007/s12665-010-0709-x. http://link.springer.com/10.1007/s12665-010-0709-x.

BPS. 2018. Kecamatan Pademawu dalam Angka 2018 [Pademawu Region in Numbers 2018]. Technical report. Badan Pusat Statistik.

Bridgewater LL, Baird RB, Eaton AD, Rice EW, Association APH, Association AWW, Federation WE, editors. 2017. Standard methods for the examination of water and wastewater. 23rd edition edition. Washington, DC: American Public Health Association.

Chidambaram S, Karmegam U, Sasidhar P, Prasanna MV, Manivannan R, Arunachalam S, Manikandan S, Anand-
Hajji S, Nasri G, Boughariou E, Bahloul M, Allouche N, Gopinath S, Srinivasamoorthy K, Vasanthavigar M, Saraee Freeze RA, Cherry JA. 1979. Groundwater. Englewood Cliffs, New Jersey: Prentice-Hall.

Efendy M, Sidik RF, Muhsuni FF. 2014. PEMETAAN POTENSI PENGENGEMBANGAN LAHAN TAMBIR GARAM DI PESISIR UTARA KABUPATEN PAMEKASAN. Jurnal Kelautan: Indonesian Journal of Marine Science and Technology. 71(1): https://journal.trunojoyo.ac.id/jurnalkelautan/article/view/791.

Freeze RA, Cherry JA. 1979. Groundwater. Englewood Cliffs, New Jersey: Prentice-Hall.

Gopinath S, Srinivasamoorthy K, Vasanthavigar M, Saravanan K, Prakash R, Suma CS, Senthilnathan D. 2018. Hydrochemical characteristics and salinity of groundwater in parts of Nagapattinam district of Tamil Nadu and the Union Territory of Puducherry, India. Carbonates and Evaporites. 33(1):1-13. doi:10.1007/s13146-016-0300-y. http://jrisetgeotam.com/index.php/jrisetgeotam/article/view/1005.

Gopinath S, Srinivasamoorthy K, Vasanthavigar M, Saravanan K, Prakash R, Suma CS, Senthilnathan D. 2018. Hydrochemical characteristics and salinity of groundwater in parts of Nagapattinam district of Tamil Nadu and the Union Territory of Puducherry, India. Carbonates and Evaporites. 33(1):1-13. doi:10.1007/s13146-016-0300-y. http://jrisetgeotam.com/index.php/jrisetgeotam/article/view/1005.

Haji S, Nasri G, Boughariou E, Bahloul M, Allouche N, Bouri S. 2020. Towards understanding groundwater quality using hydrochemical and statistical approaches: case of shallow aquifer of Mahdia-Ksour Essaf (Sahel of Tunisia). Environmental Science and Pollution Research. 27(5):5251-5265. doi:10.1007/s11356-019-06982-2. http://link.springer.com/10.1007/s11356-019-06982-2.

He X, Wu J, He S. 2019. Hydrochemical characteristics and quality evaluation of groundwater in terms of health risks in Luoke aquifer in Wuqi County of the Chinese Loess Plateau, northwest China. Human and Ecological Risk Assessment: An International Journal. 25(1-2):32-51. doi:10.1080/10807039.2018.1531693.
26(3):31592–31608. doi:10.1007/s11356-019-06103-z. http://link.springer.com/10.1007/s11356-019-06103-z.

Matahelumual BC. 2010. Kajian kondisi air tanah Jakarta tahun 2010. Jurnal Lingkungan dan Bencana Geologi. 3(1):131-149. http://jlbj.geologi.esdm.go.id/index.php/jlbj/article/view/11.

Muchamad AN, Alam BYCS, Yuningsih ET. 2017. Hydrochemical Analysis to Determine Groundwater Facies in Pati District. Geo: Journal of Science Technology and Environmental Health, Science and Engineering. 5(3):155–166. doi:10.101.

Muchamad AN, Alam BYCS, Yuningsih ET. 2017. HIDRO-GEOKIMIA AIRTANAH PADA DAERAH PANTAI: STUDI KASUS DATARAN RENDAH KATAK, DESA SUMBER AGUNG, KABUPATEN BANYUWANGI. RISET Geologi dan Pertambangan. 27(1):39. doi:10.14203/risetgeotam2017.v27.i4.422. http://risetgeotam.com/index.php/risetgeotam/article/view/442.

Mukate SV, Panaskar DB, Wagh VM, Baker SJ. 2020. Understanding the influence of industrial and agricultural land uses on groundwater quality in semiarid region of Solapur, India. Environment, Development and Sustainability. 22(4):3207–3238. doi:10.1007/s10668-019-00342-3. http://link.springer.com/10.1007/s10668-019-00342-3.

Piper AM. 1944. A graphic procedure in the geochemical interpretation of water-analyses. Transactions, American Geophysical Union. 25(6):914. doi:10.1029/TR025i006p00914. http://doi.wiley.com/10.1029/TR025i006p00914.

Poespowardooyo RS. 1986. Peta Hidrogeologi Indonesia Lembar VIII Surabaya (Jawa) [Hydrogeological map of Indonesia VIII Surabaya]. Bandung: Direktorat Geologi Tata Lingkungan.

Putranto TT, Putra BR, Marin J. 2019. Groundwater Quality Analysis to Determine Groundwater Facies in Pati-Rembang Groundwater Basin. IOP Conference Series: Earth and Environmental Science. 246:012001. doi:10.1088/1755-1315/246/1/012001. https://iopscience.iop.org/article/10.1088/1755-1315/246/1/012001.

Raghunath HM. 2003. Ground Water. second edition edition. New Delhi: New Age International (P) Limited Publishers.

Raihan F, Alam J. 2008. Assessment of Groundwater Quality in Sunamganj of Bangladesh. Iranian Journal of Environmental Health, Science and Engineering. 5(3):155–166.

Rajib M, Parveen M, Oguchi CT. 2019. A rapid technique for measuring oxidation–reduction potential for solid materials. Journal of Science Technology and Environment Informatics. 7(1):510–516. doi:10.18801/jstei.070119.53. https://www.journalbinet.com/jstei-070119-53.html.

Ramesh T, Manjaiah KM, Tomar JMS, Ngachan SV. 2013. Effect of multipurpose tree species on soil fertility and CO2 efflux under hilly ecosystems of Northeast India. Agroforestry Systems. 87(6):1377–1388. doi:10.1007/s10457-013-9643-6. http://link.springer.com/10.1007/s10457-013-9643-6.

Saedi M, Abessi O, Sharifi F, Meraji H. 2010. Development of groundwater quality index. Environmental Monitoring and Assessment. 163(1-4):327–335. doi:10.1007/s10661-009-0837-5. http://link.springer.com/10.1007/s10661-009-0837-5.

Sahu P, Siskdar PK. 2008. Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. Environmental Geology. 55(4):823–835. doi:10.1007/s00254-007-1034-x. http://link.springer.com/10.1007/s00254-007-1034-x.

Sajil Kumar PJ, Elango L, James EJ. 2014. Assessment of hydrochemistry and groundwater quality in the coastal area of South Chennai, India. Arabian Journal of Geosciences. 7(7):2641–2653. doi:10.1007/s12517-013-0940-3. http://link.springer.com/10.1007/s12517-013-0940-3.

Sawyer CN. 1967. Chemistry in Sanitary Engineering. 2nd edition edition. New York: McGraw Hill.

Selvakumar S, Ramkumar K, Chandrasekar N, Magees NS, Kaliraj S. 2017. Groundwater quality and its suitability for drinking and irrigation use in the Southern Tiruchirappalli district, Tamil Nadu, India. Applied Water Science. 7(1):411–420. doi:10.1007/s13201-014-0256-9. http://link.springer.com/10.1007/s13201-014-0256-9.

Setiawan T, P DJ, Brahmantyo B, Irawan DE. 2010. Analisis Hidrokimia Untuk Interpretasi Sistem Hidrogeologi Daerah Kars. Widyariset. 13(3):1–8.

Sheik Mujabar P, Chandrasekar N. 2013. Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. Natural Hazards. 69(3):1295–1304. doi:10.1007/s11069-011-9962-x. http://link.springer.com/10.1007/s11069-011-9962-x.

Siftianida II, Wijatna AB, Pratikno B. 2017. Aplikasi Isotop Alam untuk Pendugaan Daerah Resapan Air Bagi Mataair Di Kecamatan Cijeruk, Kabupaten Bogor, Jawa Barat. Jurnal Ilmiah Aplikasi Isotop dan Radiasi. 12(2):57. doi:10.17146/jair.2016.12.2.2274. http://jurnal.batant.go.id/index.php/jair/article/view/2274.

Situmorang RL, Agustiano DA, Suparman M. 1992. Peta Geologi Lembar Waru–Sumenep, Jawa [Geological Map of Waru–Sumenep Java]. Bandung: Pusat Penelitian dan Pengembangan Geologi.

Sivakunar N, Udayaganesan P, Chidambaram S, Venkataramanan S, Prasanna M, Pradeep K, Panda B. 2020. Factors determining the hydrogeochemical processes occurring in shallow groundwater of coastal alluvial aquifer, India. Geochemistry. 80(4):125623. doi:10.101.

Subba Rao N, Ravindra B, Wu J. 2020. Geochemical and health risk evaluation of fluoride rich groundwater in Sattenapalle Region, Guntur district, Andhra Pradesh, India. Human and Ecological Risk Assessment: An International Journal. 26(9):2316–2348. doi:10.1080/10807039.2020.174338. https://www.tandfonline.com/doi/full/10.1080/10807039.2020.174338.

Szabolcs I. 1964. The influence of irrigation water of high Sodium Carbonate content on soils. Agrokémia és talajtan. 13:237–246.

Todd DK. 1980. Groundwater hydrology. 2d ed edition. New York: Wiley.

Wagh VM, Panaskar DB, Muley AA, Mukate SV, Lelage YP, Aamalawar ML. 2016. Prediction of groundwater suitability for irrigation using artificial neural network model: a case study of Nanded tehsil, Maharashtra, India. Modeling Earth Systems and Environment. 2(4):1–10. doi:10.1007/s40808-016-0250-3. http://link.springer.com/10.1007/s40808-016-0250-3.

Wilcox LV. 1955. Classification and use of irrigation waters. circular n edition. Washington D C: United State Department of Agriculture.

World Health Organization. 2008. Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda,Vol.1, recommendations. 3rd ed edi-
Yidana SM, Yidana A. 2010. Assessing water quality using water quality index and multivariate analysis. Environmental Earth Sciences. 59(7):1461–1473. doi:10.1007/s12665-009-0132-3. http://link.springer.com/10.1007/s12665-009-0132-3.

Yuan Y, Liu Y, Luo K, Shahid MZ. 2020. Hydrochemical characteristics and a health risk assessment of the use of river water and groundwater as drinking sources in a rural area in Jiangjin District, China. Environmental Earth Sciences. 79(7):160. doi:10.1007/s12665-020-8900-1. http://link.springer.com/10.1007/s12665-020-8900-1.

Yetiş R, Atasoy AD, Demir Yetiş A, Yeşilnacar M. 2019. Hydrogeochemical characteristics and quality assessment of groundwater in Balkligol Basin, Sanliurfa, Turkey. Environmental Earth Sciences. 78(11):331. doi:10.1007/s12665-019-8330-0. http://link.springer.com/10.1007/s12665-019-8330-0.