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# Investigation of Seawater Intrusion in Coastal Aquifers of Kelantan, Malaysia using Geophysical and Hydrochemical Techniques

# Investigation of Seawater Intrusion in Coastal Aquifers of Kelantan, Malaysia using Geophysical and Hydrochemical Techniques

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**Abstract.** Seawater intrusion is known to be a major source of groundwater quality deterioration in coastal regions globally. The high population and the modern living standards demand more water, which has put the coastal aquifers under huge stress. Approximately 60% of water production in Kelantan is sourced from groundwater where groundwater abstraction for potable water supply is at its forefront. It is shown that the high rate of water abstraction from shallow and deep wells has put the coastal aquifer under stress to meet the increasing demand, as a result the movement of seawater accelerates fast towards the land which will cause mixing of groundwater with seawater. With this background, an integrated approaches using ERI and in-situ physical and hydrogeochemical technique is used to evaluate the nature and extend of seawater intrusion of shallow aquifers in coastal parts of Kelantan. A total of eight resistivity profile with a line spread of 200 meter each has been established to provide the subsurface resistivity values. The resistivity results showed low resistivity values ranging from 0.1 – 10.0 Ω m indicating that the groundwater is considered brackish or saline. Salinity results of the water analysis showed the value of 0.1, 4.1 and 6.0 parts per thousand (ppt) which considered as saline water zones. The electrical conductivity analysis values also reveal a value ranging from 200 – 2000 $\mu$s/cm suggest that aquifer is slightly brackish. Based on the result obtained, it is clear that saline water was detected in the shallow aquifer of the study area.

## 1. Introduction

Groundwater is widely adopted in Asia, accounting for about 25% of the total usage and withdrawal amount in the region consists of more than 70% of groundwater global value. Groundwater is one of the world's most valuable resources and based on hydrological interpretation, more permeable rock, fractured and fissured are the most productive aquifers while less productive aquifers are found in rocks of lower permeability. Very productive aquifers are also found in alluvial plains.

In Kelantan, groundwater supplies more than 60% of the public water supply of the state and as the groundwater demand increasing as a result of growing population, industrial and agricultural activities this has caused the deterioration in groundwater quality. Prolonged over pumping of groundwater has put the coastal aquifers under stress and vulnerable to seawater intrusion. One study reported that the chloride concentration in one of the well in Pengkalan Chepa is 1458 mg/l in 2011 which is far beyond the 250 mg/l drinking standard set by the Ministry of Health [1]. The decline in groundwater quality in coastal areas of Kelantan is becoming a serious concern owing to its ever increasing abstraction directly from the shallow and deep aquifers to meet the increasing demand, as a result the movement of seawater accelerates fast towards the land which will cause mixing of groundwater with seawater. In the study of seawater intrusion, the recognition of saltwater contamination of aquifers is crucial [2]. Mixing of seawater with freshwater aquifer zone is common phenomenon in most of the coastal regions in the world.

As recorded by many studies, hydrochemical signatures, isotopic techniques and resistivity surveys can be described as a method for intrusion of seawater in coastal aquifers [3,4,5,6,7,8,9]. The present study was carried out with the objective of assessing the seawater intrusion in the coastal aquifer of Kelantan using electrical resistivity and hydrogeochemistry analysis. Electrical resistivity method is chosen because it is non-invasive method which provides subsurface information and helps in identifying the seawater intrusion [9]. Groundwater quality is based on physical properties and chemical constituents such as major cations and anion where both of this properties of water change spatially and temporally which are affected by natural processes, human activity and seawater intrusion [10].

## 2. Study Area

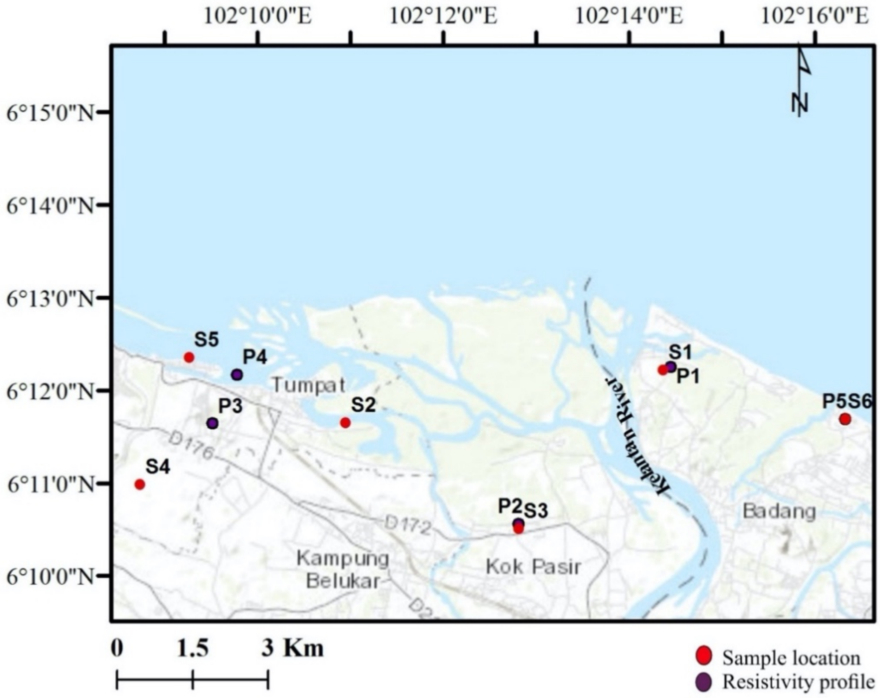


**Figure 1.** Research area with a location of sampling and resistivity profile

Kelantan river is one of the major rivers in Malaysia which commands about 85% of the Kelantan area and has four main tributaries namely Nenggiri River, Galas River, Lebir River and Pergau River. Kelantan River is the principle source of water for both irrigation needs as well as the potable water demand for the state of Kelantan. The North Kelantan River Basin is topographically dominated by the flat coastal plain with elevation less than 75m above mean sea level and mainly covered by Quartenary sediments or alluvium formation and constituents the reservoir in this region.

Research area is located at the northern part of Kelantan which is principally drain by the meandering Kelantan River. The research area involved are a part of Tumpat, Kota Bharu and Pengkalan Chepa (Figure 1). The coastal plain is mainly covered by Quaternary sediments or alluvium formation and constituents the reservoir in this region.

## 3. Material and Method

*3.1 Resistivity Survey.*

Electrical resistivity imaging (ERI) survey and in-situ hydrochemical analysis has been used in this research. ERI method uses direct electrical currents to image the electrical resistivity of the subsurface where it can be used to locate the

water table, water- or air-filled fracture zones, faults and karst conduits [11]. From the magnitude of the current applied and from the knowledge of the current electrode separation it is possible to calculate the potential distribution and the path of current flow if the underground is homogenous and in case of anomalous condition, it will deflect the current and distort the normal potentials [12].

The resistivity measurements were carried out using ABEM terrameter. Schlumberger and pole-dipole array has been used for electrode configuration in this research. Total length of 200m with Schlumberger array is used to grasp the distribution of basement rock, as well as seawater intruded zones into groundwater. Schlumberger arrays is chosen because it is the most preferred arrays for resolution of horizontal structures and it has the highest sensitivity to surface inhomogeneity in sounding. Figure 2 shows the typical range of electrical resistivity and conductivity of earth materials by Palacky, 1998.

For the classification of fresh to saline water based on resistivity of layered regolith [13] it can be seen in Table 1, where the boundary between fresh and saline groundwater zone is measured at 20 Ω m are and resistivity values of less and more than 20 Ω m are estimated to be saline and freshwater zone respectively. The source of the freshwater is assumed to be groundwater recharge process, which is driven directly by rainfall [14]. Resistivity value can also distinguish the type of of aquifer as noted in Table 2. For directly by rainfall [14]. Resistivity value can also distinguish the type of aquifers as noted in Table 2.

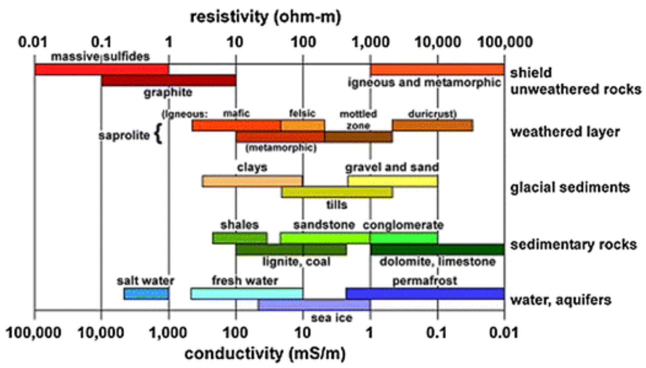


**Figure 2.** Typical resistivity values (Ω m) or conductivity (mS/m) of earth material

**Table 1.** Aquifer prospect as related to resistivity (Ω m) of layered regolith [13]

| Resistivity Value (Ω m) | Description |
|---|---|
| 0 – 20 | Clays with limited prospect (or saline water) |
| 20 – 100 | Optimum weathering and groundwater prospect |
| 100 – 150 | Medium conditions and prospect |
| 150 – 200 | Little weathering and poor prospect |
| > 200 | Negligible prospect |

**Table 2.** Resistivity value related to type of aquifer

| Resistivity Value (Ω m) | Description |
|---|---|
| 0.1 – 5.0 | Saltwater |

| | |
|---|---|
| 5.0 – 15.0 | Brackish water |
| 50.0 – 100.0 | Freshwater |

*3.2 Hydrochemical*

For hydrochemistry data, in-situ parameters analysis has been conducted with groundwater sampling the research area. The parameters include hydrogen ion activity (pH), electrical conductivity (EC), total dissolve solid (TDS), salinity, and chloride ratios from selected domestic groundwater wells. These parameters were measured with aid of pH meter and YSI 556 MPS Multi-parameter.

The simplest common indicator for sea water intrusion are the high level of Cl and TDS where the mixing zone between seawater and groundwater can be identified from TDS. In order to determine the brackish or saline waters, hydrogeochemical signatures are normally used. A simple but widely used scheme for categorizing groundwater based on TDS is presented in Table 3**.**

**Table 3.** Groundwater classification based on TDS and EC [10]

| Category | TDS (mg/L) | EC (μS/cm) |
|---|---|---|
| Fresh water | 0 – 1000 | <1500 |
| Brackish water | 1000 – 10,000 | 1500 - 3000 |
| Saline water | 10,000 – 100,000 | >3000 |

Electrical conductivity is the ability of a substance to conduct an electrical current and the presence of charged ions species in a solution makes the solution conductive [15]. In coastal region, the electrical conductivity value more than 500 μS/cm is considered as affected by seawater intrusion. The typical conductivity value of earth material can be seen in Table 1.

## 4. Result and Discussion

2D resistivity profile obtained from pole-dipole and Schlumberger configuration was compared with the in-situ water quality parameter. The in-situ parameter obtained from six wells closer to the resistivity profiles. The location of the resistivity profile is shown in Table 4.

**Table 4.** Resistivity profile location

| Profile | Location |
|---|---|
| 1 | 6°12'15"N , 102°14'30"E |
| 2 | 6°10'33"N , 102°12'52"E |
| 3 | 6°11'37"N , 102°9'34.1"E |
| 4 | 6°12'08.5"N , 102°09'49.7"E |
| 5 | 6°11'42.0"N , 102°16'22.8"E |

*4.1 Profile 1*

In Profile 1 as in Figure 3 (a), survey was carried out with a line spread of 200m at a distance of 2km from the coast. Profile 1 show a low resistivity value of 0.1 – 4.6 Ωm at the top of the profile with a depth of 0 – 25m under the ground. Influenced of seawater is noticed in Profile 1 as indicated by low resistivity. Low resistivity zones corresponds with the in-situ reading of salinity, TDS, and EC. Salinity value of 4.1 ppt is measured in the groundwater well near to this profile. EC value of 989.9

$\mu$s/cm and TDS value of 581.0 mg/L also showing the presence of seawater to this profile as stated in Table 5. Groundwater sample also taken from a well nearer to Profile 1, and the reading of physical parameter are 6.0ppt for salinity value, EC value of 1979 $\mu$s/cm and TDS value of 1061 mg/L. This also indicates the influenced of the seawater in the research area. For hydro chemical data, the concentration of chloride and sodium are high with 1288.4 mg/L and 605.4 mg/L.

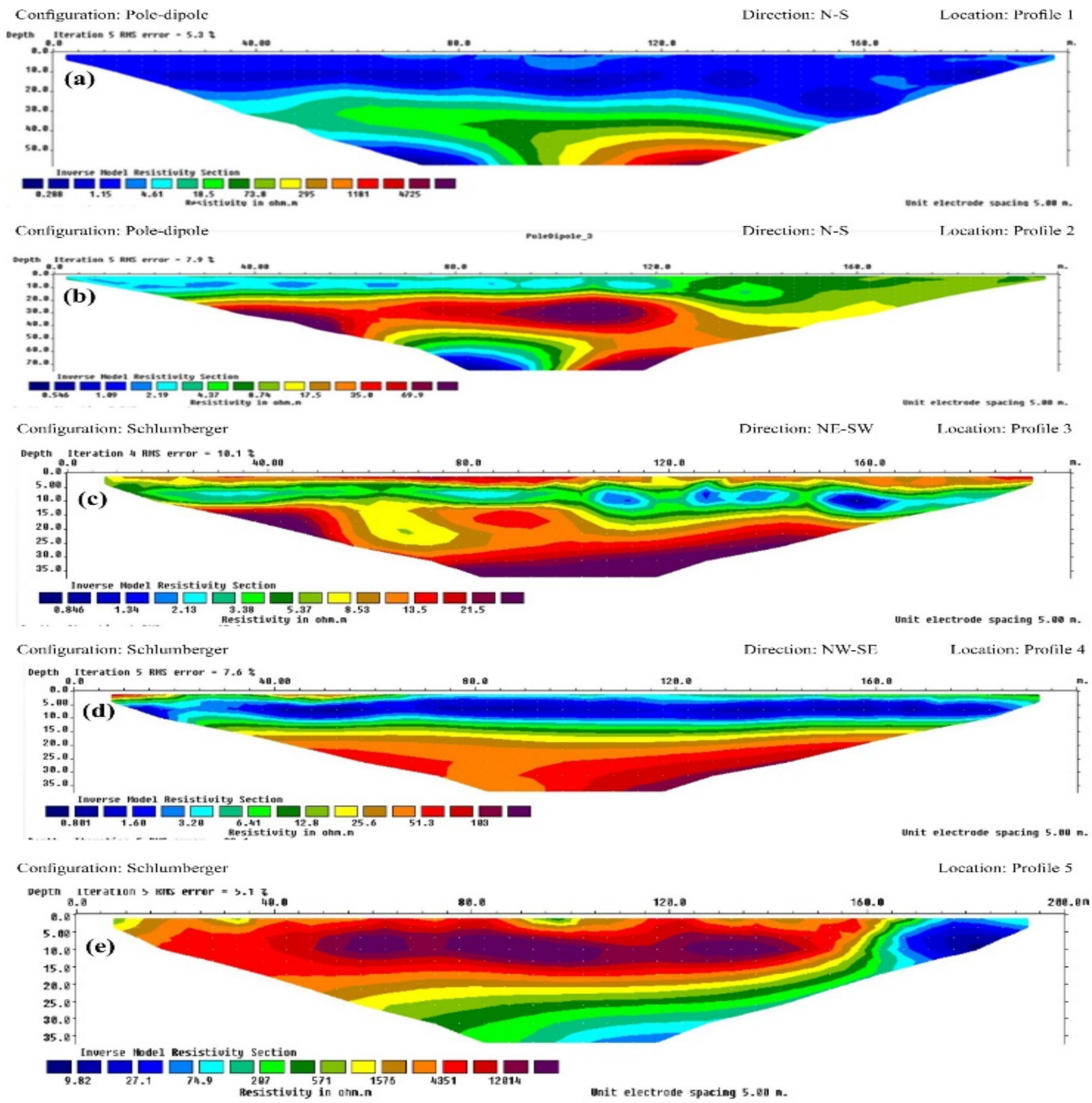


**Figure 3.** Resistivity image across profile in research area

*4.2 Profile 2*

In Profile 2 as pointed out in Figure 3 (b), survey was carried out with a line spread of 200m at a distance of 2km from the coast. Profile 2 shows low to moderate resistivity zones ranging from 0.5 – 75 Ωm. Low resistivity layer can be seen at the top of the section at distance 0 – 120 m with a resistivity value of 0.5 – 5 Ωm at depth 0 – 20 m below the ground representing saline groundwater.

Moderate resistivity value range from 6 – 30 Ωm at depth 20 – 60 m below the ground represent the saltwater mixed with brackish water. In-situ parameters taken from a well nearer to Profile 2 shows TDS of 107.8 mg/L and EC of 181.6 $\mu$s/cm (Table 5). This very low value of TDS and EC indicated that there is almost no or very little influenced of saline water in this area and it is not severely affected by seawater recharge.

Table 5. Physical and hydrochemical data of water sample

| Point | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| Location | 6°12'13"N<br>102°14'25" E | 6°11' 38" N<br>102°11' 0" E | 6°10' 30" N<br>102°12' 52 " E | 6°10' 57.26 " N<br>102°8'47.38 " E | 6°12' 19.15 " N<br>102°9' 18.56 " E | 6°11' 42.0 " N<br>102°16'22.8" E |
| pH | 6.79 | 6.48 | 6.18 | 6.61 | 7.18 | 7.23 |
| Salinity (ppt) | 4.1 | 6 | 0.1 | 0.2 | 0.4 | 6.2 |
| TDS mg/L | 581 | 1061 | 107.8 | 94 | 350 | 302.6 |
| Turbidity (NTU) | 9.99 | 2.14 | 0.31 | 11 | 7 | 0.5 |
| EC ($\mu$s/cm) | 989.9 | 1979 | 181.6 | 446 | 887 | 656.5 |
| Cu (mg/L) | 0.046 | 0.063 | 0.039 | 0.052 | 2.919 | 0.032 |
| Na (mg/L) | 19.93 | 605.4 | 7.127 | - | - | 30.08 |
| Fe (mg/L) | 0.747 | 0.765 | 0.114 | 0.599 | 2.919 | 0.079 |
| K (mg/L) | 5.776 | 27.51 | 6.303 | 5.645 | 15.05 | 8.708 |
| Mn (mg/L) | 0.148 | 0.064 | 0.041 | 0.047 | 0.604 | 0.018 |
| Cl (mg/L) | 50.55 | 1288.4 | 30.29 | 85.2 | 79.946 | - |

*4.3 Profile 3.*

In Profile 3 as shown in Figure 3 (c), survey was carried out with a line spread of 200 m at a distance of 1.37 km from the coast. Profile 3 shows a low- to moderate- resistivity layer of 0.5 – 30 Ωm. Low resistivity value can be seen depth of 5 – 15 m below the ground with a value of 0.5 – 4.0 Ωm. The low resistivity value indicating the presence of saline water zone. The physical parameter show EC of 446 $\mu$s/cm and TDS value of 96 mg/L. Hence, in this case the distance of mixing of seawater with groundwater is in low percentage of comparatively less. From 15 to 40 m depth below the ground, the resistivity value ranging from 9 – 30 Ωm which can be identify as brackish zone.

*4.4 Profile 4*

Profile 4 in Figure 3 (d), located at a distance of 0.39 km from the coast with a line spread of 200m of pole-dipole configuration as can see in Figure 3. The 2D image show a presence of three clear layers based on the resistivity value. The upper layer has a resistivity value of 0.3 – 3.2 Ωm which represent aquifer containing saline water. The second layer hold a resistivity value of 5 – 15 Ωm indicating that it contains brackish water at depth of 12 – 20 m below the ground. The lower layer shows a moderately to high resistivity value of 20 – 120 Ωm which is divided into two zones a transition zone and the unaffected zone saturated with brackish water. Groundwater sample also taken from a well nearer to Profile 3, and the reading of in-situ parameter are EC value of 887 $\mu$s/cm and TDS value of 350 mg/L. From the in-situ parameter, it indicated that profile 3 area is not severely affected by saline water.

*4.5 Profile 5*

The result of the 2D resistivity model for Profile 5 is shown is Figure 3 (e), where it is located 0.51 km from the shoreline. Profile 5 shows a moderate- to high- resistivity value of 8 – 13 000 Ωm. the high resistivity value is interpreted as hard rock and dry soil. Moderate resistivity value of profile 5 is 5 – 15 Ωm located at the distance of 170 to 200 m of the section represent the mixing of saline water and freshwater. The groundwater sample from the nearer well show EC of 656.5 $\mu$s/cm and TDS of 302.6 mg/L (Table 5).

## 5. Conclusion

Resistivity and hydrochemical techniques were used to determine the extent of seawater intrusion in coastal aquifers of Kelantan, Malaysia. Resistivity is an useful tools for seawater intruson mapping as highlighted in the research. The variation of low resistivity values and images especially in the shallow aquifer near to the coastline indicated the influenced of saline water or mixing of seawater and freshwater. In-situ water quality parameters shown moderate value in EC, TDS, salinity and pH. Thus, it is concluded that the influence of seawater mixing with freshwater present in the research area but in the minimum extend except in sampling point S2, where the physical and hydrochemical data are quite high with TDS of 1061 mg/L, EC of 1979 $\mu$m/cm, and Cl concentration of 1288.4 mg/L. The presence of saline water in the aquifer might come from over pumping of aquifer due to the high demand of water in the research area. Apart from that the short distance between the aquifer and the coast might also become one of the factor that cause phenomenon of seawater intrusion at research area.

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