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Research Article

Study on Selected Parameters of Groundwater Quality Based on Different Tides, East Coast of Terengganu, Malaysia

[1,2]Muhd. Barzani Gasim, [3]Azman Azid, [1]Norsyuhada Hairoma, [2]Nadzifah Yaakub, [1]Haniff Muhamad, [1]Fazureen Azaman and [1]Noorjima Abdul Wahab

[1]East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia
[2]Faculty of Bio-Resources and Food Industries, Universiti Sultan Zainal Abidin, Tembila Campus, 22200 Besut, Terengganu, Malaysia
[3]UniSZA Science and Medicine Foundation Centre, Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia

Abstract

Background and Objective: Most of the population along the Terengganu coast and other states in the East coast of Peninsular are dependent on the groundwater resource. As a result of continuous use, some of the wells are contaminated by seawater intrusion, especially during low tide. This study aimed are to determine the water quality in spatial and temporal variations on different tides and to investigate the impact of saltwater intrusion on each sampling well. **Methodology:** A groundwater quality study was carried out at 13 well sampling stations along the East coast of Terengganu. Each station is located along the coast with distance 38-135 m from the sea, the first sampling was July, 2015 represent for dry season and was repeated on January, 2016 represent for wet season. The eight parameters are Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, pH, turbidity, Total Suspended Solids (TSS), chloride and other parameter is depth to groundwater level. Groundwater samples were obtained from each well by using Eijelkamp Advanced Peristaltic Pump. Source of variation of these parameters were identified by using the Principle Component Analysis (PCA). **Results:** The result shows that three water quality parameters EC, salinity and chloride have close related to sea water intrusion during low tide. Distribution of DO relatively low and four other parameters such as turbidity, TSS, TDS and pH have normal concentration during the study carried out. **Conclusion:** The St. M2 was recorded as the deepest groundwater level (7.9 m) while St. B3 was the shallowest level (2.49 m). The PCA analyses on low and high tides data revealed 3 possible sources that influence the water quality pollution which are saline water contamination, tide inducing factor and anthropogenic activities. The most affected sampling wells due to saltwater contamination are B1, B3, B4 and KT1.

Key words: East coast Terengganu, groundwater quality, spatial and temporal variations, physicochemical parameters, saline water contamination

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Corresponding Author: Muhd. Barzani Gasim, East Coast Environmental Research Institute (ESERI), Universiti Sultan Zainal Abidin, Gong Badak Campus, 21300 Kuala Nerus, Terengganu, Malaysia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

For everyday practices, human need water to stay alive and to carry out daily domestic or economic uses. Malaysia is a tropical country, it received plenty of rainfall throughout the year but sometimes inadequate surface water supplies for domestic needs due to prolonged drought or other constraints. Another alternative for freshwater supply is from groundwater, it is defined as subsurface water and can be either confined or unconfined aquifer water distinguished by water components[1]. Water stored as groundwater is originated from surface water that seeps slowly into the ground, it takes a long time to fill up the groundwater storage. Groundwater quality data give important input to the historical geology regarding with their recharge, discharge and storage[2]. Variation in groundwater quality is a function of their physicochemical parameters that are greatly influenced by geological formations, fluctuation of sea level rise and anthropogenic activities[3-6]. If groundwater is being used without a proper best management approach, imbalance rate of recharge and discharge can cause threat to this valuable water resource.

Based on Schiavo *et al.*[7], the chemistry of groundwater is much influenced by rock materials, soil and pollutant sources such as mining, land clearance, saline intrusion, industrial, excessive irrigation activities and domestic wastes. Groundwater used for domestic and irrigation purposes can vary greatly in quality depending upon type and quantity of dissolved salts. According to Choudhury *et al.*[8], Abdullah *et al.*[9] and Abd-Elhamid and Javadi[10], the over exploitation of groundwater in the coastal zones has affected its quality and quantity and may result inadequate water balance and triggering of seawater intrusion or saltwater contamination. This kind of threat is generally related to aquifers that located close to the sea; these aquifers are known as coastal aquifers. Theoretically, freshwater and saltwater are of different density. Thus, these waters should not mix up and was separated by a zone known as transition zone containing brackish water. This zone kept freshwater and saltwater in natural equilibrium[11,12]. The location of the transition zone is not fixed as it is can either move further inland or towards the sea depending on several factors. Hydrogeochemical and geophysical technique according to Samsudin *et al.*[13] can be applied to map and visualize this phenomenon. In a normal condition, freshwater will flow into the sea; however, a reversed situation can occur where the saltwater flows into the freshwater under the influences of natural events and anthropogenic activities[10,14,15].

This problem has become a great concern to peoples, who living along the coast since long time ago as the saltwater intrusion that contaminated their main water supply in the coastal aquifer. Contamination of 2-3% of saltwater into coastal aquifer will increase the waters salinity and resulting in water quality degradation[16,17]. This problem is also experienced by residence living along Terengganu coastline which is the area studied. Most of the residents in this area still use groundwater that withdrawn through the drilled wells. Some of them use the water only for basic uses such as for watering crops and livestock[4]. The rest of them used the well water as their main water supply due to financial issues. The objectives of the study were to determine the water quality in spatial and temporal variations on different tides and to investigate the impact of saltwater intrusion on each sampling well.

MATERIALS AND METHODS

Study area: Terengganu is located in the east coast of Peninsular Malaysia. Specifically, it is located between longitudes 102.25°E to 103.50°E and latitude 4°N to 5.50°N. The size of Terengganu is approximately 1,295 and 638.3 ha with coastline bordered by the South China Sea, stretching 225 km from Besut (North) to Kemaman (South). It received an average rainfall of $\pm$400 mm annum^{-1} during the Northeast monsoon season (November-March) meanwhile $\pm$190 mm annum^{-1} during the other season. The average temperature is from 31-33°C throughout the year. Coastline of Terengganu is dominated by quaternary rock of marine and continental deposits. It is specifically known as Holocene beach ridges that derived from Matang Gelugor Member. It is comprises of sand, gravel and sandy clay deposits of the littoral and marine environments. In the hydrogeology perspective, quaternary sediment is characterised by high porosity and excellent permeability that allowed water to be stored in between the grains. Carboniferous rock and minor intrusive rock also present along the centre and South of Terengganu coastline.

Data collection

Groundwater: Groundwater samplings were carried out at thirteen selected private wells that located in the Terengganu coastline (Fig. 1). The coordinate for groundwater sampling well were tabulated in Table 1. Samplings were conducted twice where the first sampling was conducted from 12-14 July, 2015 and the second sampling was conducted from 4-6 January, 2016. The groundwater quality study is based on 8 selected water quality parameters, namely: Turbidity, Total Suspended Solid (TSS), Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, chloride, Dissolved Oxygen (DO), pH and other parameter is depth to groundwater level. Selection of the selected parameters which are

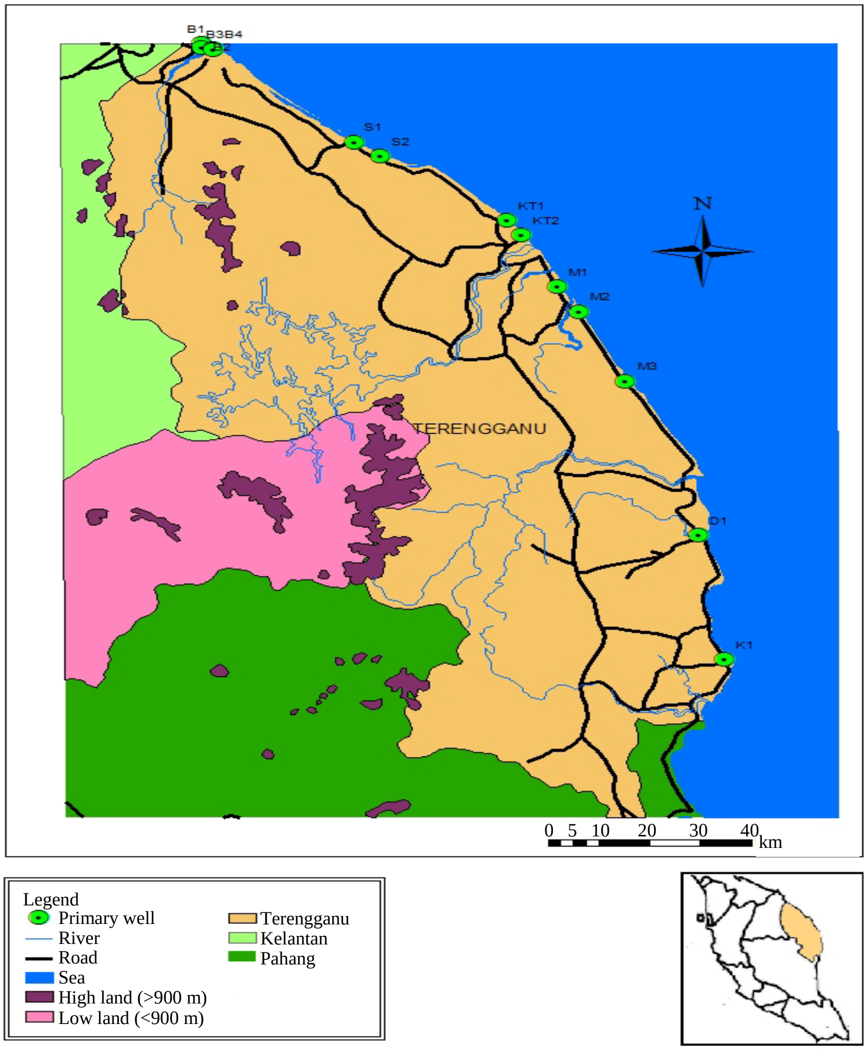

Fig. 1: Location of sampling well (Primary well) along Terengganu coastline

Table 1: Coordinate location of each sampling well

Station	Latitude	Longitude	Distance from the sea (m)
B1	5.833999	102.5553	100
B2	5.824092	102.5566	120
B3	5.821644	102.5754	125
B4	5.820214	102.5774	135
S1	5.595101	102.8262	84
S2	5.560547	102.8736	68
KT1	5.403991	103.0992	38
KT2	5.368615	103.1241	94
M1	5.243519	103.1872	118
M2	5.182462	103.2258	34
M3	5.013493	103.3096	120
D1	4.638688	103.4383	85
K1	4.336102	103.4858	57

involving physicochemical are to identify the influence of tidal movement of low and high tides onto the coastal groundwater quality. For this purpose, during each of the sampling process, water quality parameters were measured during low and high tides.

Groundwater samples were extracted from well by using Eijelkamp Advanced Peristaltic Pump. DO, EC, TDS, salinity, chloride and pH were measured *in situ* using YSI 556 Handheld Multiparameter. Turbidity was measured using HACH 2100Q Portable Turbidimeter and TSS was measured using gravimetric method. Global Positioning System (GPS) was used to locate the exact coordinates of each sampling well.

Principal component analysis: The PCA was adopted to analyse the data due to its capability in analysing a big data set and its ability in uncovering the meaningful structure behind the data mass. Before performing data analysis, the suitability of the data for PCA analysis will be tested by using Pearson correlations matrix, Bartlett's sphericity test and Keiser-Meyer-Olkin test. Pearson correlations matrix was calculated to identify the inter-relationship between parameters[18]. Bartlett sphericity test was used to confirm whether the parameters are correlated or uncorrelated[19,20]. The KMO test measures the sample adequacy that describes the quality of sample to produce reliable PCA results[21,22]. Principal Component Analysis (PCA) is performed by using XLSTAT 2014 add-in software[23-25].

RESULTS AND DISCUSSION

Pearson correlations matrix at 0.05 significance level alpha show inter-relationships between nine water quality parameters of both low and high tides that were tabulated in Table 2. During low tide, turbidity has inter-relationship with TSS, EC has inter-relationship with TDS, salinity and chloride, TDS has inter-relationship with EC, salinity and chloride, salinity has inter-relationship with EC, TDS and chloride and chloride has inter-relationship with EC, TDS and salinity. During high tide, EC has inter-relationship with TDS, salinity, chloride and pH; TDS has inter-relationship with EC, salinity, chloride and pH; salinity has inter-relationship with EC, TDS chloride and pH; chloride has inter-relationship with EC, TDS, pH and salinity and pH has inter-relationship with EC, TDS, salinity and chloride. Bartlett's test of sphericity confirmed the selected water quality parameters are correlated where the observed chi-square values are 3.66×10^{2} ($p<0.0001$, df = 36) and 2.21×10^{2} ($p<0.0001$, df = 36) for low and high tides, respectively. Both data set of low tide (0.671) and high tides (0.678) have mediocre sample as have been indicated through KMO test[26]. Therefore, PCA analysis is considered to be an effective analysis to bring out the prominent structure that underlies the data sets.

The PCA with varimax revealed three varimax factors (VFs) that representing 78.835% of total variability in the low tide data set. For high tide data set, PCA with varimax produced three varimax factors (VFs) with 75.579% of total variability. For each VF, new source of pollution will be assigned in accordance to the values of strong and moderate factor loadings that listed under each VF (Table 3).

Table 2: Pearson correlations matrix between 11 selected water quality parameters of study area

Parameters	Depth to water (m)	Turbidity (NTU)	TSS (mg L^{-1})	EC (µS cm^{-1})	TDS (mg L^{-1})	SAL (ppt)	Cl (mg L^{-1})	DO (mg L^{-1})	pH
Low tide									
Depth to water (m)	1*	0.325	-0.332	-0.230	-0.252	-0.217	-0.204	0.112	0.035
Turbidity (NTU)	0.325	1*	-0.399*	-0.152	-0.155	-0.152	-0.182	0.074	0.136
TSS (mg L^{-1})	-0.332	-0.399*	1*	-0.176	-0.159	-0.184	-0.146	-0.090	0.082
EC (µS cm^{-1})	-0.230	-0.152	-0.176	1*	0.999*	1.000*	0.930*	-0.065	0.375
TDS (mg L^{-1})	-0.252	-0.155	-0.159	0.999*	1*	0.998*	0.920*	-0.056	0.377
SAL (ppt)	-0.217	-0.152	-0.184	1.000*	0.998*	1*	0.931*	-0.063	0.378
Cl (mg L^{-1})	-0.204	-0.182	-0.146	0.930*	0.920*	0.931*	1*	-0.094	0.378
DO (mg L^{-1})	0.112	0.074	-0.090	-0.065	-0.056	-0.063	-0.094	1*	0.234
pH	0.035	0.136	0.082	0.375	0.377	0.378	0.378	0.234	1*
High tide									
Depth to water (m)	1*	0.236	-0.268	-0.198	-0.242	-0.204	-0.174	0.215	-0.022
Turbidity (NTU)	0.236	1*	-0.176	-0.162	-0.141	-0.145	-0.189	-0.017	-0.261
TSS (mg L^{-1})	-0.268	-0.176	1*	-0.295	-0.270	-0.290	-0.226	-0.350	-0.012
EC (µS cm^{-1})	-0.198	-0.162	-0.295	1*	0.806*	0.810*	0.796*	0.062	0.495*
TDS (mg L^{-1})	-0.242	-0.141	-0.270	0.806*	1*	0.998*	0.930*	-0.069	0.465*
SAL (ppt)	-0.204	-0.145	-0.290	0.810*	0.998*	1*	0.940*	-0.065	0.466*
Cl (mg L^{-1})	-0.174	-0.189	-0.226	0.796*	0.930*	0.940*	1*	-0.112	0.424*
DO (mg L^{-1})	0.215	-0.017	-0.350	0.062	-0.069	-0.065	-0.113	1*	-0.113
pH	-0.022	-0.261	-0.012	0.495*	0.465*	0.466*	0.424*	-0.114	1*

*Values are different from 0 with a significance level $\alpha = 0.05$

Table 3: Varifactors (VF) after varimax rotation and possible sources of category in the coastal of Terengganu

	Low tide			High tide		
Variables	VF1	VF2	VF3	VF1	VF2	VF3
Depth to water level (m)	-0.248	0.672*	0.157	-0.203	0.548*	0.348
Turbidity (NTU)	-0.155	0.733*	0.182	-0.105	0.001	0.913*
TSS (mg L^{-1})	-0.207	-0.833*	0.133	-0.339	-0.688*	-0.342
EC (µS cm^{-1})	0.992*	-0.009	0.036	0.882*	0.116	-0.128
TDS (mg L^{-1})	0.988*	-0.028	0.045	0.974*	-0.026	-0.037
SAL (ppt)	0.992*	0.000	0.038	0.977*	-0.003	-0.029
Cl (mg L^{-1})	0.955*	-0.030	0.026	0.945*	-0.043	-0.052
DO (mg L^{-1})	-0.120	0.070	0.788*	-0.099	0.847*	-0.188
pH	0.388	-0.013	0.743*	0.538*	-0.024	-0.353
Eigenvalue	4.184	1.745	1.166	4.112	1.661	1.029
Variability (%)	46.134	18.772	13.929	44.912	16.756	13.912
Cumulative (%)	46.134	64.906	78.835	44.912	61.668	75.579

*Values indicate strong and moderate loadings

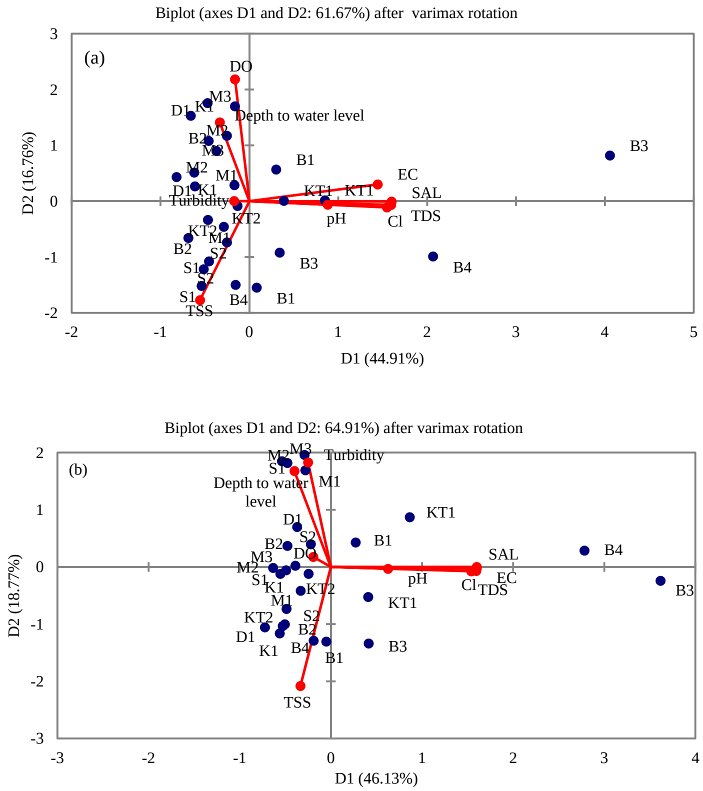

Fig. 2(a-b): Biplot of varimax factors and sampling wells in the East coast of Terengganu for (a) Low tide data and (b) High tide data

The VF1 of low tide data set accounts 46.134% of variability with strong positive loadings on EC, TDS, salinity and chloride. This VF contains variables that are related to saline water contamination into coastal aquifer. The VF2 accounts for 18.772% of variability with moderate positive loadings on depth to water level and turbidity and strong negative loading on TSS variable. The fluctuation of water level in coastal area is corresponding to the tide. During low tide, groundwater level of study area was slightly decreased about 0.05-0.34 m during low tide compared to the high tide and caused suspended solids in water to be more concentrated. Supposedly, turbidity and TSS were linearly dependent where in usual cases; turbidity increase when TSS increases and vice versa. However, in this study, TSS and turbidity is not linearly dependent as was indicated by different sign convention suggesting the interaction of these two variables when in opposing manner. One of possible explanation to this occurrence probably due to the presence of the colored dissolved organic matters that absorbed UV and blue wavelength in water presence it may reduce the turbidity readings. Thus, VF2 is assigned as the tide inducing factor. The VF3 accounts for 13.929% of variability with strong positive loading on DO and moderate positive loading on pH. This VF contains variables that linked to anthropogenic pollutants. Pollutant thrown into water caused the pH level to increase and decrease the amount of dissolved oxygen.

For high tide data set, VF1 accounts 44.912% of variability with strong positive loadings on EC, TDS, salinity and chloride and moderate positive loading of pH. These variables were related to saline water contaminations into groundwater. The VF2 accounts for 16.756% of variability with strong positive loading on DO, moderate positive loading on depth to water level and moderate negative loading on TSS. These variables were suggested to be connected to tides inducing factor. During high tide, groundwater level was slightly higher than during low tide and causing a reduction in the concentrations of suspended solids. Besides, low DO value is common in the groundwater study, because of due to lack of water ripples and obstruction of sunlight through photosynthesis. The VF3 accounts for 13.912% of variability only consists of strong positive loading of turbidity. It is probably linked to anthropogenic pollutant.

Figure 2 shows the biplot axes of VF1 and VF2 with 61.67% of total variability for low tide data and 64.91% of total variability for high tide data. Biplot graphs were examined to evaluate the relationship of sampling wells to the sources of pollutions assigned by each VFs previously. The B1, B3, B4 and KT1 sampling wells were plotted near to the salinity, EC, TDS, chloride and pH parameters that correspond to VF1 which was assigned as saline water contamination into groundwater (Fig. 2a, b). For low tide, M1, M2, M3, D1, K1, B2, S1, S2 and KT2 sampling stations are related to VF2 which was assigned as tide inducing factor (Fig. 2a). The VF3 of low tide data which was appointed as anthropogenic pollutants are corresponded to B1 and K1 sampling wells (Fig. 2a). The VF2 of high tide data which was linked to tides inducing factors is connected to D1, S1, S2, B1, B2, B4, M1, M2, M3, K1 and KT2 sampling wells (Fig. 2b). The VF3 of high tide data which was appointed as anthropogenic pollutants is correlated to M1, M2, M3 and S1 sampling wells (Fig. 2b).

CONCLUSION

Three water quality parameters EC, salinity and chloride have close related to sea water intrusion during low tide. Distribution of DO relatively low and four other parameters such as turbidity, TSS, TDS and pH have normal concentration during the study carried out. The PCA analyses on low and high tides data revealed 3 possible sources that influence the water quality pollution which are saline water contamination, tide inducing factor and anthropogenic activities. The VF1 of both low and high tides is assigned as saline water contamination due to saltwater intrusion that affects the water quality of B1, B3, B4 and KT1 sampling wells. Both tides also assigned VF2 as tide inducing factor that influence the groundwater at east coast of Terengganu. Depth to water level is fluctuated in response to tide event and alter the TSS concentration. This tide inducing factor influenced the water quality at M1, M2, M3, D1, K1, B2, S1, S2 and KT2 sampling wells during low tide. During high tide, M1, M2, M3, D1, K1, B2, S1, S2, KT2, B1 and B4 are the sampling wells that were affected by tide inducting factor. The VF3 is linked to anthropogenic contamination that correspond to sampling well B1 and K1 for low tide and sampling well M1, M2, M3 and S1 for high tide. The most affected sampling wells due to saltwater contamination are B1, B3, B4 and KT1. The St. M2 was recorded as the deepest groundwater level (7.9 m) while St. B3 was the shallowest level (2.49 m).

SIGNIFICANT STATEMENTS

- Groundwater in coastal areas may be affected by the tidal movement
- The impact of sea level changes on coastal groundwater is detected through the variation in the readings of groundwater quality parameters
- Groundwater quality monitoring is required to ensure that groundwater is suitable for use as potable water

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