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Research paper

Assessment by Multivariate Analysis of Groundwater between Low and High Tides Interactions in East Coast of Terengganu

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Abstract

World sea level rise has an effect in the rise on high and low tides levels in coastal areas of Terengganu. Because of that, as many as 13 groundwater represented of well that located close to Terengganu coastline were sampled and analyzed. Samplings were conducted for the wet and dry seasons and also for the high and low tides at the same sampling wells to identify the variation of groundwater quality temporally. A Global Positioning System (GPS) was used to locate the exact coordinates of each sampling well. Nineteen physico-chemical parameters were analyzed from groundwater samples. Principal Component Analysis (PCA) was adopted to observe the contrast of the compositional pattern among the variables and to recognize the factors that influence the parameters as an input to define water intrusion. Hierarchical Agglomerative Clustering Analysis (HACA) is performed on data to group the sampling wells into a few clusters. The results show that from nineteen parameters only five has strong positive loading; EC (0.99), TDS (0.99), chloride (0.99), sulphate (0.92) and salinity (0.99) during high and low tides. The difference are BOD and DO have strong positive loading during low tide while turbidity and TSS were strong positive loading during high tide.

Keywords: *East coast of Terengganu; Sea level rise; groundwater quality; physico-chemical parameters.*

1. Introduction

Climate change have adverse impact on the quality of groundwater especially to groundwater stored in the coastal aquifer where it is particularly vulnerable to sea water intrusion [1-4]. This is a serious problem because 1.5 - 3 billion people are depending on groundwater resources for water supply and for daily activities as well as economy activities. Among the countries that highly dependent on groundwater are Denmark, Thailand, Switzerland, Austria, India, Japan and Indonesia [5-6].

Groundwater is a term used to denote all the waters found beneath the ground surface [7].The tiny gaps of rocks, soils and sediments act like a container for groundwater that allows groundwater to flow freely. This container is known as aquifer. Aquifer's porosity determines the amount of groundwater inside aquifer meanwhile aquifer's permeability allows groundwater to flow freely.

Coastal aquifer was characterized by transient water levels, variable salinity and water density distribution and heterogeneous hydraulic properties. It is located near to coastline. Due to its location, groundwater stored in coastal aquifer is very vulnerable to saltwater intrusion phenomenon triggered by the increment of global sea level [8]. Other than climate changes, this phenomenon was worsened by over-pumping of coastal groundwater [4].

The subsurface movement of saltwater was stated into coastal groundwater can be explained based on this water density and salinity relationship. Freshwater and saltwater have different density where, freshwater is less dense than saltwater. Due to this condition, the buoyancy force caused less dense freshwater to floats meanwhile, denser saltwater sunk below freshwater [8]. Freshwater and saltwater zones were separated by transition zone that contains brackish water resulted from dispersive and mixing processes instead of sharp boundaries. The natural process of pressure equilibration of the ocean and the adjacent coastal aquifer lead to saltwater intrusion [9].

Saltwater intrusion phenomenon through river estuary happened when river freshwater discharge is low during dry season and sea water moves upstream. The intensity of saltwater intrusion is controlled by the tidal process, intensity of precipitation temporally and freshwater discharge [10]. As a consequence to sea level rise and climate changes, the tide level increases, temporal precipitation intensified and freshwater discharge decreases. For these reasons, saltwater intrusion intensity increases.

In response to saltwater intrusion phenomenon, groundwater and river estuary salinity increases [11]. Consequently, freshwater qualities is deteriorating [10]. This problem has been experienced globally and getting worse due to continuous global warming. Therefore nowadays, the community became more aware of climate change issues and increased the number of research on sea level changes since it is a very useful indicator for climate changes [1, 6, 8, 12-13].

2. Materials and Method

2.1. Description of the Study Area

Study area is located in the Terengganu coast where it is situated in the eastern part of Peninsular Malaysia. State of Terengganu consists of eight districts, which are: Kuala Terengganu, Marang, Kuala Nerus, Dungun, Hulu Terengganu, Besut, Setiu and Kemaman with the total area approximately of 13,035 km^2. Specifically, study area only comprises of Terengganu coastline. It stretches from Besut to Kemaman at 244 km long and adjacent to South China Sea [14]. Therefore, Terengganu coastline is a suitable area to conduct a research study that focuses on the identification of saltwater intrusion into groundwater aquifer.

2.2. Groundwater Sampling

Groundwater samplings were carried out at 13 private wells that located close to Terengganu coastline (Figure 1). A Global Positioning System (GPS) (Garmin GPSMAP® 64, USA) was used to locate the exact coordinates of each sampling well. GPS was navigated by using Geocentric Datum of Malaysia 2000 (GDM2000) coordinate. The coordinate for each groundwater sampling wells were tabulated in Table 1. Samplings were conducted for the wet and dry seasons and also for the low tide and high tides at the same sampling wells to identify the variation of groundwater quality temporally. The determination of the sampling time for collection of low and high tides data were based on tides chart provided by National Hydrographic Centre of Malaysia. Groundwater data for dry season was obtained twice. The data acquired during these sampling were the representative of dry season or Southwest monsoon period.

Table 1: Coordinate of Groundwater Sampling Wells

Primary Well	Latitude	Longitude
B1	5° 50' 02.39"	102° 33' 19.08"
B2	5° 49' 26.73"	102° 33' 23.76"
B3	5° 49' 17.92"	102° 34' 31.39"
B4	5° 49' 12.77"	102° 34' 38.64"
S1	5° 35' 42.36"	102° 49' 34.32"
S2	5° 33' 37.97"	102° 52' 24.96"
KT1	5° 24' 14.37"	103° 05' 57.29"
KT2	5° 22' 07.01"	103° 07' 26.73"
M1	5° 14' 36.67"	103° 11' 13.92"
M2	5° 10' 56.86"	103° 13' 32.71"
M3	5° 00' 48.57"	103° 18' 34.53"
D1	4° 38' 19.28"	103° 26' 17.71"
K1	4° 20' 09.97"	103° 29' 08.88"

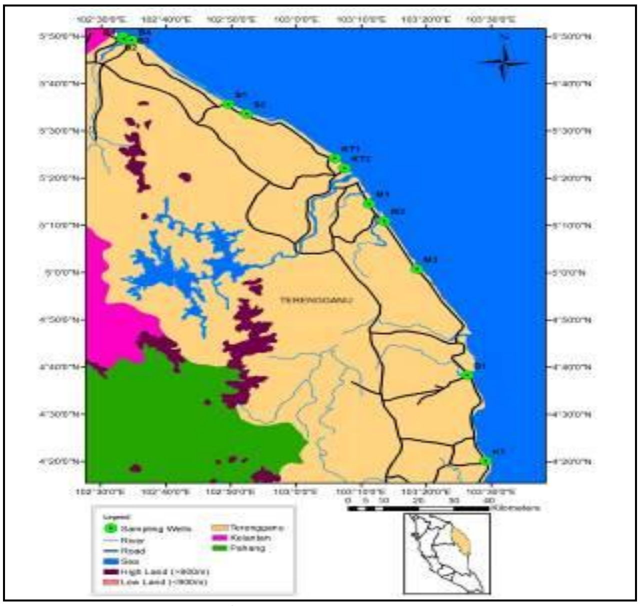

Fig. 1: Map of Study Area Terengganu, Malaysia

2.3. Physico-Chemical Parameters

Nineteen physico-chemical parameters were measured from groundwater samples. Eleven parameters were in-situ parameters that were directly measured at field. The parameters were temperature, pressure, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), salinity, pH, ammonium nitrogen (NH_4^+-N), chloride ion (Cl$^-$), biochemical oxygen demand (BOD) and turbidity. Eight other parameters which were phosphate ion (PO_4^{3-}), nitrite (NO_2), sulfate ion (SO_4^{2-}), nitrate (NO_3), total suspended solids (TSS), sodium (Na), magnesium (Mg) and calcium (Ca) were ex-situ parameters. These parameters were determined from laboratory analyses. Parameter Cl$^-$, PO_4^{3-} and SO_4^{2-} were measured in ionic form. All analyses were performed in accordance to Standard Methods for the Examination of Water and Wastewater [15].

2.4. Principle Component Analysis (PCA)

Principal Component Analysis (PCA) was adopted to observe the contrast of the compositional pattern among the analyzed physic-chemical parameters (variables) and to recognize the factors that influence each of the parameters that can be used as input to define water intrusion. Before performing data analysis, the suitability of the data for PCA analysis will be tested by using Pearson correlations matrix, Bartlett's sphericity and Keiser-Meyer-Olkin (KMO) tests. Pearson correlations matrix was calculated to identify the inter-relationship between the parameters [16]. Bartlett sphericity test was used to confirm whether the parameters are correlated or uncorrelated [17-18]. KMO test measures the sample adequacy that describes the quality of sample to produce reliable PCA results [19-20]. Principal Component Analysis (PCA) is performed by using XLSTAT 2014 add-in software [21].

2.5. Hierarchical Agglomerative CA

Hierarchical Agglomerative Clustering Analysis (HACA) is performed on data to group the sampling wells into a few clusters. This analysis is a continuation for PCA analysis. The clusters obtained from this analysis will be used concurrently to support the 2D resistivity profile produced from previous method. Dissimilarity proximity type with Euclidean distance coefficients is used in this process. Dissimilarity between clusters is calculated using Ward's method. The result of HACA is displayed as a dendrogram showing the clustering process of sampling wells [22]. Sampling wells that clustered together as a group has homogeneous character, meanwhile sampling wells of different groups have heterogeneous character [23].

3. Results and Discussion

3.1. Source of Variations in Water Quality

Source of variations to assess the groundwater quality variation spatially and temporally based on selected physico-chemical parameters. The source of variations in groundwater quality during tidal variation and seasonal variation were determined by using principal component analysis. Sampling wells which were affected by corresponding source of variations will be determined at the end of discussion.

3.2. Tidal Variation

For low tide data-set, only 11 variables from all variables were involved for interpretation which are EC, TDS, salinity, Cl$^-$, BOD, turbidity, SO_4^{2-}, TSS, temperature (Temp), pressure and DO. If these variables were taken into account, Bartlett's test of sphericity cannot be computed. For high tide data-set, there were 13 variables involved for interpretation which are EC, TDS, salinity, Cl^-, BOD, turbidity, SO_4^{2-}, TSS, temperature, pressure, DO, pH and PO_4^{3-}.

3.3. Low Tide

For low tide data-set, PCA produced 11 PCs with 100 % of cumulative variability. This dataset has three eigenvalues greater than 1.00. Thus, PCA is repeated with varimax rotation. Three VFs with cumulative variability of 78.70 % were produced (Table 2).

VF1 is the major contributor in low tide data-set variability with 45.55 % variability and eigenvalue of 5.07. It contains five strong positive factor loadings which are EC (0.99), TDS (0.99), Cl^- (0.99), SO_4^{2-} (0.92) and salinity (0.99). These variables are related to saltwater intrusion into coastal aquifer [11, 24-25]. Chloride is an ion that is associated with saltwater and is one of the significant indicators to reflect the water salinity [26]. Chloride ion is also part of total dissolved solids and has the ability to transmit the electricity [27]. Sulphate is another soluble ion contributed to the total dissolved solids of groundwater. The major sources of sulphate are possibly from decomposition of organic matter, fertilizers, atmospheric deposition, dissolution of sulphur-bearing minerals in soil and natural sources [8, 28-29]. It is also related to saltwater intrusion as sulfate is the second most abundant anion in seawater [11, 30].

VF2 contributed 17.38 % of data-set variability with eigenvalue of 2.09. It only has a strong positive loading which is TSS (0.75). This variable is indicating that the physical pollution in water may be due to rubbish dumping into wells.

VF3 represents 15.77 % of variability with eigenvalue of 1.49. BOD (0.82) and DO (0.85) were two strong positive factor loadings listed under this VF. Organisms in water will use up the dissolved oxygen to decompose organic matter. Usually, BOD and DO has an inverse relationship [31-33]. However, in this data-set, both variables have positive sign convention that suggests that the interactions of these variables are in the similar manner [11]. That’s mean, whenever DO concentration is low then, BOD concentration is also low. There could be another factor that leads to this kind of relationship between DO and BOD.

3.4. High Tide

For high tide data-set, initially, PCA produced 13 PCs with 100 % of cumulative variability. Four eigenvalues were identified as greater than 1.00 in this data-set. Therefore, the rotation factor used for the second run of PCA is four. As a result, PCA with varimax rotation produced four VFs with cumulative variability of 77.70 % (Table 2). VF1 contributed 39.62 % of data-set variability with eigenvalue of 5.18. It has five strong positive loadings which are EC (0.99), TDS (0.99), salinity (0.99), Cl^- (0.99) and SO_4^{2-} (0.93). Similar to the VF1 in low tide data-set, these variables were related to saltwater intrusion into coastal aquifer.

However, in high tide data-set, the percentage of variation contributed by saltwater intrusion is lesser (39.62 %) than low tide data-set (45.55 %). 15.97 % of data-set variability was contributed by VF2 that has eigenvalue of 2.20. Two significant strong positive loadings identified from this VF are turbidity (0.88) and TSS (0.75). This composite factor is proposed to represent the anthropogenic pollution such as waste dumping into wells. The small suspended solids originated from the waste act like a barrier for the direct light entering the wells. It would be able to reach the well basement only by scattering through the small spaces in between the particles. The measure of amount of light scattered of these particles is known as turbidity. This explains the association of total suspended solids with turbidity. If the amount of total suspended solids is high, the turbidity would be high as well.

VF3 represents 13.44 % of variability with eigenvalue of 1.70. BOD (0.83) and DO (0.80) are two strong positive loadings listed under this VF. This factor is corresponding to anthropogenic pollutions revealed by VF2. The suspended particles in water is capable in absorbing more heat and thus, increasing the water temperature. Warm water decreases the water’s ability to hold more oxygen. Besides, higher turbidity also decreases the quantity of light entering the water. As a consequence, aquatic plants cannot carry out photosynthesis efficiently and have to consume oxygen to respire.

Another 8.67 % of variability was composed by VF4 that has eigenvalue of 1.02. It only has one strong positive loading which is pH (0.80). This variable is related to the acidity or alkalinity of water. The pH level can fluctuate due to various reasons such as photosynthesis, dissolution of surrounding rocks and interaction of rainwater and carbon in atmosphere.

Table 2: Varifactors (VFs) Resulted by PCA with Varimax Rotation for Low Tide and High Tide Data-sets. Bolded Value Indicate the Strong Factor Loadings for each Corresponding VF

Variable	Low tide			High tide			
	VF1	VF2	VF3	VF1	VF2	VF3	VF4
EC (uS/cm)	0.99	0.00	-0.01	0.99	-0.01	-0.01	0.06
TDS (mg/L)	0.99	0.00	0.00	0.99	0.00	-0.01	0.06
Salinity (ppt)	0.99	-0.01	-0.02	0.99	-0.01	-0.02	0.06
Cl^- (mg/L)	0.99	0.01	0.07	0.99	-0.01	-0.01	0.06
BOD (mg/L)	-0.02	0.20	0.82	0.07	0.08	0.83	-0.04
Turbidity (NTU)	-0.16	0.65	-0.45	-0.18	0.88	-0.04	0.01
SO_4^{2-} (mg/L)	0.92	-0.07	0.21	0.93	-0.11	0.16	-0.08
TSS (mg/L)	0.24	0.75	0.20	0.24	0.75	-0.10	-0.03
Temp (°C)	-0.12	-0.62	0.24	-0.08	0.47	0.29	0.58
Pressure (mmHg)	0.39	-0.67	-0.04	0.05	-0.64	0.04	-0.06
DO (mg/L)	0.12	-0.22	0.85	0.16	-0.29	0.76	-0.20
pH	-	-	-	0.30	-0.08	-0.22	0.80
PO_4^{3-} (mg/L)	-	-	-	-0.33	0.02	0.56	0.31
Eigenvalue	5.07	2.09	1.49	5.18	2.20	1.70	1.02
Variability (%)	45.55	17.38	15.77	39.62	15.97	13.44	8.67
Cumulative (%)	45.55	62.93	78.70	39.62	55.59	69.03	77.70

During high tide, VF1 represents saltwater contamination based on variables EC, TDS, salinity, Cl^- and SO_4^{2-}. This contamination is the major factor that leads to water quality deterioration at station B1, B3 and KT1 (Figure 2). Cl^- and EC ratio is also suggesting these stations were intruded by saltwater. Anthropogenic pollutant was assigned VF2 based on variables turbidity and TSS. This pollutant gave an adverse impact on station M2, M3 and S1.

During low tide, variable EC, TDS, salinity, Cl^- and SO_4^{2-} that correspond to VF1 was assigned as saltwater contamination into coastal groundwater (Figure 3). There are three stations which were plotted close to these variables and suggested to have an association with saltwater contamination factor. The stations are B1, B3 and KT1. The Cl^- and EC ratio confirmed that stations B1, B3 and KT1 were influenced by saltwater intrusion. Station M3 was plotted near to TSS variable that corresponds to VF2 which was assigned as physical pollutant.

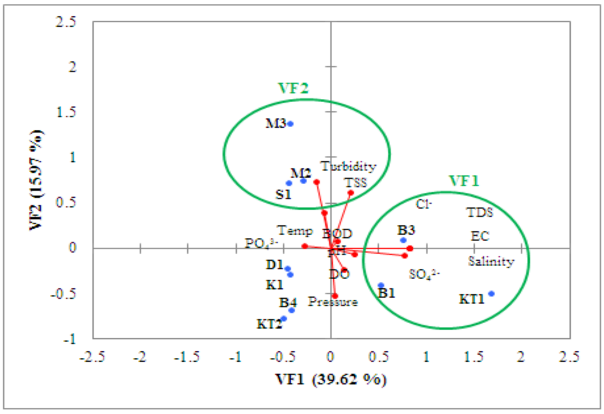

Fig. 2: Biplot of VFs and Stations from Low Tide Data-set

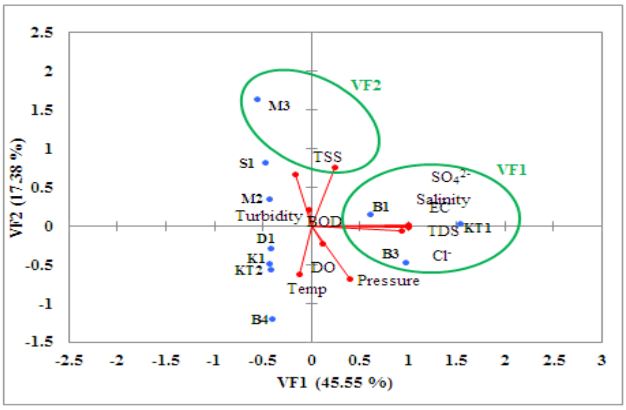

Fig. 3: Biplot of VFs and Stations from High Tide Data-set

4. Conclusion

Groundwater quality during low and high tide showed no significant difference but, during dry and wet season groundwater quality has shown a significant difference, groundwater quality during dry season is worse than during wet season. This situation was caused by sea level fluctuation that affects the groundwater level and as a results, it has triggered a dynamic variation in coastal groundwater quality. Saltwater contamination into coastal aquifer has affected groundwater quality by 45.55% during low tide, 39.62 % during high tide, 69.90 % during dry season and 49.87 % during the wet seasons. During low tide, high tide and dry season, station B1, B3 and KT1 were highly affected by saltwater contamination meanwhile, station B3 was highly affected by saltwater contamination during wet season.

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