Othman, S.Z., Ismail, Z., Hashim, R., Mohd, N.S., (2018), The application of geoelectrical and environmetric techniques in assessing the impacts of seawater intrusion on the groundwater of Carey Island, Malaysia. pp. 217-223. In Gastescu, P., Bretcan, P. (edit, 2018), *Water resources and wetlands*, 4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania), p.312

Available online at http://www.limnology.ro/wrw2018/proceedings.html

4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania)

THE APPLICATION OF GEOELECTRICAL AND ENVIRONMETRIC TECHNIQUES IN ASSESSING THE IMPACTS OF SEAWATER INTRUSION ON THE GROUNDWATER OF CAREY ISLAND, MALAYSIA

Siti Zulaikha OTHMAN, Zubaidah ISMAIL, Roslan HASHIM, Nuruol Syuhadaa MOHD
Civil Engineering Department, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia. Phone: +603-79675205. *E-mail: zulaikha_othman@yahoo.com.my, zu_ismail@um.edu.my, roslan@um.edu.my, n_syuhadaa@um.edu.my*

Abstract

In this study, the impact of seawater intrusion into the groundwater of an ex-promontory-land of Carey Island in Selangor, Malaysia was assessed using geoelectrical and environmetric techniques. The outcomes of geoelectrical imaging showed that seawater intrusion were more apparent at the estuary and river area in comparison to the shoreline area. It was also found that the intrusion has occurred up to 3 km inland of Carey Island. Groundwater quality was assessed by measuring groundwater table, salinity, total dissolved solids (TDS) and electrical conductivity (EC). High amounts of sodium ion (Na^+) of 6377 mg/L and chloride ion (Cl^-) of 10,643 mg/L have proved the occurrences of seawater intrusion in the studied area. Additionally, environmentric analysis was also conducted to characterize the hydrogeochemical and spatial variation of the groundwater quality. The outcomes of the analysis suggested that the distribution of Cl^- and Na^+ concentration in the studied area can be clustered into three significantly different clusters. Hence, confirming that the seawater intrusion was on the south-west coast of Carey Island specifically at the Ayer Hitam River surrounding area. This was presumably because of river infiltration. While the non-apparent of the intrusion at the shoreline area was probably due to the existence of the mangrove area that acts as a buffer to seawater intrusion.
Keywords: seawater intrusion, geoelectrical, environmentric, groundwater.

1 INTRODUCTION

It is commonly noted that seawater intrusion can affect the quality of both surface and groundwater. In the case of surface water various means of treatment like phytoremediation and physical methods can be used to render the water suitable for agricultural use and domestic consumption (Basheer *et al.*, 2017; Ismail and Salim, 2013; Ismail *et al.*, 2013; Mahmud *et al.*, 2017). However, the treatment for groundwater is usually more difficult and costly.

The application of geoelectrical method to delineate saltwater intrusion have been widely used in environmental surveys (Baharuddin *et al.*, 2013; Igroufa, 2011; Kaya *et al.*, 2015; Najib *et al.*, 2017). This method provides information about resistivity distribution within the subsurface structures to differentiate conductive formations. As the conductivity of groundwater depends on its mineral content, electrical method is useful to distinguish between fresh, brackish and saltwater. On the other hand, the application of environmetric is widely used to characterise a water body (Aris *et al.*, 2012; Gulgundi & Shetty, 2018; Herojeet *et al.*, 2016; Othman *et al.*, 2014;). The environmetric can interpret huge amounts of environmental data into meaningful results. Cluster analysis (CA), principle component analyses (PCA) and analysis of variance (ANOVA) are commonly applied in environmetrics analyses depending on the objective of the research. This study reports the condition of groundwater quality in Carey Island, Selangor, Malaysia and its effect to the community of the island. Carey Island is well-known as a vast plantation island named after Sir Edward Valentine Carey, a British planter. He opened the area for rubber plantation in early 1900's and now 65% (10,521.84 ha) of the island's total land is transformed to oil palm plantation while the rest is mangrove conserved area. According to the locals, Carey Island naturally was a promontory land of Selangor. However it was later separated when a canal was dug in early 19th century by Chinese traders. The studied area is located at the south-west of the island where there is a human settlement of 10, 000 peoples consisting of estate workers, locals and aborigines (Mah Meri tribe). Due to its remote location, the area does not receive enough upper-catchment surface water from Langat and Semenyih Dam. Thus, the population depends on the groundwater and rainwater as their freshwater source.

Many efforts have been initiated by various agencies in finding potential water supply in Carey Island area. Department of Mineral and Geosciences Malaysia, under the Ministry of Natural Resources and

Environment has investigated the water supply potential and suitability of using hand-pump in the nearby rural areas of Kuala Langat District, Selangor (Ngah, 1988). Construction and exploration of deep wells at Carey Island and Kelanang village were also conducted in order to seek groundwater resources (Ismail, 2008). Other than that, a study has also been carried out to determine the occurrence of freshwater lens and seawater intrusion in the Carey Island (Baharuddin *et al.*, 2010). This study is a continuity of previous work where electrical resistivity was employed to image seawater intrusion into the island. From the study, it was found that seawater intrusion is active at the river areas compared to the coast line (Igroufa, 2011). Hence, this study was carried out to collect a comprehensive set of data that can be used to develop seawater intrusion profile into the groundwater aquifers. The primary objective of the study is to determine the effects of seawater intrusion on the groundwater quality, as well as to propose a strategy for a better exploitation of water resources on Carey Island.

2 METHODS

2.1 Description of the Study Area

Carey Island is located on the west coast of the Selangor state in West Peninsular Malaysia between 2°50'3.07"N 101°17'25.16"E and 2°57'49.51"N 101°26'18.37"E (Figure 1). The total area of Carey Island is 16,187.45 ha representing about 6% of Langat Basin area. Other than oil palm plantation, there are 1,876.85 ha of mangrove forest area along the coastal areas and estuaries.

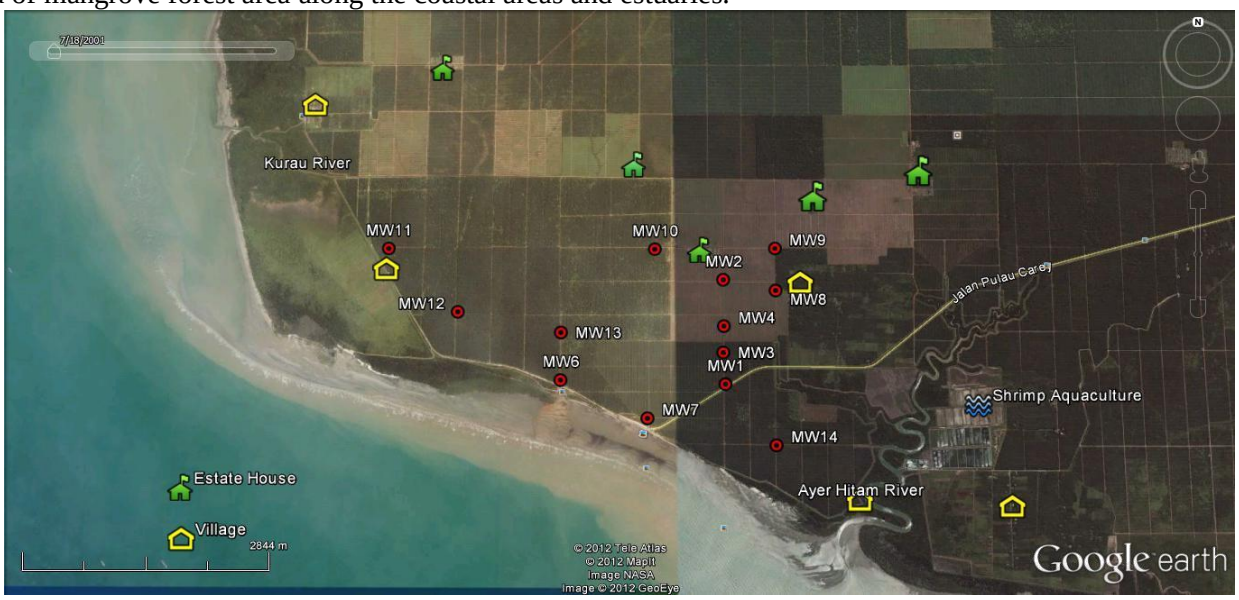

Figure 1. Location of monitoring wells, estate houses and villages

2.2 Geoelectrical Imaging Techniques

A total number of 11 electrical resistivity profiles of 400 m long were conducted perpendiculars to the coast line. The Wenner configuration and the Lund resistivity imaging system were used for the data acquisition. RES2DINV program was used to gives true resistivity versus depth pseudosections.

2.3 Groundwater Quality Monitoring

Thirteen deep boreholes were drilled at the south-west area near to the coastal area (Figure 1). The boreholes were scatterly drilled at locations such as between the estates housing area, at public facilities like school and temple, and close to the tidal gates. The boreholes results showed that the subsurface lithology of Carey Island consist of quaternary alluvial sediments such as sand, silty sand and silty clay layers. Two sandy aquifers which are semi-confined and unconfined aquifer were found in the area with composition varying from fine to coarse sand mixed with marine clay. For semi-confined aquifer, boreholes were labelled as MW1, MW2, MW3, MW4, MW8, and MW9 with the thickness of the uppermost semi-impermeable layer

varying from 27.0 to 31.5 m below ground surface. The aquifer reaching between 60 and 66 m has soil type of light grey, marine and silty clay. For unconfined aquifer, boreholes were labelled as MW6, MW7, MW10, MW11, MW12, MW13 and MW14 with the depth of 10 to 60 m from the ground level. The soil comprised of fine to coarse light-grey sand and gravel, impermeable materials (silt and clay), and fragmented shells. The presence of fragmented shells confirmed that the layers were deposited by a marine environment (Baba, 1997).

2.4 Sampling and Analysis

Groundwater samplings have been carried out for the duration of 6 months. Groundwater table was measured with TLC Meter Model 107 (Solinst, Canada). Salinity, total dissolved solids (TDS) and electrical conductivity (EC) was measured in situ using multiparameters meter IQ Scientific Instruments (Hach, USA). Cation measurements (Chloride (Cl^-) and fluoride (Fl^-)) were done according to Standard Method using Ion Chromatography 850 Professional IC (Metrohm, Switzerland) (APHA, 1992). Anion measurement (Sodium (Na^+)) was done according to Standard Method using Ion Chromatography Model ICS-1100 System (Dionex, USA) (APHA, 1992).

3 RESULTS & DISCUSSION

3.1 Geoelectrical Surveys

The electrical resistivity survey was conducted perpendicular to the shoreline in order to track the extension of seawater intrusion from the sea. Additionally, the survey area was also located close to the estuaries to study the effect of river infiltration. In agreement with an earlier study done by Igroufa, the survey concluded that seawater intrusion was more active at the estuaries areas (i.e. close to Selat Lumut river mouth and Ayer Hitam River) than the shoreline area (Igroufa, 2011). Hence, the source of saltwater intrusion in Carey Island was believed to primarily originate from saltwater infiltration of the river rather than direct infiltration of saltwater from the Straits of Malacca.

3.2 The Effects of Seawater Intrusion on the Groundwater Quality

Groundwater tables of MW6, MW7, MW11 and MW14 were found to be fluctuated indicating that they were highly affected either by the tides or groundwater recharge (Table 1). Groundwater tables in MW7 might be influenced by the tides as it is located near the shorelines. Meanwhile, as MW4 is located near the irrigation ditch, thus, explaining its high groundwater table. A study by Baharudin *et al.* (2010) also reported the similar findings at which they found that most of the water tables were influenced by the precipitation. In conclusion, the groundwater tables were significantly higher in the unconfined aquifer compared to semi-confined aquifer due to the sandy soils of the shoreline (P t-test = 0.042; df = 11; $p < 0.05$). Groundwater in both semi-confined and unconfined aquifers can be classified as brackish water as the salinity was more than 1 ppt. Salinity is a measure of the amount of dissolved particles and ions in water for examples, chloride (Cl^-), sodium (Na^+), nitrate (NO_3^-), calcium (Ca^{2+}), sulphate (SO_4^{2-}) and many more. Total dissolved solids (TDS) and electrical conductivity (EC) is the most frequently used to measure salinity. TDS levels in the groundwater were more than 1 ppt which exceeded the allowed level for Class IIA of Malaysian National Water Quality Standard (NWQS), hence, the water requires conventional treatment before it can be used as a water supply. Meanwhile, the average groundwater EC falls in Class IV of NWQS (6 mS/cm) which is suitable for irrigation of crops purposes. In addition to that, high EC readings (up to 16.4 mS/cm) of the most monitoring wells indicated disturbances in the quality of groundwater of the island.

Table 1. Main parameters of groundwater at semi-confined and unconfined aquifers.

Parameter	Semi-confined Aquifer	Unconfined Aquifer
Groundwater table (m)	0.44 – 1.08	0.78 – 1.35
Salinity (ppt)	2.66 – 10.42	0.89 – 9.65
Total dissolved solids (ppt)	2.58 – 8.56	0.88 – 8.20
Electrical conductivity (mS/cm)	4.66 – 14.66	1.76 – 16.39

Table 2 showed that there are high correlations between TDS and EC (0.988), as well as TDS and salinity (0.999) and EC and salinity (0.983). It was also noted that salinity had positive and significance correlation with Na^+ (0.983) and Cl^- (0.949), therefore, affirming their majority composition in the groundwater. In addition to that, it was also observed that Na^- and Cl^- concentration in the groundwater were very high and correlated positively (0.939) indicating the influence of seawater as the Na-Cl facies represents 100% of the total water sample. The finding was in agreement with a study of seawater intrusion in Manukan Island, Sabah, Malaysia (Aris, Abdullah and Kim, 2007).

Table 2. Correlation coefficient table of physico-chemicals of the groundwater.

	TDS	**EC**	**Salinity**	**SO_4^{2-}**	**HCO_{3-}**	**Na^-**	**Cl^-**
TDS	1						
EC	**0.987899**	1					
Salinity	**0.999149**	**0.98333**	1				
SO_4^{2-}	0.262208	0.294211	0.255447	1			
HCO_{3-}	0.316001	0.258261	0.319494	0.118899	1		
Na^-	**0.986100**	**0.980156**	**0.983235**	0.245802	0.248232	1	
Cl^-	**0.953592**	**0.969134**	**0.949086**	0.181127	0.286961	**0.939434**	1

The highest Na^+ and Cl^- concentrations were found at MW3, MW4, MW7 and MW14. MW3 and MW4, located near the main irrigation ditch; meanwhile, MW7 and MW14 are located a few kilometres from the shoreline (Figure 1). However, there were no significant differences of Na^+ and Cl^- concentrations in the semi-confined and unconfined aquifers. Furthermore, it was very interesting to note that MW11 had the lowest NaCl content (362.3 mgL^{-1}) in the groundwater and in Figure 1, it is clearly showed that MW10 and MW11 were isolated from the rest. Though MW11 was located within a few kilometres from the shoreline, the seawater intrusion of the area was not significant compared to the southern area of the island where there has been deforestation activities going. This was because of the existence of mangrove area that acts as a buffer to seawater encroachment into the inland, hence, emphasizing the importance of preserving mangrove areas along the coastline as a natural filtration system for seawater. As for the groundwater quality in different types of aquifer, a null hypothesis (H_o) that there is a difference between groundwater qualities in semi-confined and unconfined aquifer was rejected. Hence, environmetric analysis has been carried out to characterize the hydrogeochemical aspects of the groundwater.

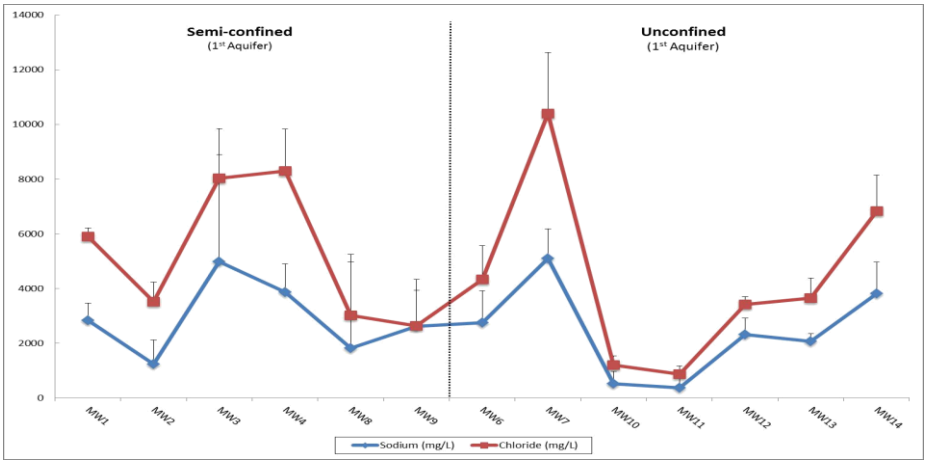

Figure 2. Average sodium and chloride concentration from Nov 2010 to Apr 2012.

3.3 Environmetric Analysis

In this study, Ward's method, cluster analysis (CA) and principal component analysis (PCA) were used to perform the environmetric analysis on the data. Ward's method was applied to the unscaled data and the results were presented in a dendogram (Figure 3(a)). From Figure 3(a), it can be seen that at the level of 6000 (the dashed line) the monitoring wells can be clustered into three groups based on the similarity of water quality variables, not the type of aquifers (i.e. unconfined and semi-confined aquifer). Monitoring

wells divided into Cluster 1 were MW2, MW6, MW8, MW9, MW12 and MW13, Cluster 2 were MW10, MW11 and Cluster 3 were MW1, MW3, MW4, MW7 and MW14. Figure 3(b) showed the scores of the sampling sites in a space formed by the first two PC's (PC1 and PC2) accounting for 98.33% of total variance (Table 3). Furthermore, the scores plots have also showed three linearly separable clusters with MW 10 and MW 11 (Cluster 2) was far different from Cluster 1 and Cluster 3. All three clusters were significantly different from each other based on water quality variables that associated with seawater intrusion (Table 4). Significant analysis results indicated that the difference between clusters (Two-way ANOVA with replication: $F_{[2, 12]} = 8.48$, $p < 0.05$), as well as the interaction between clusters and water quality variables (Two-way ANOVA with replication: $F_{[2, 12]} = 4.33$, $p < 0.05$) were highly significant. Figure 4 presented the loadings of each features (i.e. water quality variables) of PC1. From the values of the loadings of the features for PC1 (95.65%), it can be concluded that the difference between the three clusters was due to Cl^-, Na^+ and HCO_3^- concentrations associated to the elements in seawater with Na^+ and Cl^- were observed to be the major factor of the classification (Figure 5). Among the three clusters, Cluster 3 has the highest average Na^+ and Cl^- concentration, followed by Cluster 1 and Cluster 2. The result has confirmed that the quality of groundwater could not be deduced by the type of aquifer and the significant fluctuation in salinity implied that seawater intrusion was happening in the area. The result was also in agreement with the previous observation that the seawater intrusion occured on the south-west coast of Carey Island compared to the west coast area and more active at the Ayer Hitam River area (Baharuddin *et al.*, 2010; Igroufa, 2011). And, this is presumably due to river infiltration and the existence of the mangrove area that acts as a buffer to seawater intrusion.

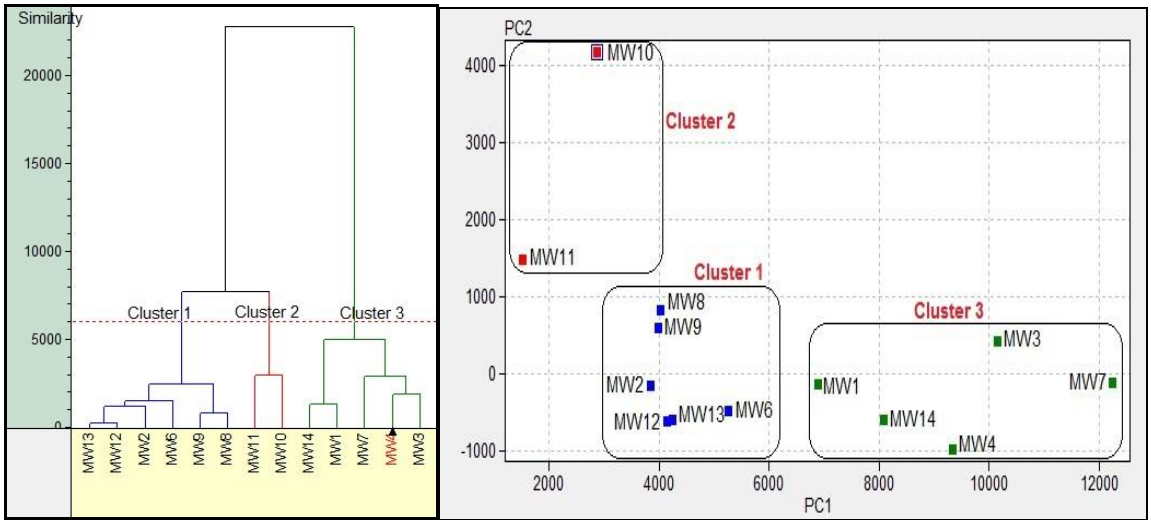

Figure 3. (a) A dendogram showing three clusters at similarity index of 6000. (b) PC1/PC2 scores in principal analysis for 13 sampling sites

Table 3. Variances of PCA for the first four PCs.

PC	Variance (%)	Total variance
1	95.65	95.65
2	3.88	99.52
3	0.45	99.98
4	0.02	100

Table 4. Summary of all effects of Two-way ANOVA for clusters and water quality parameters.

Source of Var.	SS	df	MS	F	P-value	F crit
Clusters	16594969.15	2	8297484.57	8.483612**	0.001993011	3.46680011
Variables	110071726.4	6	18345287.7	18.75680537**	1.93374E-07	2.57271164
Interaction	50789155.13	12	4232429.59	4.327370564**	0.001680105	2.250362
Within	20539267.48	21	978060.356			
Total	197995118.2	41				

**highly significant (p<0.01);*significant (p<0.05); *ns* not significant (p<0.05).

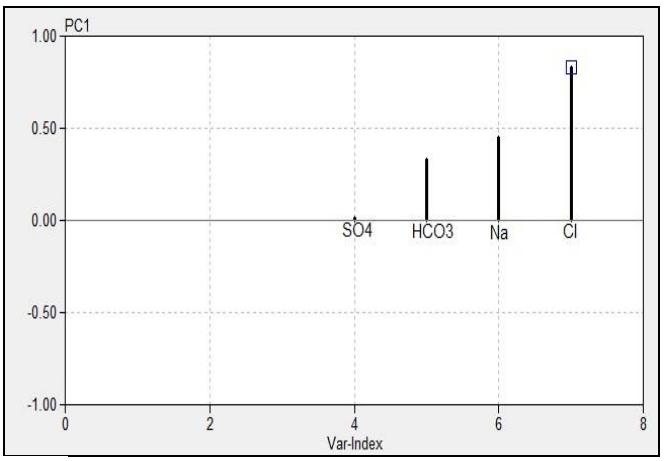

Figure 4. Plot of PC1 loadings.

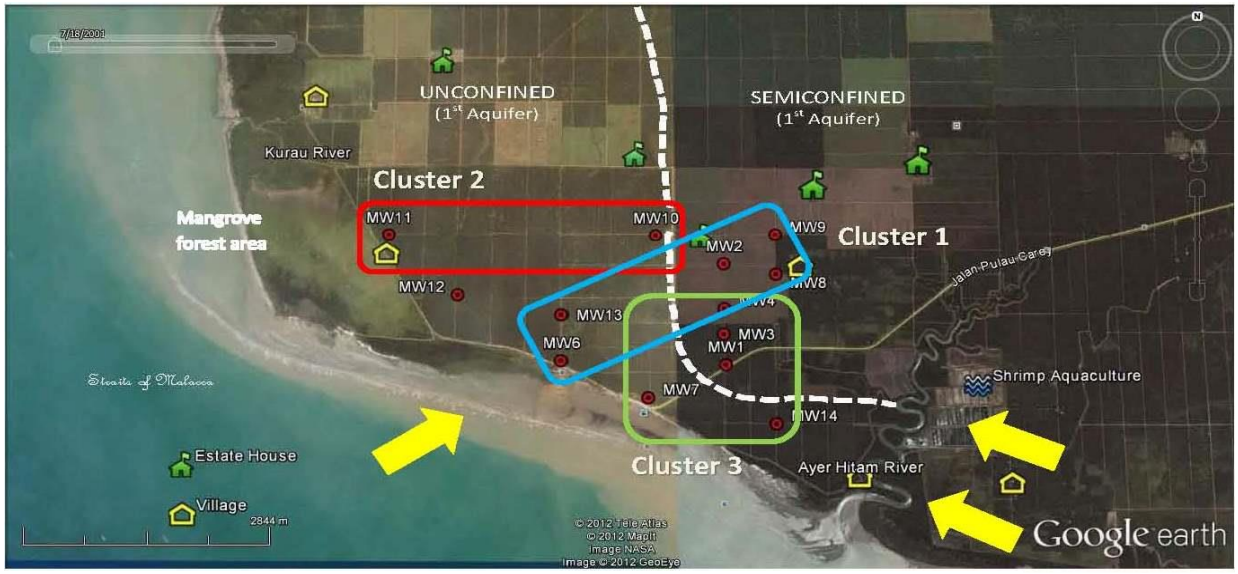

Figure 5. Spatial variation of groundwater quality clusters based on NaCl concentrations

4 CONCLUSIONS

In this study, the impact of seawater intrusion into the groundwater of an ex-promontory-land of Carey Island in Selangor, Malaysia was assessed using geoelectrical and environmetric techniques. The outcomes of geoelectrical imaging showed that seawater intrusion were more apparent at the estuary and river area in comparison to the shoreline area. It was also found that the intrusion has occurred up to 3 km inland of Carey Island. High amounts of sodium ion (Na^+) of 6377 mg/L and chloride ion (Cl^-) of 10,643 mg/L have proved the occurrences of seawater intrusion in the studied area. Additionally, the outcomes of the environmetric analysis suggested that the distribution of Cl^- and Na^+ concentration in the studied area can be clustered into three significantly different clusters. Hence, confirming that the seawater intrusion was on the south-west coast of Carey Island specifically at the Ayer Hitam River surrounding area. This was presumably because of river infiltration. While the non-apparent of the intrusion at the shoreline area was probably due to the existence of the mangrove area that acts as a buffer to seawater intrusion.

5 ACKNOWLEDGEMENT

This research was conducted with permission by Sime Darby Plantation. The authors wish to express their sincere thanks for the funding support received from HIR-MOHE University of Malaya under Grant UM.C/HIR/MOHR/ENG/34 and Vote IPPP (PV057/2011B) University of Malaya.

6 REFERENCES

Alongi, D.M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change, *Estuarine, Coastal and Shelf Science*, **76**(1), 1-13.

APHA. (1992). *Standard Methods for the Examination of Water and Wastewater, 18th Edition*. American Public Health Association, Washington D.C.

Aris, A.Z., Abdullah, M.H. and Kim, K.W. (2007). Hydrogeochemistry of groundwater in Manukan Island, Sabah, Malaysia, *Journal of Analytical Sciences,* **11**(2), 407-413.

Aris, A.Z., Praveena, S.M., Abdullah, M.H. and Radojevic, M. (2012). Statistical approaches and hydrochemical modelling of groundwater system in a small tropical island, *Journal of Hydroinformatics,* **14**(1), 206–220.

Baba, M.F. (1997). *Geology Quaternary at Teluk Datuk area, State of Selangor (Sheet 101), Geology Quaternary Report.* Department of Mineral Geoscience Malaysia, Ministry of Natural Resource and Environment, Malaysia.

Baharuddin, M.F.T., Ismail, Z., Othman, S.Z., Taib, S. and Hashim, R. (2013). Use of time-lapse resistivity tomography to determine freshwater lens morphology, *Measurement*, **46**(2), 964-97.

Baharuddin, M.F.T., Taib, S., Hashim, R., Abidin, M.H.Z. and Ishak, M.F. (2010). Time-lapse resistivity investigation of salinity changes at an expromontory land: A case study of Carey Island, Selangor, Malaysia, *Environmental Monitoring Assessment,* **180**(1–4), 345–369.

Barlow, P.M. and Reichard, E.G. (2010). Saltwater intrusion in coastal regions of North America, *Hydrogeology*, **18**, 247-260.

Basheer, A.O., Hanafiah, M.M., Abdulhasan, M.J. (2017). A study on water quality from Langat River, Selangor. *Acta Scientifica Malaysia*, **1**(2), 01-04.

Dufrene, E., Dubos, B., Rey, H., Quencez, P. and Saugier B. (1992). Changes in evapotranspiration from an oil palm stand *(Elaeis guineensis Jacq.)* exposed to seasonal soil water deficits, *Acta Oecologica*, **13**, 299-314.

Gulgundi, M.S., Shetty, A. (2018). Groundwater quality assessment of urban Bengaluru using multivariate statistical techniques, *Applied Water Science*, **8**, 43.

Herojeet, R., Rishi, M.S., Lata, R., Sharma, R. (2016). Application of environmetrics statistical models and water quality index for groundwater quality characterization of alluvial aquifer of Nalagarh Valley, Himachal Pradesh, India, *Sustainable Water Resources Management*, **2**(1), 39-53.

Igroufa, S. (2011). *The use of geolectrical method for the assessment of saltwater intrusion in Carey Island.* University of Malaya, Malaysia.

Ismail, Z. and Salim, K. (2013). Determination of critical factors in implementing river clean-up projects: a Malaysian case study, *CLEAN- Soil, Air, Water,* **41**(1), 16-23.

Ismail, R. (2008). *Construction and exploration of deep wells at Carey Island and Kg Kelanang, Kuala Langat District, Banting Selangor. National Groundwater Resources Study under Subproject groundwater resources for State of Selangor*. Department of Mineral and Geoscience Selangor State, Malaysia.

Ismail, Z., Othman, S.Z., Law, K.H., Sulaiman, A.H. and Hashim, R. (2015). Comparative Performance of Water Hyacinth (*Eichhornia crassipes*) and Water Lettuce (*Pistia stratiotes*) in Preventing Nutrients Build-up in Municipal Wastewater, *CLEAN – Soil, Air, Water,* **43**(4), 521–531.

Kaya, M.A., Ozurlan, G., Balkaya, C. (2015). Geoelectrical investigation of seawater intrusion in the coastal urban area of Canakkale, NW Turkey, *Environmental Earth Sciences*, **73(**3), 1151-1160.

Mahmud, M.H., Lee, K.E., Goh, T.L. (2017). On-site phytoremediation applicability assessment in Alur Ilmu, Universiti Kebangsaan Malaysia based on spatial and pollution removal analyses, *Environmental Science and Pollution Research*, **24**(29), 22873-22884.

Najib, S., Fadili, A., Mehdi, K., Riss, J., Makan, A. (2017). Contribution of hydrochemical and geoelectrical approaches to investigate salinization process and seawater intrusion in the coastal aquifers of Chaouia, Morocco, *Journal of Contaminant Hydrology*, **198**, 24-36.

Ngah, D. S. (1988). *Groundwater investigation for determination of suitability using handpump at rural area of Kuala Langat District, Selangor Darul Ehsan, Report No. GPH1/1988*. Department of Mineral and Geosciences Malaysia, Ministry of Natural Resources and Environment, Malaysia.

Othman, S.Z., Hashim, R., Baharuddin, M.F.T. and Mohamad, S. (2014). Effects of long-term mixed land use of human settlement and oil palm plantation on the groundwater quality of ex-promontory land, *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT),* **8**(7) Versions III, 01-09.

Shirazi, S.M., Ismail, Z., Akib, S., Sholichin, M. and Islam, M.M.A. (2011). Climatic parameters and net irrigation requirement of crops, *International Journal of Physical Sciences,* **6**(1), 15-26.

Ward, J.H. (1963). Hierarchical grouping to optimize an objective function, *Journal of the American Statistical Association*, **58**, 236-244.