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Groundwater Quality Assessment for Drinking Purposes Using Multivariate Analysis and Surfer in Seremban, Negeri Sembilan

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Abstract: Groundwater deterioration is usually related to pollution caused by human activities and natural sources that occur underground. Water quality is important in to maintain individual health. The objectives of this study are to determine the factor impacting groundwater quality for drinking purposes using multivariate statistical analysis and to generate a groundwater contour map and flow direction using Surfer software. Multivariate analysis was used to analyse and identify the element or factor that impacted the water quality in Seremban, Negeri Sembilan. A total of ten parameters of five wells were analysed. The results of descriptive analysis explained that based on the quality of physical and chemical parameters, water from these five wells is suitable to be used as drinking water. The qualities are all below the limit recommended by the Ministry of Health (MOH) and the World Health Organization (WHO), except for electrical conductivity (EC) and bicarbonate (HCO_3) parameters. Hierarchical analysis results then classified the groundwater into three clusters. Cluster 1 has less salinity type of water, and Cluster 2 it might cause by the replenishment of freshwater. For Cluster 3, the value of EC has the highest compared to others at 508.00 µS/cm. In principal cluster (PC) analysis or factor analysis, the result shows that PC2 (Principal for Cluster 2) has a total variance of 11.91%. This PC2 result indicated that the source of pollution in the groundwater sample is might due to anthropogenic activities such as agriculture, urbanisation, and natural sources (mineral dissolution) based on previous studies. The generation of the water table map using Surfer software shows that the groundwater is flowing from the East to West direction of the Seremban map.

Keywords: Groundwater, water quality, multivariate analysis, hierarchical analysis

1. Introduction

Major sources of humankind's clean drinking water are surface water and groundwater. It can either remain underground for hundreds of thousands of years; or surface to fill rivers, streams, lakes, ponds, and wetlands. Groundwater flows in the same way as surface water does in a pond, river, or lake, but at a considerably slower rate. Groundwater can come out to the surface area by either pumping or flowing as a spring [1]. The presence of groundwater can be reached practically everywhere. Nearly a third of the world's population is expected to rely on groundwater for their daily needs. Malaysian groundwater provides for nearly 90% of the country's water supplies [2]. With an annual recharge rate of 64 – 120 billion cubic meters, groundwater storage in aquifers is estimated to be over 5000 billion cubic meters [3].

Groundwater is the main source of freshwater in states such as Kelantan, Pahang, and Terengganu in the west and north of the nation, as well as Sabah and Sarawak in the East [4]. Groundwater quality issues are usually linked to

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*Corresponding author: hartini@uthm.edu.my excessive hardness, high salinity and an increase in other heavy metals that are harmful to human health [5]. There are different ways that groundwater may become polluted. When liquid hazardous chemicals seep down through the earth and into the groundwater, they can pollute the water. Contaminants that dissolve in groundwater will travel with the water and might end up in drinking water wells. It is crucial to make sure the water quality from the groundwater is safe to be used to maintain human health.

Numerous studies on multivariate analysis techniques have been done, including Mahmood *et al.,* [6] using multivariate statistical techniques including correlation analysis (CA), factor analysis (FA) and discriminant analysis (DA) to analyse geographic changes and interpret datasets on Punjab, Pakistan's water quality. In Malaysia, Hairoma *et al.* [7] used multivariate analysis methods, including CA and principal component analysis (PCA), which aims to identify all the primary sources of contaminants in coastal groundwater and to measure the amount of saltwater intrusion. Similarly, Usman *et al.* [8] used multivariate analysis method including DA, CA and PCA, to identify the spatial variability of groundwater and to determine the sources of pollution that currently affect the groundwater. Based on a study by Oborie and Nwankwoala [9], in the Yenegoa metropolis, the groundwater of 16 wells was examined to establish the direction of the groundwater flow. Otutu and Oviri, [10] investigated the groundwater flow pattern of the area in the Utagba-Ogbe Kingdom, Ndokwa west Local Government Area of Delta State utilising the global positioning system (GPS) and meter tape.

The objective of this study is to determine the factor impacting groundwater quality using multivariate analysis and to generate a groundwater contour map and flow direction using Surfer software. Multivariate statistical methods were utilised in the study, including hierarchical cluster analysis (HCA) and PCA. Surfer software is used to generate the groundwater flow direction in the study area.

2. Material and Method

2.1 Study Area

This study is located in Seremban city, with a total land area of 935.02 km^2. This city is one of the seven districts located around Negeri Sembilan. Seremban city includes Seremban, Rasah, Labu, Pantai, Setul, Ampangan and Rantau (Fig. 1). It is located on the Malacca Strait, about 25 miles (40 km) inland from Port Dickson. The landscape is largely hilly, and the soil is mostly reddish laterite, which is suited for rubber and palm oil agriculture, making Seremban the state agricultural centre. The Linggi River was an important transit route for tin dealers at the peak of the tin mining industry. Seremban climate is like another part of west Malaysia that is hot and humid. The average temperatures range from 26° to 30° C. Most of the rain falls between April and October, during the inter-monsoon season. Throughout the year, the weather is mostly dry, with a few showers.

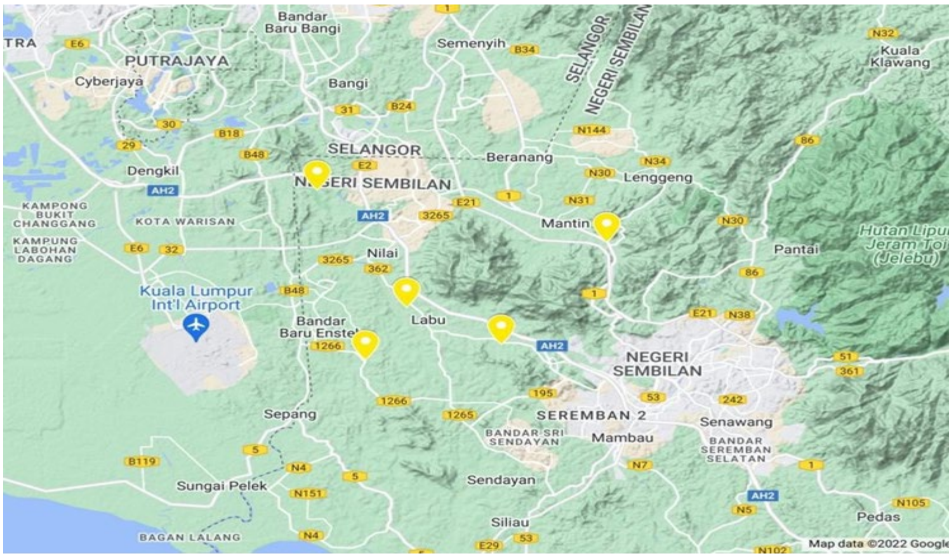

Fig. 1 - Study area [11] (Sources: Google Maps, 2022)

2.2 Data Collection of Water Quality

The groundwater information was collected based on the data obtained from Jabatan Mineral dan Geosains Negeri Sembilan. In this study, data aquifer from 2016 to 2020 was collected and analysed. Five confined aquifers in Nilai Spring Golf & Country Club, Nilai, Masjid Kg. LBJ, Labu, Masjid Kg. Pulau, Labu, Sekolah Menengah Agama Persekutuan (SMAP), Labu and Kem Sri Perkasa, Mantin that located in the Seremban area, were selected. A total of ten water quality parameters from the five different wells were analysed in this study. After that, the data sets were sorted based on locations, assembled, and transformed. All non-numerical data are subject to transformation. Besides that, secondary data such as reading journals, articles, internet sources and related website portals were used to obtain additional data needed. For the static data analysis, Microsoft Excel 16 version was used in this study to conduct multivariate statistical procedures, including PCA and HCA. The data were analysed using descriptive statistics, which included the mean and standard deviation.

2.3 Hierarchical Cluster Analysis (HCA)

Cluster analysis is a method for grouping wells based on their water quality into homogeneous groups [12]. HCA determined the geographic variability of groundwater, and it was used to assemble all of the sample sites to categorise them into clusters and reduce the number of them. HCA connects sample sites in the shape of a tree with distinct branches (Dendrogram), which provides a graphic representation or summary of the clustering process by depicting the group and their closeness. Closer connectivity between branches indicates a greater association between variables or clusters of the sampling sites or variables. In this study, the HCA approach was used in order to group the five different wells. According to Guler et al. [13], the most distinctive groups are produced by a classification scheme that uses Euclidean distance (straight-line distance between two points in C - dimensional space defined by C variable) for similarity measurement and the Ward method for linkage. The samples were classified into various hydrochemical groups using Q-mode HCA. Q-mode closure classifications of samples based on their properties.

2.4 Principal Component Analysis (PCA)

PCA is a technique for reducing huge datasets while preserving as much information as possible [14]. The number of variables will be equal to the total variance taken into account by all PCs [15]. Only PCs with small values in the analysis were kept for interpretation purposes. Loading plot and scores can be used to explain PCA. Loading plots and score plots both explain the relationships between samples and factors [16]. Multivariate analysis for groundwater quality was conducted using the Kaiser Varimax Rotation method in this study. Strong VF coefficients are defined as those with correlations greater than 0.75, which indicates a high percentage of the factor's variance is explained by it. Moderate VF coefficients are defined as those with correlations between 0.50 and 0.75, while weak VF coefficients are defined as those with correlations between 0.30-0.50, which indicate the attribute's significance is low and much of its variance is unaccounted for [17].

2.5 Surfer Software

In a groundwater study, a computer-generated contour map is required since the finished map should be saved as an XYZ computer file. Surfer by Golden Software was used to construct the water table contour map. The groundwater level data must be structured into XYZ files, with X and Y being plane coordinates of the measuring location and Z being a function of water table elevation or piezo metric surface above a reference level selected, generally the mean sea level. The surface elevation was obtained using Google Earth. In order to generate groundwater flow direction; the water table contour maps were needed.

3. Results and Discussion

3.1 Descriptive Statistics

Physical parameters of water quality show that pH and total dissolved solids (TDS) values are within the recommended limit stated by MOH and WHO standards. But only electrical conductivity (EC) is above the recommended limit. Chemical parameters show that most of the parameters, including calcium (Ca), potassium (K), magnesium (Mg), sulphate (SO_4) and chloride (Cl) within the recommended limit, which is safe to use as drinking water. Only for bicarbonate (HCO_3) which is above the standard limit.

Table 1 - Descriptive analysis for a total of five well water quality parameters

Parameters	Minimum	Maximum	Mean	Standard Deviation
pH	6.80	8.80	7.70	0.51
Conductivity (EC)	44.00	3624.00	342.33	607.50
Total solids (TS)	52.00	426.00	205.48	104.01
Total dissolved solids (TDS)	25.00	422.00	149.58	89.41
Bicarbonate (HCO_3)	5.90	418.00	154.71	104.12
Calcium (Ca)	2.57	86.00	32.06	21.59
Potassium (K)	0.50	62.60	5.33	10.50
Magnesium (Mg)	0.24	5.30	2.66	1.71

Sulphate (SO_4)	2.20	7.30	4.13	1.74
Chloride (Cl)	0.00	9.80	2.51	2.04

3.2 Hierarchical Cluster Analysis (HCA)

The weight per group approach was used in Euclidean distance prior to cluster analysis. According to HCA, the groundwater is classified into three groups Cluster 1, Cluster 2 and Cluster 3, as shown in Figure 2. Cluster 1 consists of Well 2, which are (Obs 15, 16, 19, 7, 20, 17, 14, 18, 1, 2, 3, 5, and 6), and it is classified as “moderate polluted” due to mild average value of pollutant. Cluster 2 consists of Well 3 and Well 1 (Obs 12, 4, 9, 10, 8, 11, 13, 22, 21 and 23) and it is classified as “less polluted” due to the lowest average value of pollutant. For Cluster 3, including Well 4 and Well 5 (Obs 26, 33, 24, 27, 29, 32, 28, 30, 25, and 31), it is classified as “highly polluted” due to the high average value of pollutants. The Obs in the dendrogram refers to the well observation in the study area.

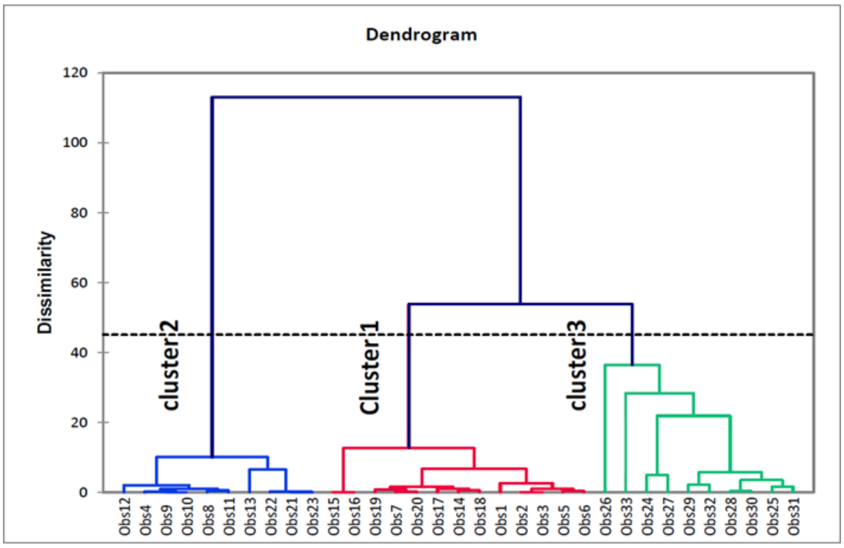

Fig. 2 - Dendrogram of water quality sample from cluster analysis in Q-mode

The water quality means value supports the three-group classification of wells, as shown in Table 2 below. The mean value of EC in Cluster 1 obtained is 252.00 µS/cm, which shows the type of water is less salinity. This higher value of EC following by TS, TDS and HCO_3. Cluster 2 obtained a low value of EC compared to other clusters, which is 44.00 µS/cm. The HCO_3 value in this location is lower than other parameters. Freshwater replenishment is the reason that contributes to low HCO_3 in groundwater. All water sample well are close to one another and have the same water quality distribution are also influenced by geological formation and strata from which water is tapped [15]. For Cluster 3, the value for EC is the highest compared to others, 508.00 µS/cm.

Table 2 - Mean values for the three principal water quality groups

Group	pH	EC	TS	TDS	HCO_3	Ca	K	Mg	SO_4	Cl
1 (n=20)	7.50	252.00	190.00	131.00	175.00	39.00	5.10	5.00	3.00	2.90
2 (n=4)	7.10	44.00	90.00	60.00	26.00	2.80	0.50	3.70	6.30	1.00
3 (n=25)	8.80	508.00	342.00	225.00	168.00	60.13	5.56	0.66	3.00	2.00

3.3 Correlation Matrix

The first process in PCA is determining the correlation matrix parameter. Pearson’s correlation coefficient was utilised to highlight the interdependence and pattern of coherence among groundwater quality measures [18]. The value of the correlation coefficient (r) indicates the degree of a linear link between two groundwater quality measures. Table 3 below shows the correlation coefficient values for the examined water quality indicators. pH showed a positive correlation with TS ($r = 0.65$), TDS ($r = 0.53$), HCO_3 ($r = 0.60$), and Ca ($r = 0.58$). TS show positive correlation with TDS ($r = 0.80$), HCO_3 ($r = 0.91$), Ca ($r = 0.92$), Cl ($r = 0.57$) and negative correlation of SO_4 ($r = 0.57$). TDS show positive correlation with HCO_3 ($r = 0.81$), Ca ($r = 0.77$) and Cl ($r = 0.56$). The substantial positive correlation between SO_4 and Cl might indicate surface pollution in the studied region due to agricultural operations. HCO_3 the positive correlation with Ca (r = 0.89) and Cl (r = 0.57). For Ca showed that the negative connection with SO_4 (r = 0.58). The presence of Ca in water might be due to the natural water-rock interaction. In addition, Ca can also be found in agricultural fertilisers like lime. While EC presents only one positive correlation with TS (r = 0.42).

Table 3 - Correlation matrix of groundwater sample

Variables	pH	EC	TS	TDS	HCO_3	Ca	K	Mg	SO_4	Cl
pH	1									
EC	0.22	1								
TS	**0.65**	0.42	1							
TDS	**0.53**	0.26	**0.80**	1						
HCO_3	**0.60**	0.37	**0.91**	**0.81**	1					
Ca	**0.58**	0.36	**0.92**	**0.77**	**0.89**	1				
K	-0.08	0.06	0.17	0.09	0.03	0.37	1			
Mg	-0.12	0.02	-0.38	-0.19	-0.14	-0.21	-0.16	1		
SO_4	**-0.55**	-0.26	**-0.57**	-0.38	**-0.56**	**-0.58**	-0.15	0.09	1	
Cl	0.16	0.30	**0.57**	**0.56**	**0.57**	0.42	-0.07	-0.30	-0.26	1

Correlation coefficient > 0.5 are in bold

3.4 Principal Component Analysis (PCA)

PCA analysis were applied using the normalised data set by including 10 parameters. In order to determine the source of change in water quality using multiple parameter testing, factor analysis with principal component analysis is performed [19]. Only factors with eigenvalues larger than or equal to 1 are considered potential sources of variation in the data under this criterion, with the component with the greatest eigenvector sum receiving the most attention. PCA generated three major components with eigenvalue >1 that accounted for 72.69 % of the variation in the data set shown in Figure 3 below.

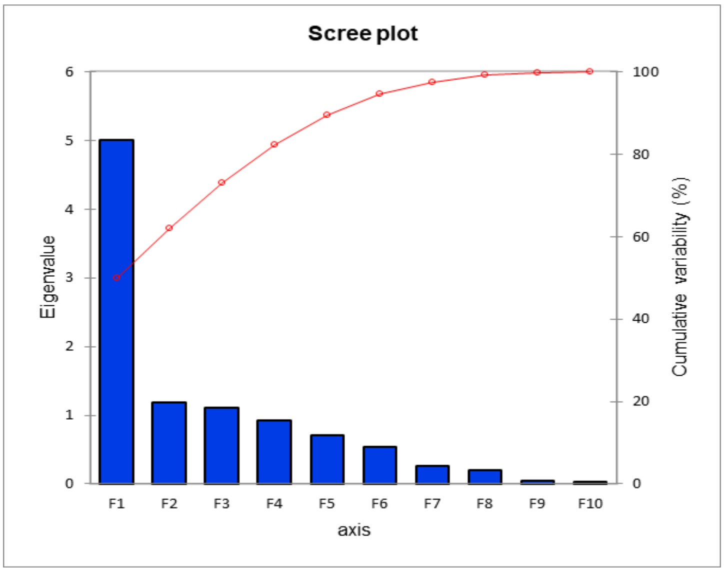

Fig. 3 - Scree plot showing the eigenvalue

The first result of PC 1 shows that 50.02% of total variance with positive loadings that are strong to moderate on pH, TS, TDS, HCO_3, Ca and Cl which is 0.690, 0.971, 0.848, 0.932, 0.926 and 0.614 (Table 4). As a result, PC1 most likely represent the consequence of the mineralisation process present in the groundwater. This might be the major effects of minerals including silicates, calcite, dolomite and gypsum dissolving and precipitating. Positive TDS loading indicates that the groundwater contains more dissolved ions [20].

The result for PC2 consists of variance and eigenvalue of 11.91% and 1.19 %, respectively. The result shows that the only strong positive loading in PC2 which is K (0.821). Sources of potassium include urban growth, mineral dissolution, and the use of synthetic fertilisers like potash in agricultural regions [21].

Based on the result, it shows a moderate correlation in PC3 is Cl with 0.590 and whereas for negative loading is pH, EC, Ca, K and Mg values. Cl values show that it might potentially be a sign of pollution from urban wastewater discharge, which is a point source of pollution, for negative loading in PC3, including Mg concentration. It occurs in groundwater due to dissolved minerals.

The graphical representation is another way to see the relationships between parameters and factor loadings (Figure 4). From the result, plotting PC1 vs PC2 obtained that the parameters were grouped into five primary clusters. Only Mg was found in Cluster 1. Cluster 2 contained SO_4. Cluster 3 belongs to K. Cluster 4 includes Ca and TS. Cluster 5 consists of Cl, HCO_3, pH, EC and TDS. The 2D scatter plot shows that all the groundwater samples were grouped into similar chemistry, sources, or flow path.

Table 4 - Factor loading and eigenvalues of principle component

Parameters	F1	F2	F3
pH	**0.690**	-0.289	-0.230
EC	0.455	-0.194	-0.108
TS	**0.971**	0.067	0.055
TDS	**0.848**	-0.037	0.137
HCO_3	**0.932**	-0.149	0.017
Ca	**0.926**	0.159	-0.196
K	0.172	**0.821**	-0.453
Mg	-0.302	**-0.580**	**-0.539**
SO_4	**-0.658**	0.074	0.369
Cl	**0.614**	-0.034	**0.590**
Eigenvalue	5.002	1.191	1.103
Variability (%)	50.020	11.910	11.034
Cumulative %	50.020	61.930	72.964

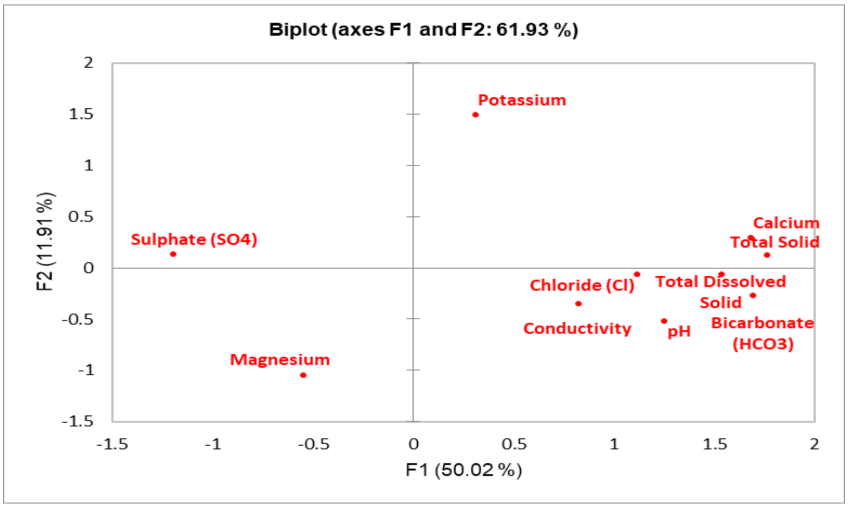

Fig. 4 - Plot of PCA score for PC 1 and PC 2

3.5 Water Table Contour Map

Surfer 2016 by Golden Software was used to create the groundwater contour map for the study area. Hydraulic Head (HH) data are used to create water table contour maps and to generate the groundwater flow directions. In order to obtain the HH of each location, Static Water Level (SWL) in the boreholes is subtracted from the ground surface elevation [22]. Google Earth was used to determine the surface elevation. For the static water level, Latitude and Longitude data were obtained from Jabatan Mineral dan Geosains Negeri Sembilan (JMG).

SWL = Static water level in the borehole
SE = Surface elevation with respect to the mean sea level.
HH = SE – SWL

Table 5 - Data for water table contour map

Well No	Longitude	Latitude	Elevation (M)	SWL	Hydraulic Head (M)	Location
1	418866	313581	42	1.32	40.68	Nilai Spring Golf & Country Club

2	420859	301888	40	0.1	39.9	Masjid Kampung LBJ
3	423772	306175	37	5.83	31.17	Masjid Kampung Pulau Lambar, Batu 11
4	435290	310786	71	3.21	67.79	Pusat Pemulihan Integriti Penjara
5	429499	303251	60	8.4	51.6	Sekolah Menengah Agama Persekutuan (SMAP)

3.6 Groundwater Flow Direction

The overall flow direction of groundwater in the study region in Seremban, Negeri Sembilan, was indicated using the water table contour map (Figure 5) below. Five locations of the well and the static water level value were contoured on the map of the Seremban area by connecting equivalent values of static water levels and ensuring that no cuts across each other or lines overlapped. From the water table contour, the groundwater flow direction was created, and it moved towards well 3, which is located at Masjid Kampung Pulau Lambar Batu 11, Rasah, Negeri Sembilan. The groundwater moves from the East to West direction, as shown in the water table. All wells from different location flow in the same direction that is, towards Well 3. As shown in the contour maps, groundwater moves from the higher to lower part or level. The higher level is in the East, and for slope is located in the West region. Figure 6 reveals that the aquifer in the West part of the study region is more likely to receive pollution transferred from the East part of the study region. The finding of this study explained that the most affected population is in the West region by activities such as solid waste disposal and landfill. These activities will cause the pollution to seep into the aquifer. In order to minimise the pollution, it is recommended to re-locate the area of the landfill, site industry and solid waste disposal in the West area and not in the East region.

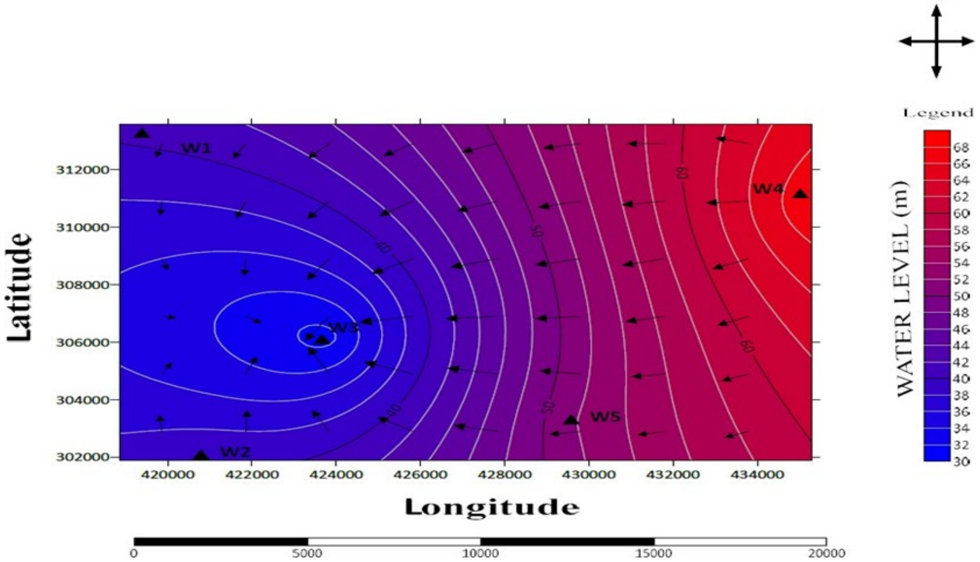

Fig. 5 - Water table contour map in Seremban town

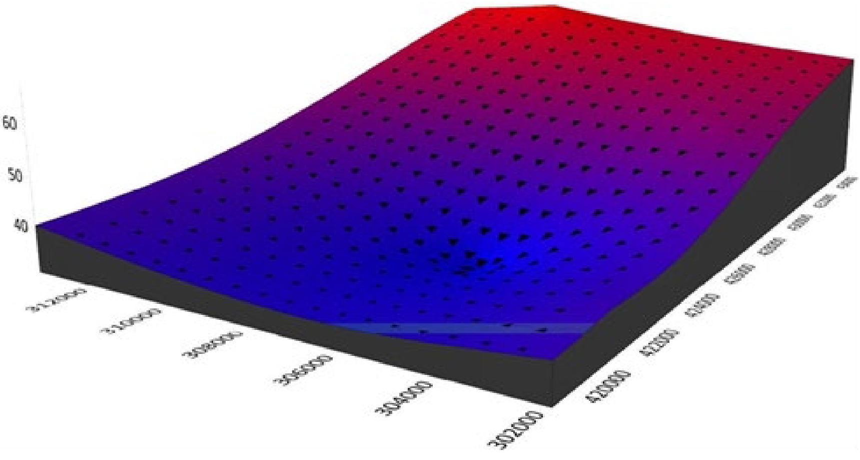

Fig. 6 - 3D groundwater flow direction map

4. Conclusion

Multivariate statistical analysis was effectively used in this study to determine the probable pollution sources. From HCA analysis, it can be concluded that all the water samples in the different locations were clustered into three groups which are Cluster 1 (less polluted), Cluster 2 (moderate polluted) and Cluster 3 (highly polluted). Synthetic fertilisers used in agriculture and mineral dissolution might be the sources of pollution in the water quality of the groundwater in the Seremban area. Point source pollution, which is included in the urban wastewater discharge, also might contribute to the deterioration of the water quality. PCA analysis shows that the major source of pollution to the groundwater quality in the study region are the mineral-water process, agriculture and human anthropogenic activities. In conclusion, this study has the potential to help the related agencies in charge, such as the government, in making decisions to handle related issues to restore the deteriorating quality of water resources due to the pollution from numerous human activities. This study also has the potential to be used as a future reference in the study of groundwater quality.

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