

Spatial Statistical Analysis of Groundwater using Geopack and ArcGIS

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Abstract

The main objective of this paper is using ArcMap GIS, from Environmental Sciences Research Institute (ESRI), and Geopack as an efficient way to generate contour lines and maps for the underground formation surfaces (e.g. clay unit), water table and different water quality maps of groundwater applied to Ottawa landfill site, Canada. Based on stratigraphical description (well logs) of monitoring wells, there are about 200 monitoring wells in this area, and on monitoring observation, three main aquifers (shallow, deep and bedrock) were assigned under and around of the landfill site. By using available borehole data and Geopack, different variogram models were generated. Then by using the best variogram, based on the variance output map, and Spatial Analyst of ArcGIS, contours of the clay unit surfaces, thickness of the clay unit between shallow and deep aquifers, clay layer windows, and groundwater surfaces were generated. Values of nugget effect, sill and range were calculated in Geopack and were applied in contouring by Kriging in ArcGIS. In this paper, the leachate influence on groundwater was assessed on the basis of Cl⁻, DOC, EC, and pH output maps of ArcGIS. The shallow and deep aquifers were contaminated somewhere in the north and beneath of Ottawa landfill site. Coupling a geostatistical software such as Geopack to a GIS such as ArcGIS can help to better understand and model hydrogeological parameters and study the contamination patterns and their relationship to other factors in this area.

Key words: ArcMap GIS, Geopack, variogram models, Spatial Analysis, Groundwater, Landfill sites.

1. Introduction

The Trail Road Landfill (TRL) and Nepean Lanfill (NL) sites are owned and operated by the City of Ottawa and are located in Nepean about 25 km to the west of the city of Ottawa. Site operation was started at the NL in the early 1960's. It was continued about 20 years. Since 1980, NL has not received waste with the exception of some minor construction debris and TRL has operated to receive municipal solid waste. TRL is divided into stage 1 through stage 4. Stage 1 and stage 2 are, the same as NL, designed based on a natural attenuation landfill and they have no bottom liner, clay and geomembrance, and leachate collection system. S1, S2 and NL were covered in 1988, 1991 and 1993, respectively. The last two stages of TRL, stage 3 and stage 4, were both equipped to bottom liner (clay and geomembrane) and leachate collection system [1]. The main object of this paper is to use Geographical Information System (GIS) to define the underground formation surfaces (e.g. clay unit), water table and distribution of water quality maps of groundwater.

2. Site Setting and Hydrostratigraphy

The landfill is situated a Northwest-Southeast ridge of glacio-fluvial sand deposit. This sand and gravel ridge extends out to the Jock River, and locally confined by clay materials unit. The TRL and NL sites are located on the east and the west side of this ridge, respectively. The

sequences of deposited sediments are sand and gravel unit, then clay unit followed by sand redeposited unit. Due to the deposition, erosion of the clay layer and redeposition of the geological materials, the clay layer is not a continuous plain and it has some windows in some parts of the study area. [1].

Based on the geological history of study area, on the stratigraphy interpretation of monitoring well logs, there are about 200 monitoring wells in this area, and on monitoring observation, there are four hydrogeological unit in this area; (1) the shallow perched aquifer on the top of the clay aquitard, (2) the clay aquitard, (3) the deep aquifer, and (4) limestone bedrock aquifer [1, 2].

Where the ground surface elevation drops, the shallow aquifer pinches out and where the water table of the shallow sand aquifer and the underlying clay contact to ground surface, groundwater seeps during certain periods of the year. In areas of clay windows, the shallow aquifer is continuously connected with the deep aquifer. In the past, before dewatering ponds were generated (Fig. 1-a) the hydraulic gradient was upward from the deep aquifer to the shallow aquifer. After generating dewatering ponds in a sand and gravel deposit located near west of the landfill site, the hydraulically connection between the shallow and deep aquifers was reversed [2]. The dewatering ponds have lowered the water table of deep aquifer and produced a discontinuity between the water tables of shallow and deep aquifers (Fig. 1-b).

3. Methodology, Data and Map Analysis

Since 1985, a large amount of quality and quantity data has been collected as part of a monitoring program at TRL and NL sites [1, 3]. The water table levels and groundwater chemistry data in Access format (both up to the end of 2001) and monitoring well logs, have been provided by Golder Associate Ltd. with the permission of Ottawa City [3]. The available tables were edited and joined by using the Access, Excel and ArcGIS softwares. By importing the final dbase table to the ArcGIS, it was converted to shape file and then by using the query builder ability of ArcGIS some queries were made based on type of aquifer, year and selected parameters. Some tables of MapInfo, same as Theme in ArcGIS, were exported as .e00 files by using the Mapinfo/ArcView tool of MapInfo. These .e00 files were import to ArcGIS by using the Import71 software and then merged and clipped to produce the required shape files such as drainage system and transportation network. The Kriging interpolation method is available in ArcGIS Spatial Analyst. Figure 2 shows the procedure of data and map analysis as a flowchart.

4. Geopack and Generating Different Variograms

As mentioned earlier, there are more than 200 monitoring wells in study area. Before using any interpolation methods to generate contour maps, evaluating of the spatial correlation of monitored data is very important. The spatial dependence of the data can be evaluated by a variogram. Gaussian, Exponential, Spherical, Power and Linear models are the most common variograms models [4]. Based on the characteristics and variables of each variogram (i.e. Nugget, Sill, Range and Sum Square Error (SSQ)), we can select the best fit variogram models to our data. Generating and selecting the best variogram for the TopClay surface, as an example, will be discussed briefly. By using boreholes that intersect the top of the clay unit and based on the initial data base, input data set prepared in the format understandable for

Geopack. The values equal to “0” and “9999.99” were eliminated from the set and not taken into account in the calculation. Figure 3 shows the five generated variograms and their variables for the TopClay surface.

As it can be seen in the Spherical model, Nugget effect of variogram and the SSQ has relatively small values in respect to the other variograms. Although the SSQ of Exponential model is a little bit larger than Spherical ones, and its Nugget effect is equal to zero, The values of generated variance map for the TopClay surface based on Exponential variogram are smaller than that of Spherical variogram variance map. Hence, Exponential variogram model was chosen as a function of Kriging interpolation and eventually generating the contour maps.

5. Map Generating by Using ArcMap GIS

ArcMap GIS, from Environmental Sciences Research Institute (ESRI), is a powerful tool for mapping and analyzing spatially correlated data. Spatial Analyst of ArcMap GIS were used to generate different useful maps for better understanding the stratigraphy of study area, groundwater movement, leachate-polluted groundwater area and the extent of the leachate plum. After preparing the final dbase files (see the Figure 2 flowchart) all surfaces; top and bottom surfaces of formations (e.g. TopClay surface), BottomClay, Thickness of clay unit and Groundwater surfaces were generated based on the selected variogram and by using Spatial Analyst of ArcMap. For this purpose Kriging interpolation method was used and for the amount of its required parameter; nugget, sill and range, the output of Geopack was used. It is worth mentioning that if the data of a surface be few and sparse, we cannot fit a good model, variogram, to these data and thus, the Kriging interpolation method cannot be efficiently used to generate related surface. In this case, a non-interpolation method (e.g. the point buffering, Thiessen polygons, etc.) might give more accurate results.

Figure 4 shows borehole locations, TopClay contour lines, TopClay surface map, and the 3D view of these layers generated by ArcMap. As it can be seen, the elevation of TopClay surface change about 20.0m over the study area. By using Raster Calculator of ArcMap, it is possible to subtract two maps. Therefore, if we generate BottomClay surface map, the same way as TopClay one, then subtract it from the TopClay raster map, the clay layer thickness map can be made (Fig. 4). By making a query for the negative thickness values, the area with possible existence of clay windows, can be found (Fig. 4). Although we can generate the thickness map by preparing the dbase file for the thickness, by subtracting the elevation of BottomClay from TopClay elevation, and then import it to ArcMap. However, in this case, we can not make query for the negative thickness values and it is difficult to determine clay windows.

Figure 5 illustrates the water table contour lines for the shallow and deep aquifer based on groundwater elevation data collected in 2001, these data prepared by Golder Associates Ltd [2, 3, 5]. In the north part of TRL sites the groundwater flow direction is northward and follows the general slope of the underlying clay layer surface (Fig. 4). Although the flow direction is reasonable, as mentioned earlier, since the number of data for the shallow aquifer is limit and sparse, it should be better in order to generate surface map, one of the non-integration methods was chosen. The Kriging interpolation method does not work for the

given data. The general groundwater flow direction in the deep aquifer is toward the north and northwest (Fig. 5).

In the same procedure, different water quality maps were generated by using Kriging interpolation method in ArcMap Spatial Analyst [e.g. 6]. Figure 6 shows the chloride concentration, Dissolved Organic Carbon (DOC), Electrical Conductivity (EC) and pH maps in the shallow aquifer. The Cl⁻, DOC concentrations and EC were increased beneath the north part of the S1 and S2 of TRL site and beneath the NL site as well. On the other hand, the leachate of landfills causes the pH of shallow aquifer was decrease in north of TRL site and also beneath the NL site. Accordingly, this maps show the shallow aquifer was contaminated in the north of the S1 of TRL and beneath the NL as well.

6. Conclusion

ArcMap GIS, with Spatial Analyst extension was used in this study to generate contour lines and maps for the underground formation surfaces (e.g. clay unit), water table and different water quality maps of groundwater. For this purpose Kriging interpolation method was used and for the amount of its required parameter; nugget, sill and range, the output variogram model of Geopack was used. As a result, the extent of clay aquitard unit, its thickness and its window were identified. Moreover, the water table contour lines and water table surface maps for the shallow and deep aquifer show that in the north part of TRL sites the groundwater flow direction is northward and follows the general slope of the underlying clay layer surface and the general groundwater flow direction in the deep aquifer is toward the north and northwest, towards the dewatering ponds. The chloride concentration, Dissolved Organic Carbon (DOC), Electrical Conductivity (EC) and pH maps of the shallow aquifer show the shallow aquifer was contaminated in beneath the north of the S1 of TRL and the NL sites.

7. Acknowledgments

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8. References

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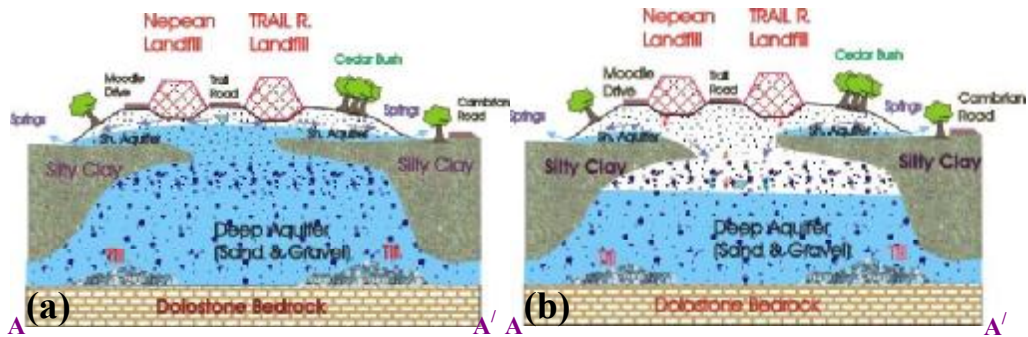


Figure 1: Schematic cross sections of hydrogeological unit in study area, the trend of cross section is NE-SW.

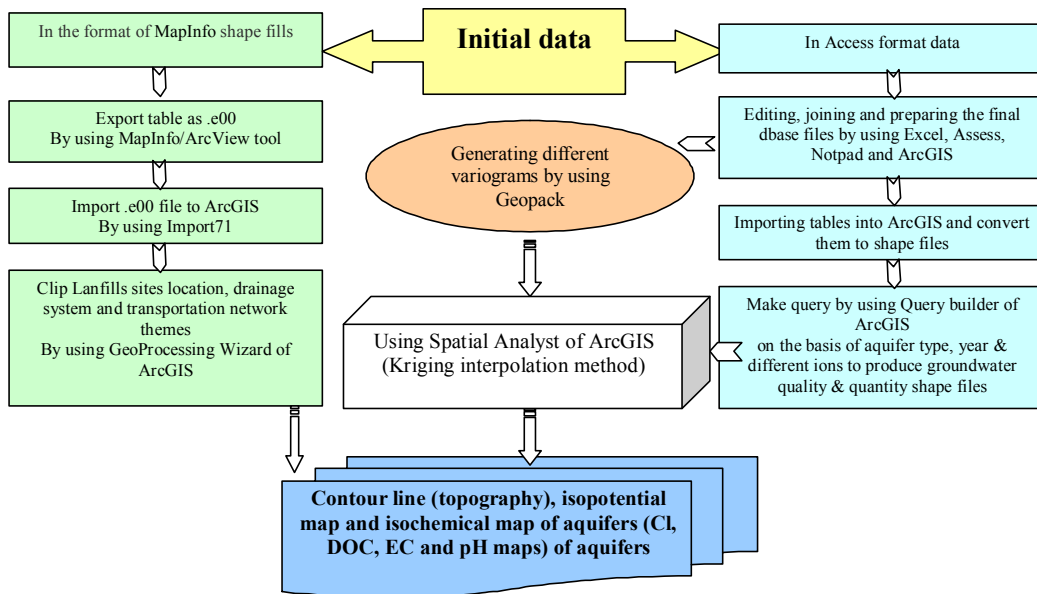


Figure 2: Data and map analysis flowchart.

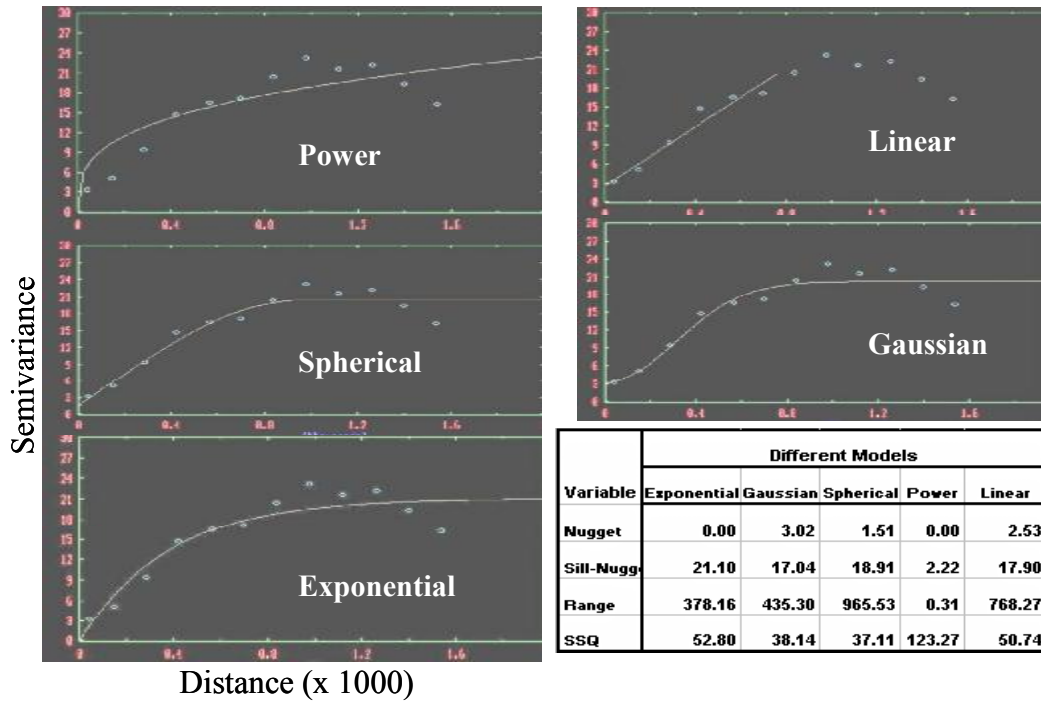


Figure 3: Different variogram models and their variables for the TopClay surface which generated by Geopack.

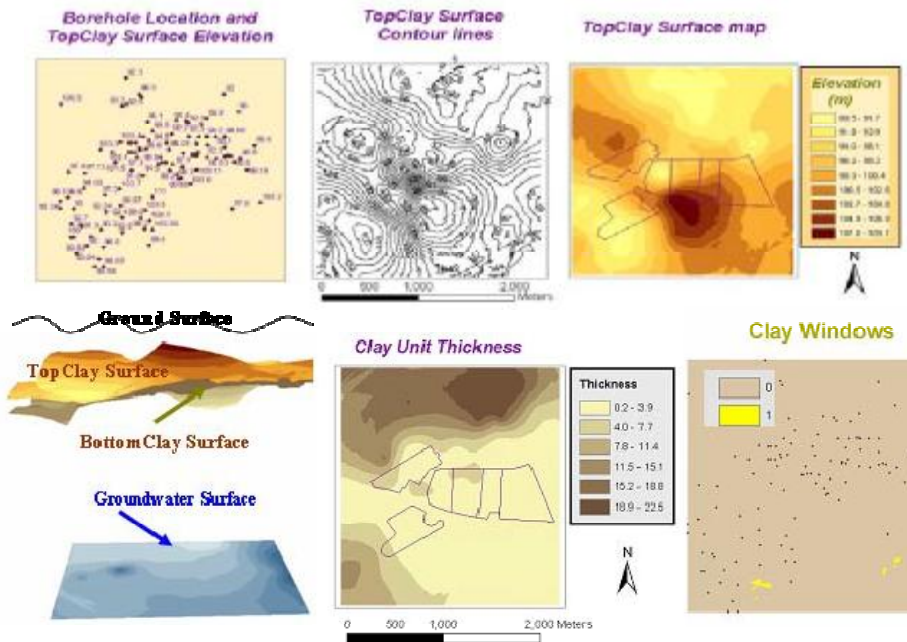


Figure 4: Borehole locations, TopClay contour lines and surface map, 3D view of clay layers surfaces, the clay layer thickness map and clay windows.

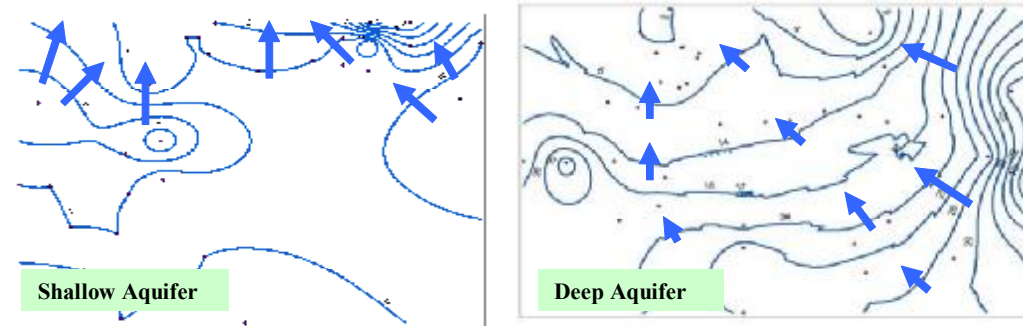


Figure 5: Water table contour lines elevations.

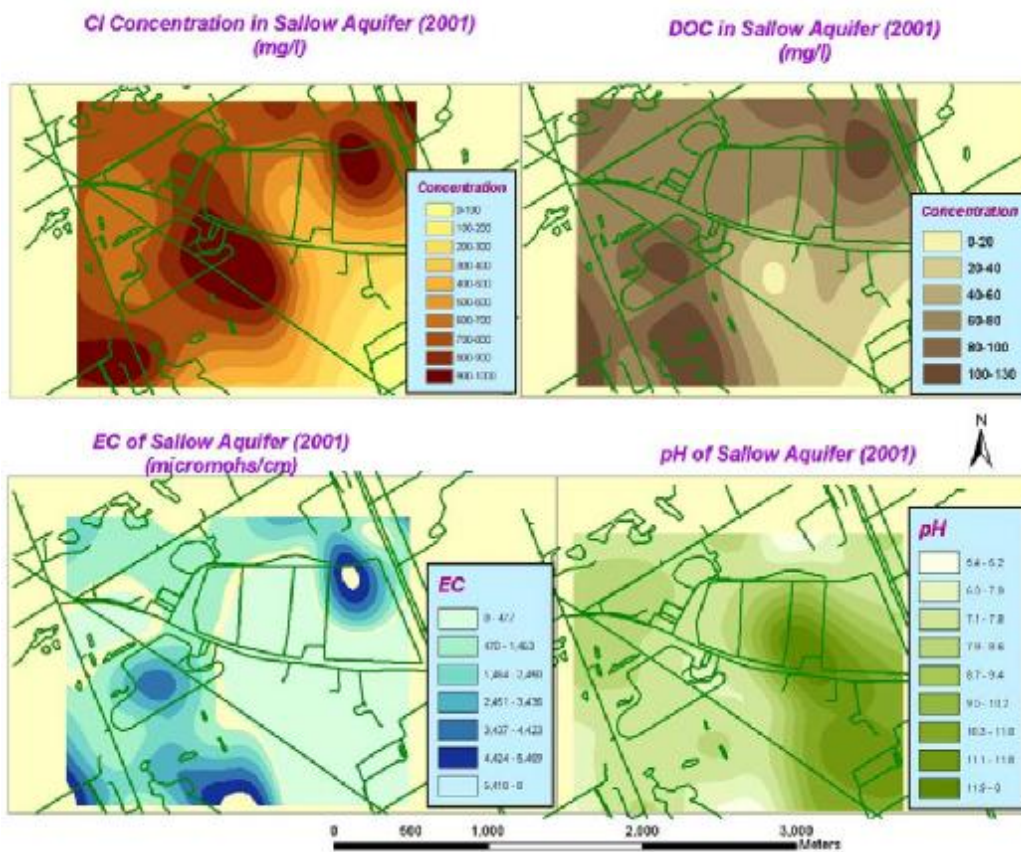


Figure 6: The Cl^- concentration, Dissolved Organic Carbon (DOC), Electrical Conductivity (EC) and pH maps in the shallow aquifer.