Geostatistical Analysis of Groundwater Quality in Western Australia

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***Abstract*— This study analyzed groundwater quality in Western Australia using geostatistical tools based on kriging interpolation technique. Four semi-variogram models were tested and out of the four semi-variogram models, exponential semi-variogram model was considered as the best fit for groundwater quality parameters. Surfer software was highly used in vulnerable mapping of the analyzed data and generated gridding report of each plotted graph was advantageous in determining geostatistical characteristics of data sets. The spatial distribution of groundwater quality across Western Australia concluded that Perth and Wheatbelt regions experience major groundwater quality issues due to commercial and industrial impacts. Temporal analysis of groundwater quality shows that, almost all the locations indicated increasing groundwater pollutant levels. The main focus was on the period of time from 2005 to 2011 due to inconsistent readings in the certain years before 2005. This study is beneficial for engineers, decision makers and managers for their management processes on groundwater quality control.**

Keywords-Groundwater quality; pollution; geostatistic; land use; mapping

I. INTRODUCTION

Groundwater is one of the essential and valuable natural resources in the world. It derives from water which runs through the soil to pores within the bedrock and soil. Water resources are major environmental, social and economical value to Western Australia and groundwater quality plays a key role in protecting water resources [1]. Groundwater quality reflects the composition and solubility of the soil or rock that the groundwater is in contact with and time that it has been in the subsurface. The importance of investigating groundwater quality is not being limited to protection of public health; groundwater is used for farming, fishing and mining, and contributes to recreation and tourism. [2]. Groundwater quality varies with the presence of contaminants and the characteristics of groundwater. Groundwater quality can be measured by its biological (total and faecal coliforms), chemical (hardness, nitrate, nitrite, sulphate, ammonia, pH, electrical conductivity and arsenic) and physical (total dissolved solids and turbidity) and aesthetic characteristics (odors, taints, color) [3].

Factors affecting the groundwater quality can be categorized as effects of urbanization, agricultural threats, industrial and commercial impacts, environmental and other indirect potable usage [4]. Over the past decade, the groundwater quality in Western Australia has been fluctuating continuously. The distribution of groundwater quality over time and space has to be monitored and analyzed regularly, in order to maintain the groundwater quality. Geostatistical analysis provides a suite of statistical models and tools for spatial data exploration and surface generation of groundwater quality [5], [6]. It is useful in exploring data variability and spatial relationships [7]. This study will be beneficial for managers, decision makers and engineers in evaluating groundwater quality in Western Australia.

II. STUDY AREA

The study area was limited to Western Australia, which is the largest state in Australia. The total area occupied by Western Australia is around 2,526,786 km^2 [8]. For the ease of analysis, Western Australia was divided into 10 regions. Majority of the data was received from the coastal area of the state highlighting Perth, Peel and South West regions. Lack of data from other areas across the state affected the data analysis process in this study.

All the locations of groundwater monitoring wells used in this study are shown in the Fig. 1. Data distribution in Fig.1 clearly indicates that data set is concentrated to the coastal strip from South West till the end of Wheatbelt region due to the fact that majority of the groundwater bores monitored by the Department of Water are located in the high population area. Lack of data from other areas across the state affected the data analysis process in this study. However an estimation of the groundwater quality behavior in those areas was taken into consideration using geostatistical interpolation techniques.

III. METHODOLOGY

A. Data collection

Quantitative groundwater quality data over the past recent years in Western Australia was taken from the Department of Water. Selection of groundwater quality parameters for the analysis was carried out considering the importance of assessing the parameter, sufficiency of data received from Department of Water and the severity of threats and risks experienced in groundwater quality under the particular parameter.

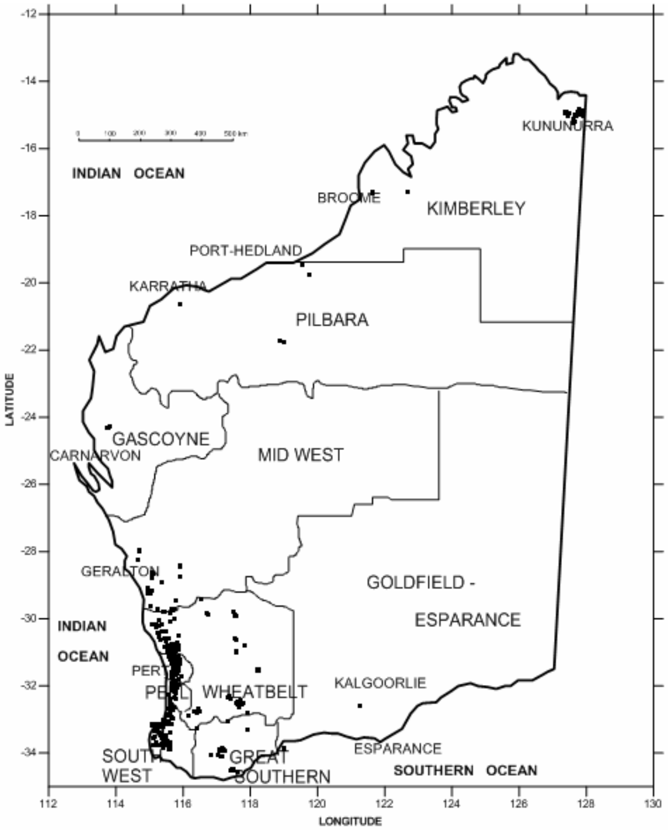


Figure 1. Study area and groundwater bore locations

Data distribution was assessed spatially for all the selective groundwater parameters. Thereafter, temporal variation of data from the same groundwater well was taken into account to identify its behavior over the past years. In the meantime, data was compared against the Australian Drinking Water Quality Guidelines to figure out the areas where groundwater fails drinking water guidelines.

B. *Geostatistical analysis*

Geostatistical method of analysis was the key tool used to analyze the groundwater quality in Western Australia. Kriging interpolation technique and semivariogram modeling approach were used to analyze groundwater spatially across the state. Initially, four semivariogram model types namely, exponential, linear Gaussian and quadratic were taken into consideration for selective groundwater quality parameters. Each parameter was analyzed under those four semivariogram models. After that, the most appropriate model of semivariogram was selected by examining the spatial distribution of the data set along with geostatistical characteristics such as standard deviation, error percentage and skewness. Kriging interpolation technique was used in interpolating readings in the locations where actual data was not present. Surfer helps to produce maps with the best representation of the data set. It provides the option of choosing the semivariogram type, interpolation method, type of mapping.

IV. RESULTS AND DISCUSSIONS

A. *Spatial distribution of groundwater quality*

Spatial analysis of groundwater quality in Western Australia was conducted to identify vulnerable areas and variation of groundwater quality across the state. Kriging interpolation technique and semivariogram were the key geostatistical techniques used in the spatial analysis of larger catchment areas with fewer data points [9]. Spatial analysis was conducted for selective groundwater quality parameters which significantly impacts groundwater quality in the area. Nine groundwater quality parameters including acidity, ammonia, calcium, pH phosphorus, hardness, aluminum, sulphate and copper were the selective groundwater quality parameters in this study. Consistency of data received from Department of Water mainly influenced in selection of groundwater quality parameters

Spatial distribution of groundwater quality across Western Australia was analyzed under four semivariogram models; exponential, linear, gaussian and quadratic semivariograms. The best numerical model was taken for further analysis for each groundwater quality parameter. Selection of the semivariogram was undertaken by visual check of the maps and examining the distribution of groundwater across Western Australia. Moreover, statistical characteristics such as standard deviation, error percentage and skewness were also taken into consideration. Every groundwater quality parameter was analyzed for all four semivariogram along with the kriging interpolation technique. Then the analyzed results were further examined with the Australian Drinking Water Guideline. A similar procedure was conducted for all groundwater quality parameters in determining the best semivariogram for each data.

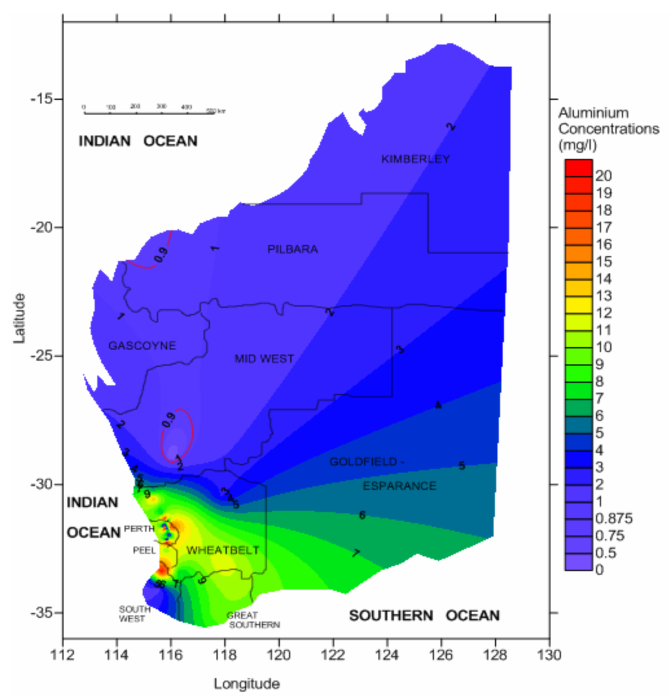


Figure 2. Spatial distribution of Aluminium in groundwater.

Fig 2 explains the spatial distribution of aluminium in groundwater across Western Australia. Taking key geostatistical characteristics into account, exponential semivariogram along with the kriging interpolation technique was selected as the best fit for this particular data set. Fig 2 indicates the spatial distribution of groundwater aluminium from 45 locations across the entire state. Aluminium concentration in groundwater ranges from 0.005mg/l to 20 mg/l. Majority of the observation data indicated aluminium concentrations in groundwater below 5mg/l. However, considerably higher groundwater aluminium concentrations above 20mg/l were highlighted in Yeal Wetland and Swan Coastal Plain. These significantly higher levels are mainly due to the clay minerals and aluminosilicates in that area. Kriging interpolation technique and exponential semi variogram model are used to model the spatial distribution of data using the readings from nearest locations. As per Australian drinking water guidelines, the maximum aluminium concentration in drinking water should limit to 0.9mg/l [10]. However, in most parts of Western Australia aluminium concentration in groundwater is above the drinking water quality limits. Only some areas satisfy drinking water quality standards.

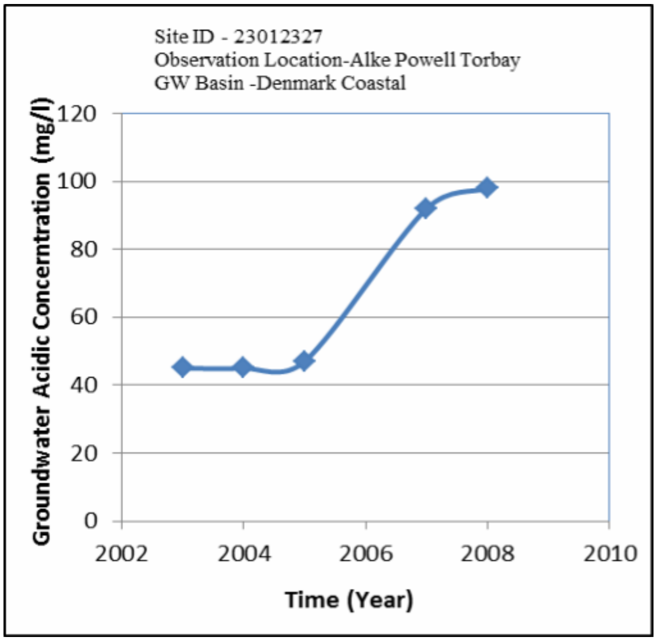
A similar procedure was carried out for all nine groundwater quality parameters followed by a brief discussion of the analysis results. A summary of the results of spatial distribution analysis of groundwater quality in Western Australia is summarized in Table 1. As shown in Table 1, spatial analysis of groundwater quality was carried out for nine groundwater quality parameters. Variation of groundwater quality parameter concentrations was investigated in the analysis. Population growth and industrial development in Perth Metropolitan area and its close regions caused escalating levels in majority of the groundwater quality parameters. However, Department of Water has conducted several projects to monitor and control the quality of groundwater in these high vulnerable areas.

TABLE I. SUMMARY OF SPATIAL ANALYSIS OF GROUNDWATER QUALITY FOR NINE GROUNDWATER QUALITY PARAMETERS

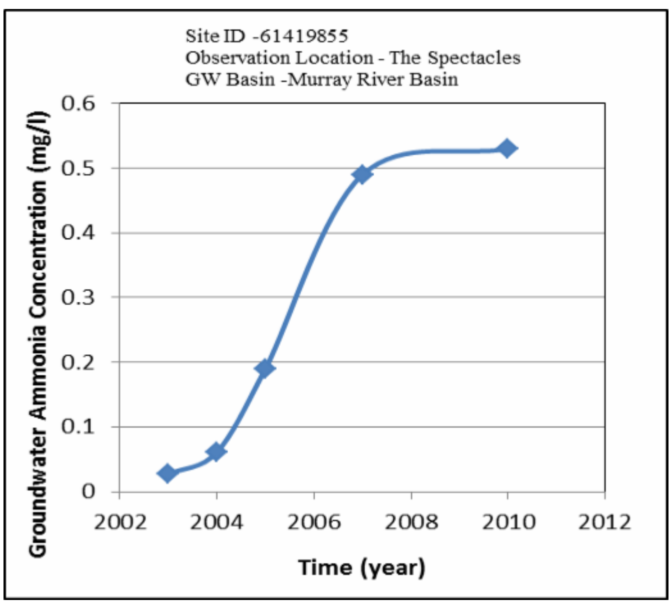
Groundwater Parameter	Highest Region	Lowest Region	Analysis Results/ Findings
Acidity	Goldfield-Esparance	Peel	Wheatbelt valleys experience severe issues acidic groundwater. Wastewater discharge from factories and industries was the direct cause for high groundwater acidic levels. No Australian Drinking Water Guidelines recommended.
Ammonia	Perth	Wheatbelt	Majority of the state has groundwater ammonia levels under control. Cockburn Sound catchment has significant impacts from higher ammonia levels in groundwater. Unlimited disposal of agricultural chemicals such as pesticides and fertilizer caused significant ammonia levels in groundwater.
Calcium	Peel	Wheatbelt	Direct threats by microbial contamination, chemicals and agricultural activities. No Australian Drinking Water Guidelines.
Sulphate	Kimberley	Pilbara	Considerably higher levels of groundwater sulphate in Kimberley has to be controlled. Western suburbs in the state have groundwater sulphate levels under Australian Drinking Water Guidelines.
Aluminium	Perth	Gascoyne	Majority of the state have groundwater aluminium levels above Australian Drinking Water Guidelines. Perth, Peel and Wheatbelt regions are highlighted with higher aluminium levels in groundwater.
Copper	Perth	South West	Entire state is under Australian Drinking Water Guidelines. Comparatively less population areas such as Mid-West, Pilbara have equal level of groundwater copper concentrations.
Hardness	Kimberley	South West	Higher levels highlighted in northern suburbs. Majority of the state has hardness levels beyond Australian Drinking Water Guidelines. Mining, power generation, irrigated agriculture and horticulture, forestry and tourism have direct impacts on groundwater hardness.
pH	Perth	Goldfield-Esparance	pH in groundwater is a temporary method of assessing groundwater quality as it varies constantly. Coastal area of WA has pH levels between 6.5 to 8.5, which is recommended by Australian Drinking Water Guidelines. Rest of the state indicates pH levels below 6.5.
Phosphorus	Kimberley	Peel	Groundwater phosphorus levels increase as it goes northern suburbs of WA. Mining and chemical activities have major impacts on groundwater phosphorus levels. No Australian Drinking Water Guidelines.

B. Temporal distribution of groundwater quality

Temporal analysis was conducted for all the groundwater quality parameters that were used in the spatial analysis and for all the groundwater bores locations with sufficient reading over the past years. Excel graphs was used in plotting the analyzed results and clarity of analysis was depending on the consistency of the data set. Analysis was carried out for more than 100 bores and the results of two selective locations are shown in Fig 3.



(a). Groundwater Acidity



(b) Ammonia in groundwater

Figure 3. Temporal variation of groundwater quality

The first graph in Fig. 3 indicates the temporal variation of groundwater acidity in Denmark Coastal Basin from 2003 to 2008. The rapid growth of acidic levels from 2005 to 2007 explains how the industrial development and population growth affected the groundwater quality in that particular area. The second graph in Fig. 3 explains temporal analysis of groundwater in Spectacles, Murray River Basin. It highlights the increment of groundwater ammonia from 2003 to 2010. In that period, groundwater ammonia concentrations increased from 0.027mg/l to 0.53mg/l, exceeding the Australian drinking water guideline limit. Disposal of wastes from factories and other industrial wastes is the main reason for this significant increment of pollutants. Land use activities and fertilizer usage is also heavily affects. The farming and agricultural activities should be controlled in order to control higher ammonia concentrations in groundwater.

After analyzing the temporal distribution of nine groundwater quality parameters for more than 100 bores, the highlight that every groundwater bore indicated increasing groundwater quality levels. Around the period from 2005 to 2007, groundwater quality levels in majority of the bores escalated rapidly due to the industrial boom and vast developments in Western Australia at that time. The vast growth of industry, technology, population, and water use in Western Australia have increased the stress upon groundwater resources. As a result, the quality of groundwater has been fluctuating over the recent years.

In order to control and maintain the quality of groundwater in Western Australia it is important to control the main sources of contamination to the groundwater. Mainly factories and industries have to be advised and guided for proper disposal of their chemical wastes. Groundwater resources should be monitored regularly and relevant advice has to be provided on the location, distribution and quality of the groundwater resources of vulnerable areas. Contamination of groundwater resources should be strictly prohibited. Environmental investigations and research should be conducted on groundwater related problems such as salinity and specific groundwater and estuary investigations into contamination and other groundwater related issues especially in vulnerable areas. Factors influencing the groundwater quality should be addressed as early as possible and to be kept as minimum as possible. Maintaining and monitoring the quality of groundwater has to be in a regular, dynamic routine across the state.

Further studies can be carried out to compare the land use in Western Australia along with the quality of groundwater. Impacts of land use on groundwater quality were not thoroughly addressed in this study. However, land use and groundwater quality has a close relationship as this study can be broadened to justify the groundwater quality behavior in terms of land use in Western Australia. Future research about groundwater quality in Western Australia should also be carried out taking groundwater flow characteristics into account, in the study of spatial and temporal variability distribution analysis.

V. CONCLUSIONS

Throughout this study, groundwater quality parameters were assessed and analyzed geostatistically by semivariogram models and kriging interpolation technique. Four semivariogram models were used and out of the four semivariogram models, exponential semivariogram model was considered as the best fit for seven out of nine groundwater quality parameters. The other two groundwater quality parameters had data sets which perfectly complied with the linear semivariogram model type. Kriging interpolation technique was used in interpolating values in the locations where data points were not present. Surfer software was highly used in vulnerable mapping of the analyzed data and generated gridding report of each plotted graph was advantageous in determining geostatistical characteristics of data sets. Lack of data in Northern and Eastern areas of the state was a significant issue and it mostly impacted on selection of groundwater quality parameters for this study.

The spatial distribution of groundwater quality across Western Australia concluded that Perth and Wheatbelt regions with major groundwater quality issues due to commercial and industrial impacts. Spatial analysis of groundwater acidity highlighted Wheatbelt valleys with severe issues regarding groundwater acidity. Majority of the areas in Western Australia has ammonia levels under control. However, Cockburn Sound catchment has significant impacts from higher groundwater ammonia levels. In terms of calcium and copper, majority of the areas in Western Australia are under the Australian Drinking Water Guidelines. In addition, Sulphate and aluminium in groundwater are considerably higher in majority of the areas across the state. Thus, it is important to control and maintain those levels in order to improve the quality of groundwater in Western Australia.

In terms of the temporal analysis of groundwater quality, all most all the location indicated increasing groundwater quality parameter levels. The main focus was on the period of time from 2005 to 2011 due to inconsistent readings in the certain years before 2005. Annual average groundwater quality level was taken where more than one date reading was present for the same groundwater bore. Temporal analysis results were presented in the form of graphs and plotted graphs were clear enough to understand the temporal distribution of selective groundwater bores.

This study is beneficial for engineers, decision makers and managers for their investigations on groundwater quality control. The identified vulnerable areas in this study can be applied in controlling and maintaining fair groundwater levels across the state. Moreover, this study, geostatistical analysis of groundwater quality can be used in assessing and analyzing land use and other groundwater related subjects across Western Australia.

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