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Research Article

Geo-statistical approach for prediction of groundwater quality in Chunnakam aquifer, Jaffna Peninsula

[1]Sutharsiny Arasalingam, [1]Herath Manthrithilake, [2]Selvarajah Pathmarajah, [3]Thushyanthy Mikunthan and [4]Meththika Vithanage

[1]*International Water Management Institute, Sunil Mawatha, Battaramulla, Sri Lanka*

[2]*Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Sri Lanka.*

[3] *Department of Agricultural Engineering, Faculty of Agriculture, University of Jaffna, Sri Lanka.*
[4] *Chemical and Environmental Systems Modeling Research Group, Institute of Fundamental Studies, Kandy, Sri Lanka.*

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Abstract

Chunnakam aquifer is the main limestone aquifer of Jaffna Peninsula. The population of the Jaffna Peninsula depends entirely on groundwater resources to meet all of their water requirements. Thus for protecting groundwater quality in Chunnakam aquifer, data on spatial and temporal distribution are important. Geostatistics methods are one of the most advanced techniques for interpolation of groundwater quality. In this study, Ordinary Kriging and IDW methods were used for predicting spatial distribution of some groundwater characteristics such as: Electrical Conductivity (EC), pH, nitrate as nitrogen, chloride, calcium, carbonate, bicarbonate, sulfate and sodium concentration. Forty four wells were selected to represent the entire Chunnakam aquifer during January, March, April, July and October 2011 to represent wet and dry season within a year.After normalization of data, variogram was computed. Suitable model for fitness on experimental variogram was selected based on less Root Mean Square Error (RMSE) value. Then the best method for interpolation was selected, using cross validation and RMSE. Results showed that for all groundwater quality, Ordinary Kriging performed better than IDW method to simulate groundwater quality. Finally, using Ordinary Kriging method, maps of groundwater quality were prepared for studied groundwater quality in Chunnakam aquifer. The result of Ordinary Kriging interpolation showed that higher EC, chloride, sulphate and sodium concentrations are clearly shown to be more common closer to the coast, and decreasing inland due to intrusion of seawater into the Chunnakam aquifer. Also higher $NO_3^- - N$ are observed in intensified agricultural areas of Chunnakam aquifer in Jaffna Peninsula.

Keywords: Chunnakam aquifer, groundwater quality, geostatistics, interpolation, IDW, Ordinary Kriging.

1 Introduction

The usage of groundwater has gradually increased due to the increase of water demand during the growth of population and rapid industrialization. Groundwater can become contaminated from numerous types of human activities such as agricultural, residential, municipal, commercial and industrial usage (Nas, 2009).The Jaffna Peninsula lies in the Northern most part of Sri Lanka. The Jaffna Peninsula has four main types of aquifer

Corresponding author: Prof. Thushyanthy Mikunthan, Department of Agricultural Engineering, Faculty of Agriculture, University of Jaffna, Sri Lanka. e-mail: dr.thushyanthym@gmail.com

system such as Chunnakam, Thenmaradchi, Vadamaradchi and Kayts (Punthakey and Nimal, 2006). The water resources of the Valigamam region (Chunnakam aquifer) of the Jaffna Peninsula depend totally on rainfall recharge to the Miocene limestone aquifer (Rajasooriyar *et al*., 2002). Fertilizer and pesticide residues leached from agricultural fields often contribute significantly to groundwater pollution in Jaffna Peninsula. Pollution of groundwater by nitrate as nitrogen has been receiving attention in the Peninsula since early 1980s (Maheswaran and Mahalingam, 1983; Dissanayake and Weerasooriya, 1985; Nagarajah *et al*., 1988; Maheswaran, 2003; Mikunthan and Silva, 2008). Determination of water quality is important because of it helps to protect, restore the quality of the groundwater, and management of groundwater that consistent with the requirements of the clean water.

Geographic Information System (GIS) produced graphical image will provide for user an easier visual inspection of the water quality conditions. Geostatistical method is one of the tools for mapping of groundwater quality. The most common interpolation techniques calculate the estimates for a property at any given location by a weighted average of nearby data. Weighting is assigned either according to deterministic or geostatistical criteria. Among geostatistical methods, kriging based techniques, including simple and Ordinary Kriging (OK), universal kriging and simple cokriging have been often used for spatial analysis (Deutsch, 2002). Among deterministic interpolation methods, Inverse Distance Weighting (IDW) method and its modifications are often applied (Nalder and Wein, 1998). Kriging and IDW are the most commonly used methods in agriculture practices (Franzen and Peck, 1995). Kriging is a method of interpolation, which predicts unknown values from data observed at known locations, and it minimizes the error of predicted values, which are estimated by spatial distribution of the predicted values (Huang *et al*., 2012). Kriging requires the preliminary modeling step of a variance-distance relationship, but IDW does not require such step and is very simple and quick technique for interpolation (Jafar *et al*., 2009).

In recent years, many scientists have evaluated accuracy of different spatial interpolation methods for prediction of soil and water quality parameters. Fahid *et al*. (2011) performed IDW, Kriging, Spline techniques for predicting chloride concentration and groundwater level in Gaza Strip, which showed that Kriging method, provide results that are more accurate. Abdolrahim *et al*. (2011) said that for the estimation of SAR and chloride of groundwater in Iran, the Cokriging method was more accurate than Kriging method. Jafar *et al*. (2009) studied to determine degree of spatial variability of soil chemical properties with Ordinary Kriging and IDW methods, which showed that the Ordinary Kriging performed much better than the IDW in Fars province, Iran. The Ordinary Kriging method was used to produce the spatial patterns of important water quality in Turkey by Nas (2009). The effect of interpolation methods on the accuracy of the GIS mapping was also recognized by Mehrjardi *et al.,* 2008. They compared the efficiency of three interpolation techniques such as IDW, Kriging and Cokriging for predicting some groundwater quality indices in Azarbayjan Province, Iran. The results showed that Cokriging performed better than the other methods. Also Mehrjardi *et al.* (2008) compared above three interpolation techniques for predicting some other groundwater quality characters in Yazd-Ardakan Plain. Results showed that Kriging and Cokriging methods are superior to IDW method.

Therefore, the present study was carried out to select best-suited method to evaluate accuracy of different interpolation methods, Ordinary Kriging and IDW, for prediction of some groundwater quality parameters of Chunnakam aquifer in Jaffna Peninsula.

2 Materials and methods

2.1 Description of the studied area

Valikamam area, which is covered by Chunnakam aquifer, is an intensified agricultural and high population density area in Jaffna Peninsula. The major rainy season in the Peninsula occurs from October to December and the minor rainy season occurs from April and May. The period between South-West monsoon and the North-East monsoon is the dry season and extends from June to September. The major soils are the calcic red-yellow latosols which are shallow, fine textured and well-drained with very rapid infiltration rate (De Alwis and Panabokke, 1972). Agriculture is the main source of livelihood for 65 % of the population and about 34.2 % of the land is cultivated intensively and commercially with high value cash crops (Thadchagini and Thirudchelvam, 2005).

2.2 Selection of wells

Forty four wells were selected for long term water quality monitoring in a systematic manner to represent the entire Chunnakam aquifer. All selected wells are under multiple usages such as domestic wells, wells with domestic and home gardening, public wells for drinking purpose, and farm wells. ***Figure 1*** shows the locations of the wells selected for monitoring in Chunnakam aquifer of the Valikamam area in Jaffna Peninsula.

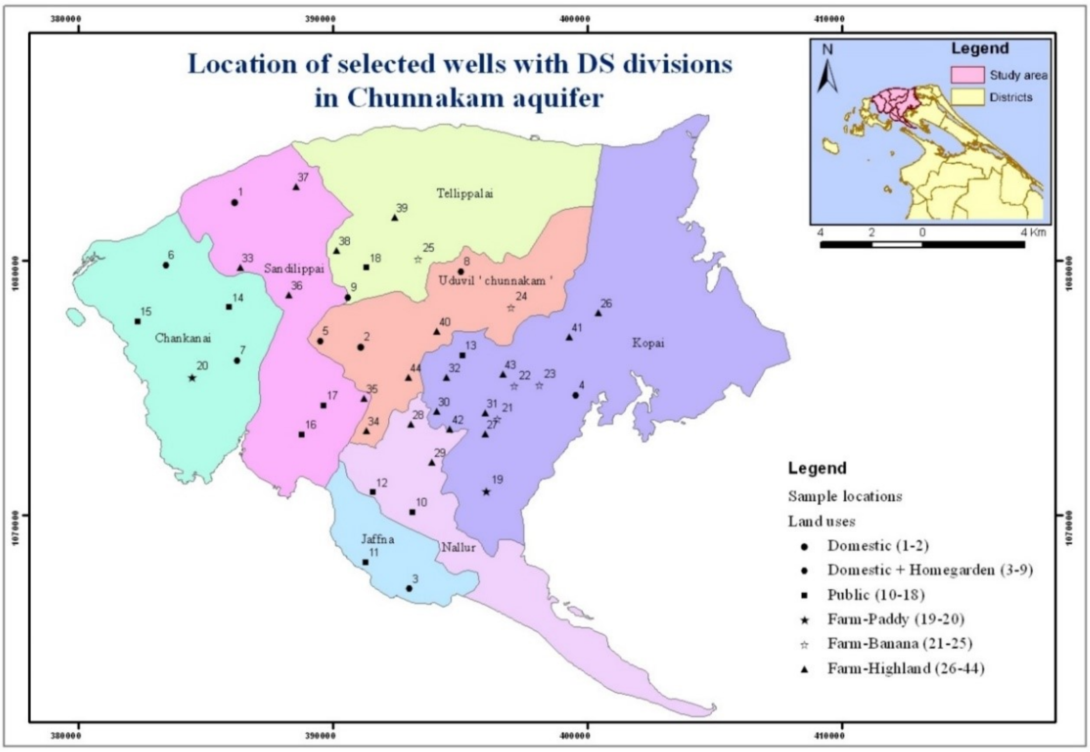

Figure 1: *Location of selected wells with different land usage in Chunnakam aquifer*

2.3 Collection of water sample and analytical techniques

Water samples were collected for chemical analysis five times during mid of January, early part of March, mid of April, mid of July and mid of October 2011 to represent various rainfall regimes within a year. Samples were analyzed for Electrical Conductivity (EC), pH, nitrate as nitrogen, chloride, calcium, carbonate, bicarbonate, sulfate and sodium concentration. Conductivity meter and pH meter were used to measure the pH and EC respectively. Nitrate-N concentration was estimated using colorimetric spectrophotometer. Chloride concentration was measured by silver nitrate titration. Calcium content was determined by EDTA titration using Eriochrome black T as indicator. Carbonate and bicarbonate content were measured by acid-base titration. Sulfate content was estimated by turbidimetric method using turbidity meter. Sodium content was determined by using a flame photometer in Institute of Fundamental Studies (IFS), Hantana, Kandy. The procedures of the analysis were based on Sri Lankan Standard 614 (SLS, 1983).

2.4 Geostatistical approach for spatial prediction of groundwater quality

After normalization of data, for interpolation of groundwater quality, Ordinary Kriging and IDW methods were used. With the use of cross validation, the best method of interpolation was selected. The maps of groundwater quality were prepared based on Ordinary Kriging and IDW interpolation method using ArcGIS 10. Geospatial techniques; Gradient analysis and local indicators of spatial autocorrelations were used to study the groundwater quality and availability assessment for the sustainable management of groundwater in the coastal areas of Jaffna Peninsula (Gunalan *et al.*, 2018).

2.5 Spatial prediction methods

2.5.1 Ordinary Kriging

The presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) is a prerequisite to the application of geostatistics (Robinson and Metternicht, 2006). Variogram is used to describe the spatial structure of variable. The variogram of samples, which is also called experimental variogram, measures the average degree of dissimilarity between un-sampled values and a nearby data value and thus can depict autocorrelation at various distances. The value of the experimental variogram for a separation distance of h (referred to as the lag) is half the average squared difference between the value at $z(x_i)$ and the value at $z(x_i+h)$ (Robinson and Metternicht, 2006):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2 \quad \text{.....(1)}$$

where N(h) is the number of data pairs within a given class of distance and direction. If the values at $z(x_i)$ and $z(x_i + h)$ are auto correlated the result of ***Equation (1)*** will be small, relative to an uncorrelated pair of points. From analysis of the experimental variogram, a suitable model (circular, spherical, exponential and guassian) is then fitted, usually by weighted least squares and the parameters (nugget, sill and range) are then used in the Ordinary Kriging procedure.

2.5.2 Inverse Distance Weighting (IDW)

In interpolation with IDW method, a weight is attributed to the point to be measured. The amount of this weight is depended to the distance of the point to another unknown point. These weights are controlled on the bases of power of ten. With increase of power of ten, the effect of the points that are farther diminishes. Lesser power distributes the weights more uniformly between neighbouring points. In IDW, the distance between the points count, so the points of equal distance have equal weights (Burrough and McDonnell, 1998). In this method, the weight factor is calculated with the use of the following formula ***Equation (2)***:

$$\lambda_i = \frac{D_i^{-\alpha}}{\sum_{i=1}^{n} D_i^{-\alpha}} \quad \text{(2)}$$

where λi = the weight of point,
Di = the distance between point i and the unknown point,
a = the power ten of weight

2.6 Comparison between the different methods:

Finally, criterion of Root Mean Square Error (RMSE) is used to evaluate model performances in cross validation mode. The smallest RMSE indicate the most accurate predictions. The RMSE was derived according to ***Equation (3)***.

$$\text{RMSE}=\sqrt{1/N \sum_{i=1}^{N}(Z(x_i) - Z^*(x_i)^2} \quad (3)$$

$Z(x_i)$ is observed value at point xi, $Z^*(x_i)$ is predicted value at point xi, N is number of samples.

3 Result and discussion

A statistical summary of the groundwater quality properties is presented in ***Table 1***. The EC of the water samples is an indicator of their salinity. The values of EC ranged from 556 to 4701µS/cm, with a mean of 1534.31 µS/cm. This behavioural response was used to determine the nature of salinity in studied area. The results revealed that pH ranged from 7.12 to 8.25. All groundwater samples were found to be below the desirable level of Sri Lankan Standard (SLS) for drinking water of pH (7 – 8.5), with a mean of 7.52 and slight alkalinity in nature. The nitrate as N concentration was ranged from 0.28 to 13.86 mg/L. The chloride concentrations of water samples were between 153.86 mg/L to 1145.95 mg/L and mean value is 327.39 mg/L. All values of measured wells were below the permissible level of SLS (1200 mg/L) for drinking. Based on the chloride concentrations all the wells were suited for drinking. The concentration of calcium values of selected wells varied from 58.90 mg/L to 203.06 mg/L and all measured wells were below the permissible level of SLS which is 240 mg/L for drinking water. The concentration (mg/L) of other ions varied as CO_3^{2-} from 11.73 to 61.37; HCO_3^- 158.45 to 545.75; SO_4^{2-} 35.16 to 499.46 and Na^+ 17.71 to 763.20.Results showed that the majority of studied parameters had high skewness, due to insufficient number of samples and unsuitable distribution. However, data were normalized using logarithmic method ***(Table 1).***

Table 1: *Results of statistical analysis on groundwater quality*

Groundwater quality	Minimum	Maximum	Mean	Std. dev.	Kurtosis	Skewness
EC	556	4701	1534.3	1045.7	5.4416	1.8551
EC**	6.32	8.45	7.17	0.53	3.268	0.9435
pH	7.198	8.25	7.52	0.173	8.326	1.5798
pH**	1.973	2.111	2.018	0.022	7.622	1.422
$NO_3^- - N$	0.28	13.86	4.86	3.99	2.507	0.805
$NO_3^- - N$**	-1.273	2.629	1.139	1.0782	2.4067	-0.586
Cl^-	153.86	1145.9	327.39	246.21	6.8104	2.2182
Cl^-**	5.036	7.044	5.62	0.527	4.181	1.4076
Ca^{2+}	58.9	203.06	95.46	35.72	5.33	1.6891
Ca^{2+}**	4.07	5.31	4.504	0.317	3.478	0.9954
CO_3^{2-}	11.73	61.366	28.18	9.5122	4.656	0.7781
CO_3^{2-}**	2.4623	4.1169	3.28	0.3461	2.867	-0.31126
HCO_3^-	158.45	545.75	258.68	90.97	4.555	1.4609
HCO_3^-**	5.065	6.3022	5.5055	0.3073	3.028	0.8655
SO_4^{2-}	35.161	499.46	150.99	106.71	4.506	1.445
SO_4^{2-}**	3.55	6.2135	4.8068	0.6477	2.4464	0.2337
Na^+	17.708	763.2	149.32	171.96	6.8354	2.1071
Na^+**	2.874	6.6375	4.544	0.9234	2.6243	0.5531

Except pH and EC (µS/cm), the others parameters are expressed in mg/L.
**Using logarithm to normalize data

After data normalizing, experimental variogram was computed. In this study, the variogram models (circular, spherical, exponential and guassian) were tested for each parameter in groundwater quality. Prediction performances were assessed by cross validation, which examines the accuracy of the generated surfaces. The best model for fitting on experimental variogram was selected based on less RMSE value (***Table 2***).Circular and exponential model are selected for EC and Ca^{2+} respectively. Spherical model is selected for $NO_3^- - N$, SO_4^{2-} and Na^+. Guassian model is selected for pH, Cl^-, CO_3^{2-} and HCO_3^- in geostatistic analysis.

Table 2: *Selection of the most suitable model for evaluation on experimental variogram according to RMSE*

Groundwater quality	Models			
	Circular	**Spherical**	**Exponential**	**Guassian**
EC	**782.6545**	783.0075	792.9405	784.9210
pH	0.1760	0.1763	0.1803	**0.1751**
$NO_3^- - N$	3.4702	**3.4488**	3.4672	3.4812
Cl^-	157.5719	157.5118	160.1213	**156.7297**
Ca^{2+}	31.6084	31.6577	**31.5644**	31.7122
CO_3^{2-}	8.5052	8.5046	8.5031	**8.5000**
HCO_3^-	73.6457	73.6817	74.2180	**73.5617**
SO_4^{2-}	88.2393	**88.2262**	90.2392	88.6274
Na^+	120.6330	**120.5626**	121.2188	122.2146

Table 3: *Best fitted variogram models of groundwater quality and their parameters*

Groundwater quality	Model	Nugget (C_o)	Sill (C_o+C)	Range effect (km)	(C_o/C_o+C) %
EC	Circular	0.01871	0.22860	5.21	8
pH	Guassian	0.00025	0.00033	4.58	76
$NO_3^- - N$	Spherical	0.25110	0.51510	2.26	49
Cl^-	Guassian	0.04838	0.21480	6.76	23
Ca^{2+}	Exponential	0.00000	0.09550	4.72	0
CO_3^{2-}	Guassian	0.00560	0.11110	5.06	5
HCO_3^-	Guassian	0.02031	0.07660	6.81	27
SO_4^{2-}	Spherical	0.02254	0.41070	5.25	5
Na^+	Spherical	0.10320	0.78260	7.24	13

Also, ***Table 3*** illustrates parameters of groundwater quality variograms. The ratio of nugget variance to sill expressed in percentages can be regarded as a criterion for classifying the spatial dependence of groundwater quality parameters. If this ratio is less than 25%, then the variable has strong spatial dependence; if the ratio is between 25 and 75%, the variable has moderate spatial dependence; and greater than 75%, the variables shows only weak spatial dependence (Jiachun *et al.*, 2007).Some parameters of groundwater quality such as EC, Cl^-, Ca^{2+}, CO_3^{2-}, SO_4^{2-}, and Na^+ have strong spatial dependence due to the effect of natural factors including sea water intrusion and water-soil/rock interaction. NO_3^- as N and HCO_3^-in groundwater quality have moderate spatial dependence, indicating an involvement of human factors and pH has weak spatial dependence. Also effective range of most parameters is close together with the range of 2.26 km to 7.24 km.

Table 4: *Selecting the best power according to RMSE in IDW method*

Groundwater quality	Power		
	1	2	3
EC	933.2	853.0	**783.9**
pH	0.180	0.179	**0.178**
$NO_3^- - N$	3.560	**3.505**	3.553
Cl^-	207.3	183.1	**162.2**
Ca^{2+}	33.110	31.898	**31.569**
CO_3^{2-}	**8.97**	9.21	9.64
HCO_3^-	80.40	76.70	**74.10**
SO_4^{2-}	101.80	96.80	**92.55**
Na^+	147.40	133.18	**119.96**

IDW predictions were performed varying the number of power (from 1-3). The results, in terms of RMSE, obtained from the cross validation procedures are presented in ***Table 4***. The RMSE are generally lower for IDW with power of 3 in comparison to that of other powers for most of the groundwater quality parameters such as EC, pH, Cl^-, Ca^{2+}, HCO_3^-, SO_4^{2-} and Na^+. Power 1 and 2 are fitted for CO_3^{2-} and $NO_3^- - N$ respectively.

RMSE, for determination of the most suitable method, among Ordinary Kriging and IDW, was used. Based on ***Table 5***, Ordinary Kriging method increased prediction accuracy and had less RMSE for all studied parameters in Chunnakam aquifer. Results showed that Ordinary Kriging method is best GIS interpolation method for predicting all studied parameters of Chunnakam aquifer in Jaffna Peninsula. Karami *et al.*, 2018 showed that assessment of groundwater resources through the ordinary kriging is an appropriate method for estimating the values and producing reliable data and increasing the accuracy of assessment. Also study showed that geostatistics is a powerful tool to determine subsurface heterogeneity for hydrogeological applications in a wide range of complex geological environment by applying geostatistics tool to a real aquifer.

Table 5: *Selecting the best interpolation method according to RMSE*

Groundwater quality	IDW	Ordinary Kriging
EC	783.9	**782.7**
pH	0.178	**0.175**
$NO_3^- - N$	3.505	**3.449**
Cl^-	162.2	**156.7**
Ca^{2+}	31.569	**31.564**
CO_3^{2-}	8.97	**8.50**
HCO_3^-	74.10	**73.56**
SO_4^{2-}	92.55	**88.23**
Na^+	119.96	**119.56**

Finally, maps of groundwater quality were prepared using Ordinary Kriging which was the best method for interpolation in Chunnakam aquifer. ***Figure 2- 10*** shows the spatial distribution of studied groundwater quality parameters using Ordinary Kriging and IDW in Chunnakam aquifer. Based on these figures, Ordinary Kriging avoids the “bulls eye” effect. The spatial distribution of EC in Chunnakam aquifer is shown in ***Figure 2.*** Higher EC was clearly shown to be more common closer to the coast, and decreasing inland of Chunnakam aquifer in Jaffna Peninsula. The above results are in agreement with the spatial distribution of chloride, sodium and sulphate (***Figure 3, 4*** and ***5*** respectively). The concentration of Na^+, Cl^- and SO_4^{2-} in seawater is much greater than in continental water. This distribution pattern can be ascribed to the intrusion of seawater into the aquifer system which increases the concentrations of these ions and hence values of the dissolved solids. The trend of EC generally reflects the chloride concentration available in groundwater and enriched by the discharge ions of sodium, calcium and magnesium (Jothivenkatachalam *et al*., 2011).

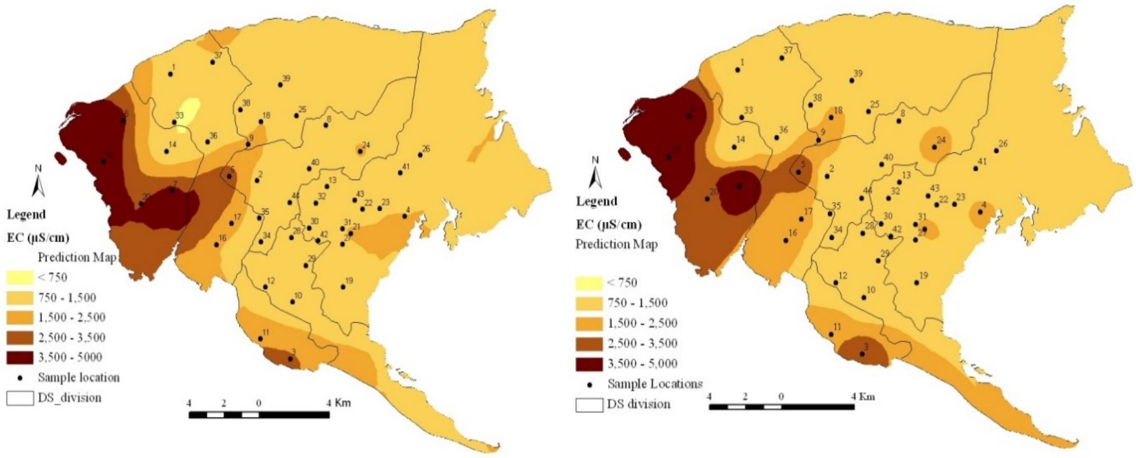

Figure 2 : *Spatial distribution of EC based on (a) Ordinary Kriging and (b) IDW methods*

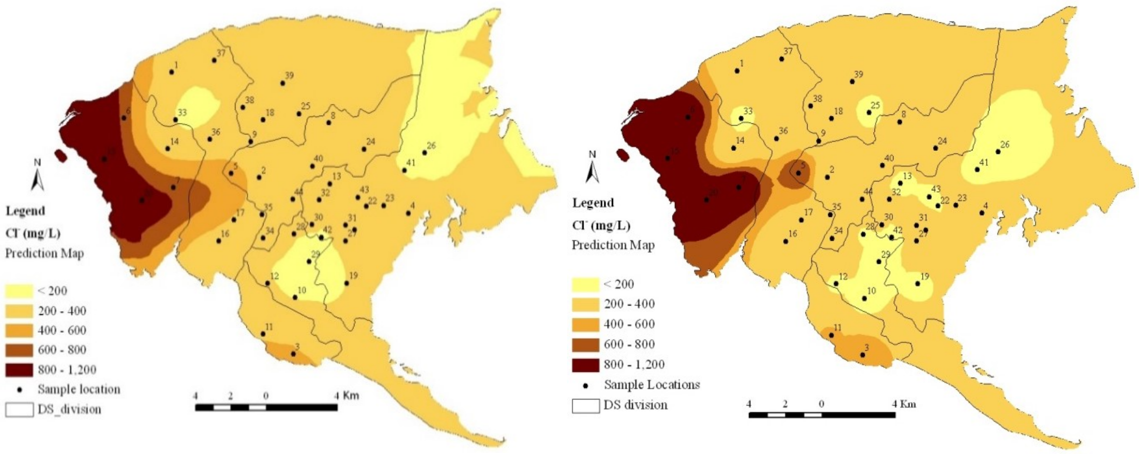

Figure 3: *Spatial distribution of Cl^{-} based on (a) Ordinary Kriging and (b) IDW methods*

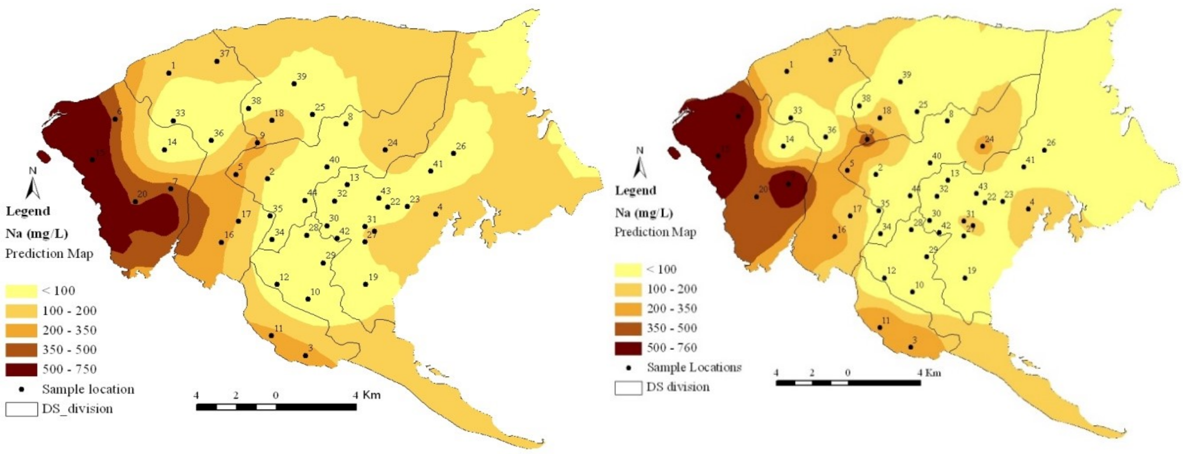

Figure 4: *Spatial distribution of Na based on (a) Ordinary Kriging and (b) IDW methods*

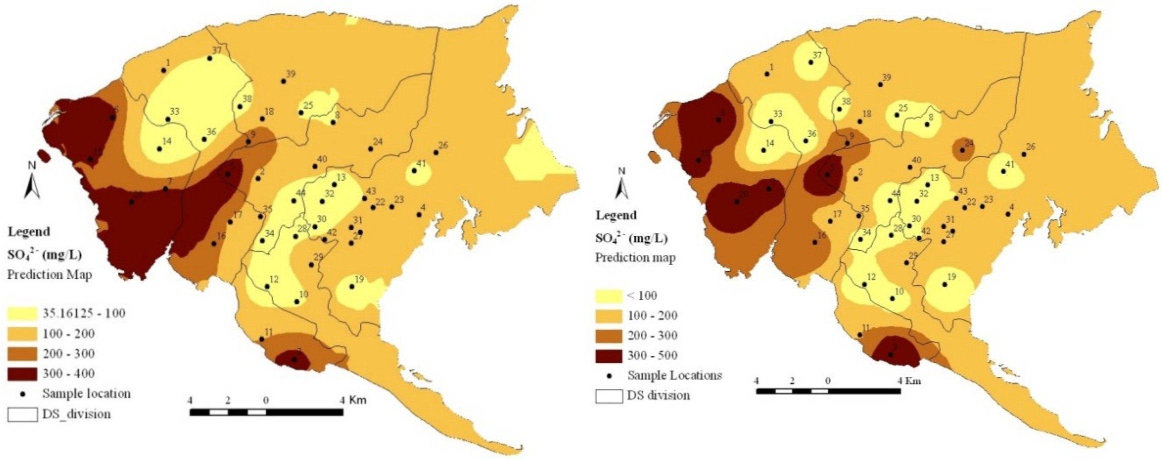

Figure 5: *Spatial distribution of* $\mathbf{SO_4^{2-}}$ *based on (a) Ordinary Kriging and (b) IDW methods*

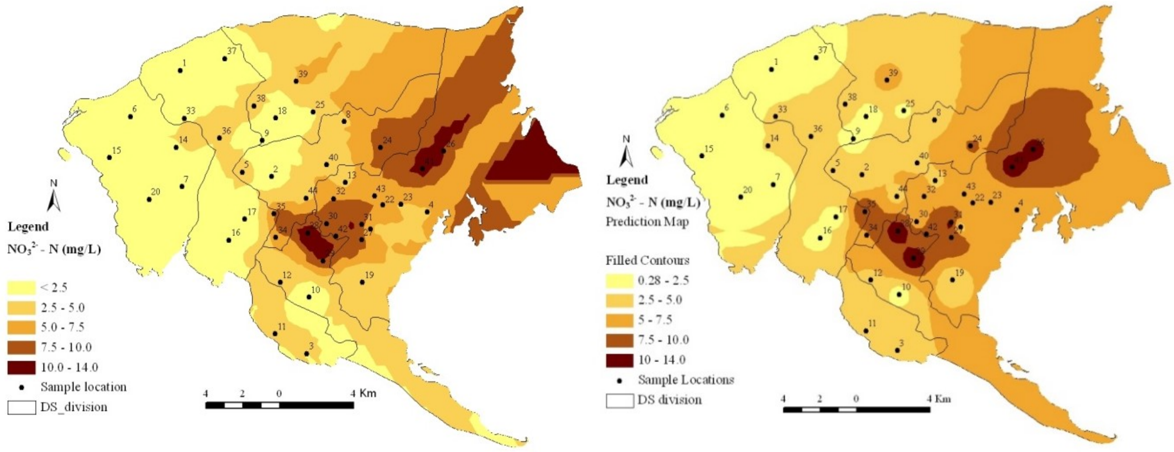

Figure 6: *Spatial distribution of* $\boldsymbol{NO_3^{-} - N}$ *based on (a) Ordinary Kriging and (b) IDW methods*

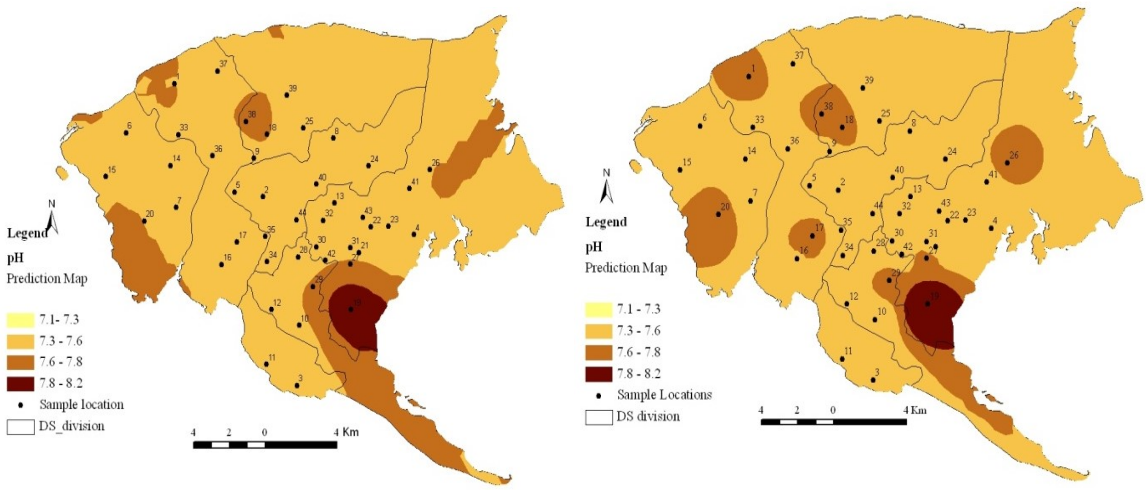

Figure 7: *Spatial distribution of pH based on (a) Ordinary Kriging and (b) IDW methods*

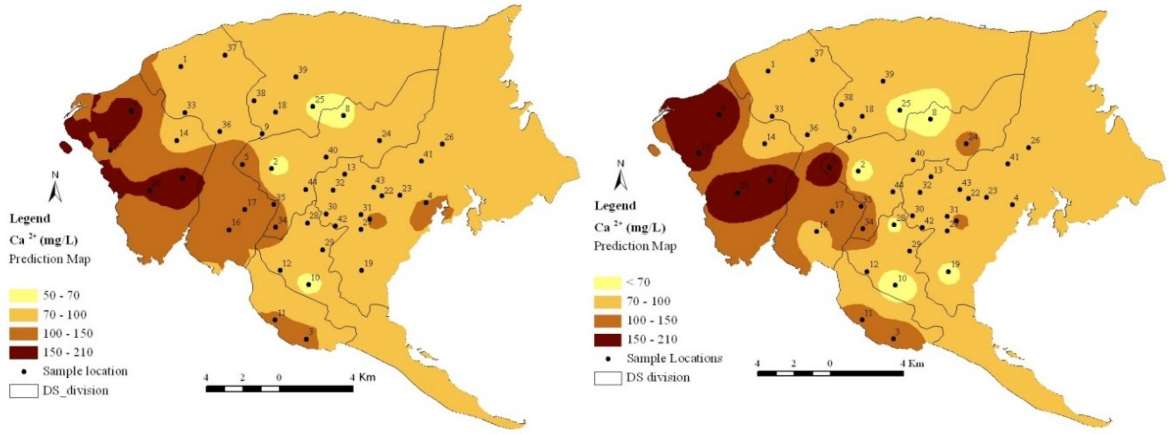

Figure 8: *Spatial distribution of Ca^{2+} based on (a) Ordinary Kriging and (b) IDW methods*

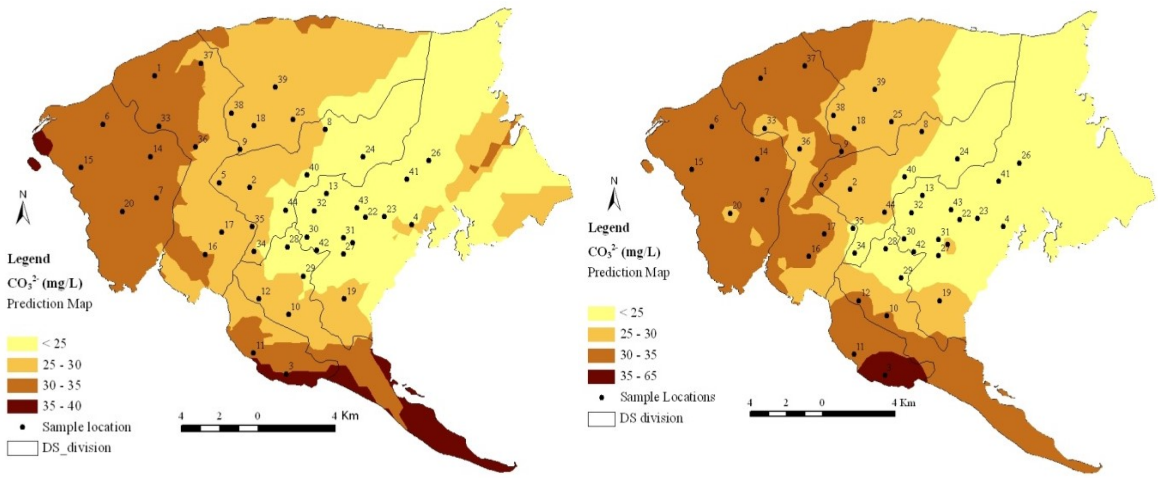

***Figure 9**:* *Spatial distribution of CO_3^{2-} based on (a) Ordinary Kriging and (b) IDW methods*

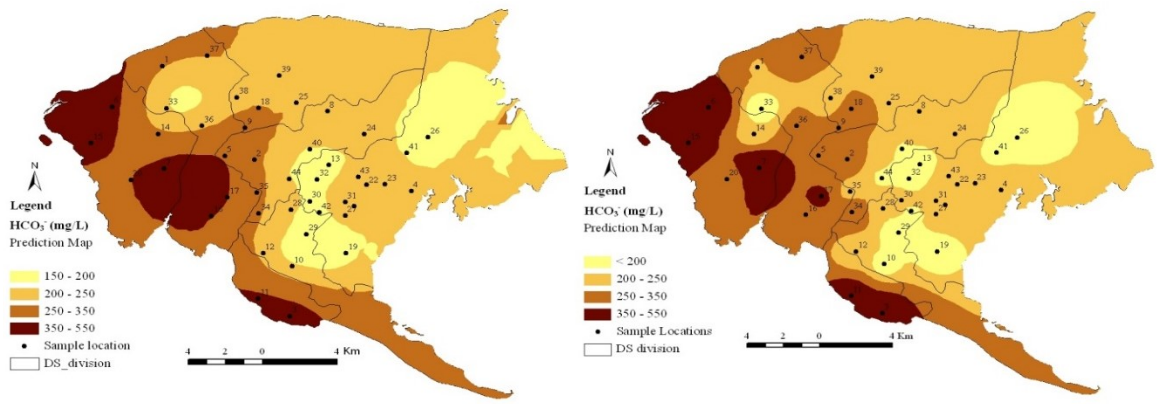

Figure 10: *Spatial distribution of HCO_3^{-} based on (a) Ordinary Kriging and (b) IDW methods*

Based on NO_3^- as N, intensified agricultural areas of Chunnakam aquifer have above permissible level of SLS for drinking which is showed in *Figure 6*. Gunasegaram (1983) studied extensively groundwater contamination in the Jaffna Peninsula and found that the nitrate levels exceeded standard limits, which is due to the mixing up of abundant nitrogenous waste matter and synthetic and animal fertilizers reaching the shallow groundwater table. Dissanayake and Weerasooriya (1985) pointed out in hydro geochemical atlas of Sri Lanka that Jaffna Peninsula has the highest nitrate content among the groundwater of Sri Lanka.

Salinity development and high concentrations of nitrate–N were the identified problems in Chunnakam aquifer of Jaffna Peninsula.

4 Conclusion

This study has attempted to predict the spatial distribution and uncertainty of some groundwater quality in Chunnakam aquifer, Jaffna Peninsula, using two interpolation techniques (Ordinary Kriging and IDW).The majority of studied parameters had high skewness. The analysis showed that for all groundwater quality Ordinary Kriging performed better than IDW techniques in characterizing the spatial variability.The result of Ordinary Kriging interpolation showed that development of salinity is clearly shown to be more common closer to the coast, and decreasing inland and higher $NO_3^- - N$ also is observed in intensified agricultural areas of Chunnakam aquifer in Jaffna Peninsula. It is suggested that in the future studies, other methods especially indicator and disjunctive kriging is used in order to prepare risk maps of Chunnakam aquifer.

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