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Geostatistical analysis of spatial and seasonal variation of groundwater level: A comprehensive study in *Malwathu Oya* cascade-I, Anuradhapura, Sri Lanka

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Abstract

Groundwater is one of the major sources of fresh water to meet the domestic, irrigation and industrial water demands. Because of its easy accessibility and assurance of water during dry periods, farmers tends to exploit more groundwater basically for irrigation purposed without assessing the hydro-geological properties, spacing, safe yield and recharge potential. Though management programs often give less importance to groundwater because it is less visible than surface water, management of groundwater is very imperative. Mapping of groundwater level can be used as the initial step of management of this valuable natural resource. Even though geostatistical analyst tool in Arc GIS has become more popular among the methods used to create the interpolation surfaces, it is required to find out the method which gives the best results. In this study geostatistical analyst tool was used to compare the accuracy of different interpolation methods to interpolate groundwater level in Malwathu Oya cascade-I in Anuradhapura district using Arc GIS 10.2. The total area of the cascade was divided in to 1 Km^2 grids and forty wells were purposely selected as two wells per grid to assess the groundwater level in dry and wet seasons. Groundwater level was measured with reference to both mean sea level (MSL) and land surface datum. Inverse Distance Weighted (IDW), Radial Basis Function (RBF) which are deterministic interpolation methods and Kriging and Empirical Bayesian Kriging (EBK) which are geostatistical interpolation methods with different parameters were used for this study. Groundwater level in dry and wet seasons with reference to MSL and land surface datum was interpolated using different interpolation methods. Results revealed that EBK with power semivariogram recorded the lowest root mean square error (RMSE) for interpolating groundwater level in both dry and wet season with reference to MSL as well as for interpolating groundwater level in wet season with reference to land surface datum. Lowest RMSE value for mapping groundwater level in dry season with reference to land surface datum was given by Simple and Universal Kriging methods. Therefore, it can be concluded that EBK has better accuracy in most of the cases of mapping groundwater level in Malwathu Oya cascade- I.

Keywords: Geostatistical analyst, GIS, Groundwater level, Interpolation.

Introduction

Our planet often called as “Blue planet”, warning of increasing fresh water scarcity is common in the world. However, groundwater has become one of the major sources of fresh water and one third of world’s total population depends on groundwater for their needs[1]. Due to cheap and easy to access source of irrigation and it is available when they need, farmers use more and more groundwater to increase their income[2]. Groundwater potential in the dry zone area is limited due to low storage and transmissivity of the underlying crystalline hard rock formations[3]. Therefore, agro-wells act as short term storage reservoirs as well as groundwater abstraction points[2]. However, the development of agro-wells has been taken place in an unorganized manner without proper assessment of the hydro-geological properties, spacing of agro-wells, safe yield and recharge potential[3]. As a result of that the declination of groundwater level creates adverse effects on water pollution, groundwater contamination and imbalance of ecosystem[4,5].

Therefore, management of groundwater resources is important for its sustainable development and adequate information about spatio-temporal behavior of water table depths over a region has to consider. But the water table depth measurement are expensive and time consuming during the installation phase, spatial interpolation method has become popular to analyze such spatial characteristics of the groundwater level[6]. However, it is important to know the best interpolation method to estimate the ground water level variation of a particular area. Almedeij and Al-Ruwaih[7] studied the periodic behaviour of groundwater level fluctuations in the residential areas of Kuwait and Bui and others[5] studied on spatio-temporal trend in the red river delta basin in Vietnam using geostatistical interpolation methods. Other than that, Inverse Distance Weighting Method (IDW)[8,9], Ordinary Kriging (OK)[8,10], Universal Kriging (UK)[8,11], and Radial Basis Function (RBF)[8,9] methods were used for mapping of groundwater depth. According to Sun and others[8], Simple Kriging performed well in mapping groundwater table and

Mashaland others[12] concluded that Cokriging method gives less error for mapping groundwater table compared to Kriging and IDW.

Therefore, to select an optimal interpolation method for a given a study area, IDW, Emperical Bayesian Kriging (EBK), Simple Kriging (SK), Universal Kriging (UK), Ordinary Kriging (OK) and Radial Basis Function (RBF) methods were evaluated.

Materials and Methods

Study Area and Data Collection: *Malwathu Oya* begins from Ritigala, which connect the city of Anuradhapura to the coast of Mannar, while feeds several perennial reservoirs. Catchment area of *Malwathu Oya* is 3284 Km^2 [13,14]. In *Malwathu Oya* river basin, there are 15 of sub-watersheds and 179 numbers of cascades[15]. A highest density of small tank cascades is observed around the upper area of the *Malwathu Oya* watershed, while the density decreases in the mid and lower aspects of the main *Malwathu Oya*, which is a forth order stream[16].

Malwathu Oya cascade-I area in Anuradhapura districtwas selected for the study (Figure-1). Total land area of this cascade is 25 Km^2 and it was divided into 1 Km^2 grids and two wells from each grid were purposely selected for the study. Locations of the selected wells were taken using handheld global positioning system unit (Magellan - eXplorist 510). Availability of groundwater was assessed by measuring the depth to groundwater level from the surface and total depths of wells.

Groundwater depths of the selected wells were measured during dry and wet season in year 2015. Google earth pro was used to get the ground level profile of the study area and ground level above mean sea level of the selected wells. The groundwater level with reference to mean sea level was obtained by deducting depth to groundwater level from the ground surfacefrom MSL. Also total depth of each well was measured to calculate water column in the well.

Geostatistical Analysis: Geostatistics is a class of statistics used to analyze and predict the values associated with spatial or spatio-temporal phenomena and geostatisticsis considered as an effective tool for modeling the spatial variation of different physical parameters[17]. GIS has immerged as a powerful tool which can be used to solve environmental problems. Thereafter geostatistical analyst tool was introduced to fill the gap between GIS and geostatistics, currently it is widely used for research purposes. Geostatistical analyst tool provide different interpolation methods and for this study IDW, RBF, SK, UK, OK and EBK were used find the best method to map groundwater level. IDW and RBF can be categorized as deterministic interpolation methods based on either the extent of similarity or the degree of smoothing and SK, UK, OK and EBK can be categorized as geostatistical interpolation methods which utilize the statistical properties of the measured points[18].

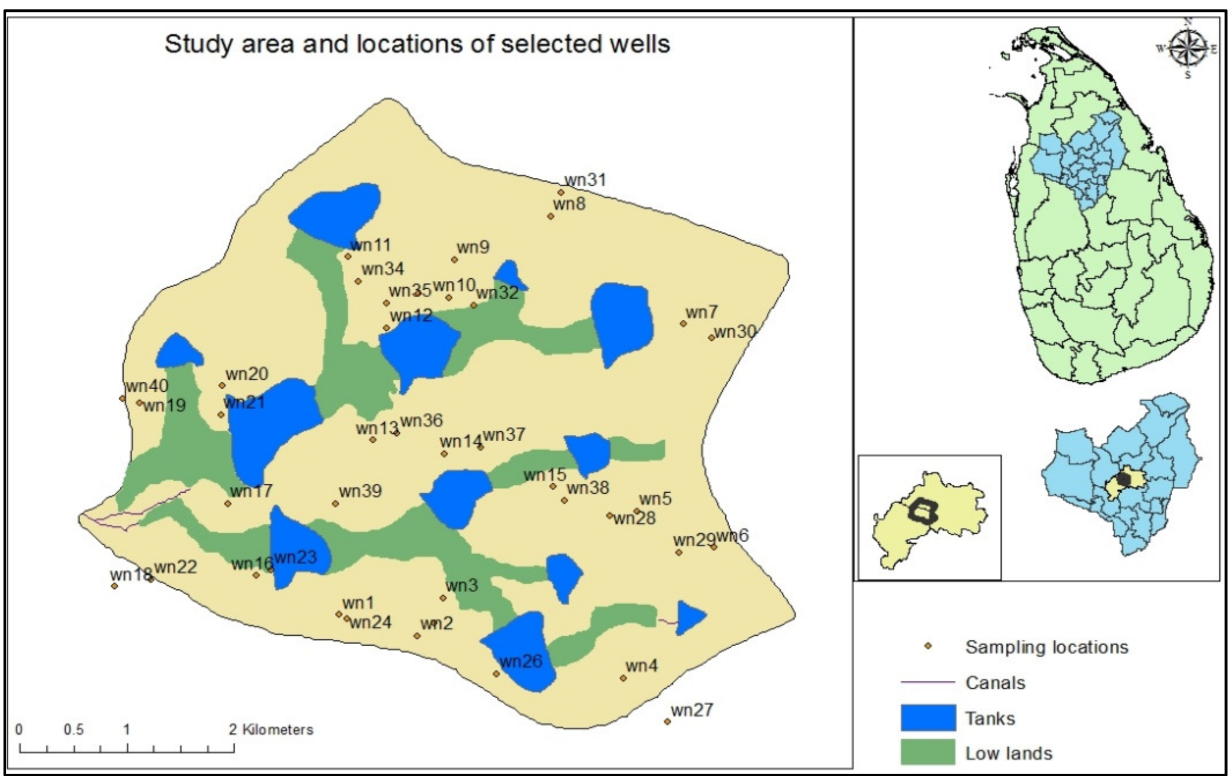

Figure-1
Study area and selected well locations

IDW uses the measured values of surrounding samples of the prediction location to predict a value for any non-sampled location, assuming things that are close to one another are more alike than those that are farther away and formula is shown below (Equation-1).

$$Zj = \frac{\sum_i \frac{Zi}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}} \quad (1)$$

Where: Zj- estimated value for the unknown point at location j, dij- distance between known point iand unknown point j, Zi- is the value at known point I, n - user-defined exponent for weighting.

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation of the surface. The Kriging tool use mathematical function to a specified number of sampling points or all points within a specified radius, to determine the output value for each location[18].

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i \, Z(S_i) \quad (2)$$

Where: $Z(s_i)$ = the measured value at the i^{th} location, λ_i = an unknown weight for the measured value at the i^{th} location, s_0 = the prediction location, N = the number of measured values.

The difference between Kriging and other interpolation methods is that Kriging uses the variance of the estimated values[19]. Theodossiou and Latinopoulos[20] used Kriging to estimate the level of groundwater in Greece. Ordinary Kriging is a widely used Kriging method[21] and EBK is a new type of Kriging method which implemented in ArcGIS 10.1[22].

RBF interpolation method includes thin plate spline, regularized and tension spline. In this method, surface is passing through the measured data points to minimize the overall curvature of the estimated surface and performs best when the surface is relatively smooth and when having large number of measured data points[23].

Comparisons of Interpolation Methods: The fitness of the interpolation method can be tested using cross validation technique. In cross validation method it removes each data location one at a time and predicts the associated data value with remaining data. Root Mean Square Error (RMSE) and correlation coefficient were used tocompare these interpolation methods.

Results and Discussion

Groundwater level with reference to MSL was varied from 89.95 m to 114.25 m during dry season with the mean and standard deviation of 101.66 m and 6.71 m respectively while, it was varied from 94.20 m to 120.25 m during wet season along with mean and standard deviation of 105.52 m and 7.19 m respectively. Groundwater level with reference to land surface datum was varied from 1.25 m to 10.00 m in the dry season with mean and standard deviation of 4.62 m and 1.88 m respectively while, it was varied from 0 m to 1.95 m in wet season along with mean and standard deviation of 0.758 m and 0.58 m respectively.

The groundwater column in the selected wells during the dry season was varied from 0.20 m to 5.95 m and during wet season it was 2.90 m to 9.70 m. According to Perera and Wijekoon[24], the agro-wells have categorized into four groundwater potential classes based on the depth of water availability at the end of the dry season. Based on that, groundwater potential of selected wells was shown in Table-1.

Table-1
Classification of groundwater potential classes

Depth of water at the end of the dry season (m)	Classification	% of wells
0.0-0.5	Low groundwater potential	05
0.5-1.0	Moderate groundwater potential	05
1.0-2.0	High groundwater potential	27
>2.0	Very high groundwater potential	63

Groundwater level with reference to MSLwas interpolated using different interpolation methods using geostatistical analyst tool and Table-2 shows the cross validation performance of prediction maps generated by those methods.

Furthermore, groundwater level with reference to land surface datum was also interpolated using above mentioned methods and the cross validation performance of prediction maps generated by those methods was shown in Table-3.

Consistent with the results of mapping groundwater level with reference to MSL, EBK with power semi variogram was given the lowest RMSE for both dry as well as wet seasonin *Malwathu Oya* cascade-I area. Mapping groundwater level with reference to land surface datumshows different results. Lowest RMSE value for mapping groundwater level in dry season was given by Simple and UniversalKriging methods at the same time in wet season lowest RMSE was given by EBK method with power semivariogram type.

Conclusion

Based on the height of groundwater in selected agro-wells at the end of dry season, 63%, 27%, 5% and 5% had very high, high, moderate and low groundwater potential respectively. EBK with power semi variogram was recorded the lowest error for interpolating groundwater level in both dry and wet season with reference to MSL as well as for interpolating groundwater level in wet season with reference to land surface datum. Lowest RMSE value for mapping groundwater level in dry season with reference to land surface datum was given by Simple and Universal Kriging methods. Therefore,it can be concluded that EBK has better accuracy in most of the cases of mapping groundwater level in *Malwathu Oya* cascade-I.

Table-2
Cross validation performances of interpolation methods (with reference to mean sea level)

			Dry season		Wet season	
			RMSE	R^2	RMSE	R^2
IDW	Power 2	Standard	2.152	0.949	1.999	0.963
		Smooth	2.135	0.949	1.994	0.962
	Power 3	Standard	2.238	0.942	2.021	0.959
		Smooth	2.247	0.942	2.029	0.959
	Power 1	Standard	2.587	0.946	2.542	0.956
		Smooth	2.433	0.944	2.431	0.952
Empirical Bayesian Kriging	Standard circular	Power	1.921	0.957	1.667	0.972
		Linear	2.015	0.953	1.744	0.969
		Thin plate spline	1.961	0.958	1.673	0.973
	Smooth circular	Power	2.026	0.952	1.723	0.970
		Linear	2.040	0.952	1.764	0.969
		Thin plate spline	2.117	0.949	1.727	0.970
Kriging/Cokriging	Standard	Simple	2.077	0.950	1.769	0.968
		Universal	2.722	0.941	2.687	0.951
		Ordinary	2.188	0.951	2.200	0.953
	Smooth	Simple	2.040	0.952	1.735	0.970
		Universal	2.477	0.926	2.305	0.948
		Ordinary	2.470	0.930	2.267	0.949
Radial Basis Function	Completely regularized Spline		2.066	0.952	1.858	0.967
	Spline with tension		2.072	0.952	1.856	0.966
	Thin Plate Spline		2.331	0.941	1.940	0.964

Table-3
Cross validation performances of interpolation methods (with reference to land surface datum)

			Dry		Wet	
			RMSE	**R^2**	**RMSE**	**R^2**
IDW	Power 2	Standard	1.963491	0.263664	0.595638	0.27794
		Smooth	1.968923	0.262038	0.597257	0.275999
	Power 3	Standard	2.117974	0.229373	0.639906	0.244967
		Smooth	2.117236	0.230286	0.640033	0.245256
	Power 1	Standard	1.798345	0.309595	0.555284	0.312536
		Smooth	1.816761	0.295376	0.557488	0.306919
Empirical Bayesian Kriging	Standard circular	Power	1.786616	0.294157	0.561296	0.261804
		Linear	1.785821	0.289924	0.56188	0.254845
		Thin plate spline	1.891539	0.181325	0.573757	0.257014
	Smooth circular	Power	1.779741	0.304141	0.551278	0.308897
		Linear	1.780835	0.298772	0.552086	0.30351
		Thin plate spline	2.036979	0.306823	0.579615	0.223091
Kriging/ Cokriging	Standard	Simple	1.778616	0.309483	0.55811	0.281175
		Universal	1.840266	0.257143	0.566189	0.228593
		Ordinary	1.853622	0.252844	0.574549	0.241579
	Smooth	Simple	1.778259	0.310814	0.552091	0.308924
		Universal	1.778259	0.310814	0.593361	-1
		Ordinary	2.036979	0.306823	0.601743	0.246395
Radial Basis Function	Completely regularized Spline		1.838555	0.28002	0.567511	0.296311
	Spline with tension		1.821195	0.287002	0.563299	0.30226
	Thin Plate Spline		2.526214	0.115482	0.837351	0.0472

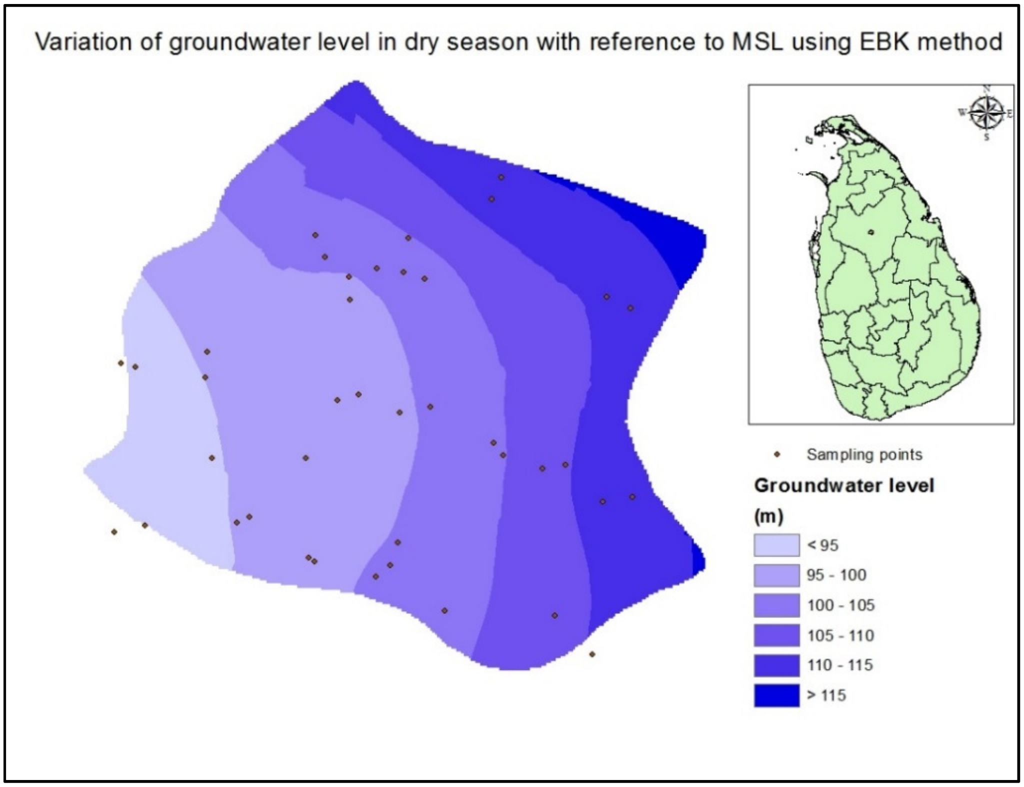

Figure-2
Variation of groundwater level in dry season with reference to MSL using EBK method

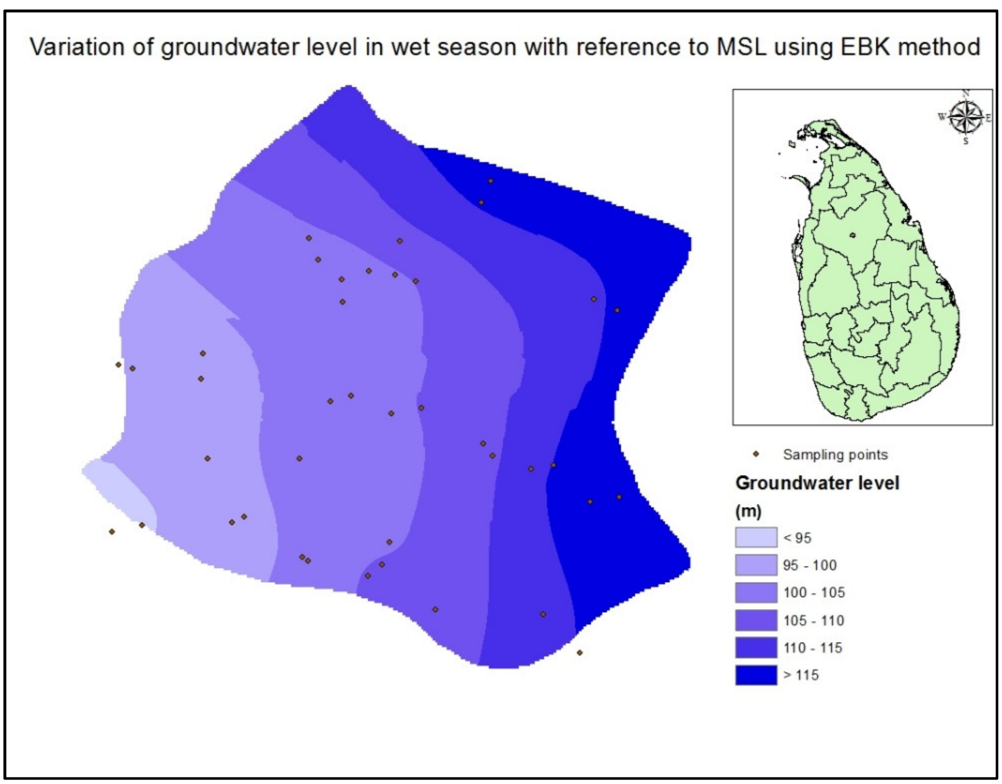

Figure-3
Variation of groundwater level in wet season with reference to MSL using EBK method

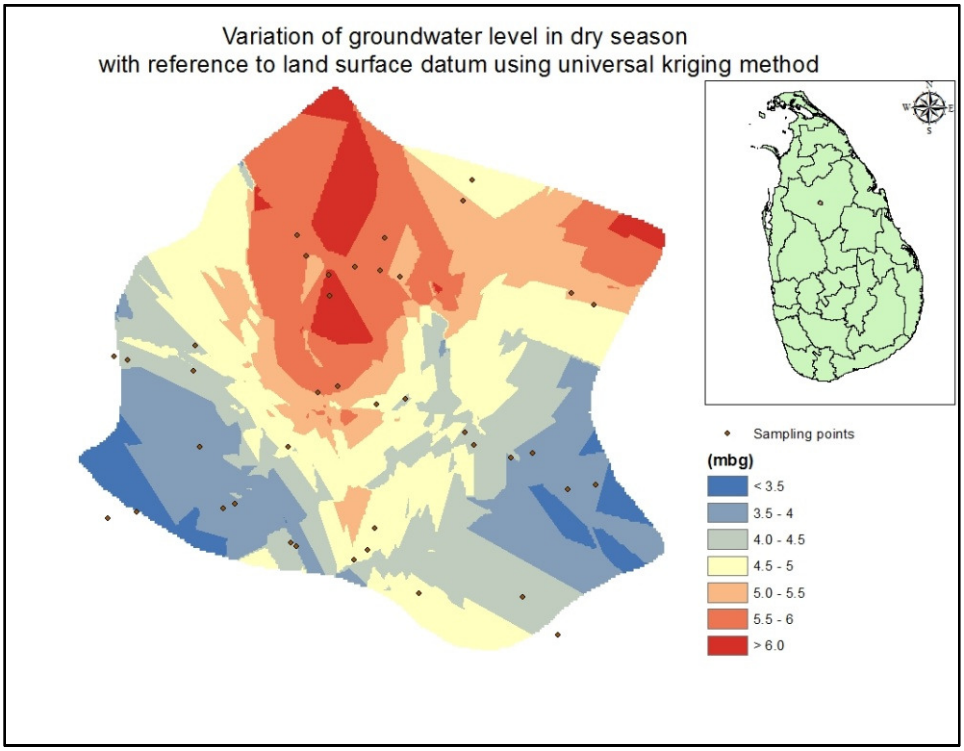

Figure-4
Variation of groundwater level in dry season with reference to land surface datum using universal kriging method (mbg; meters below ground)

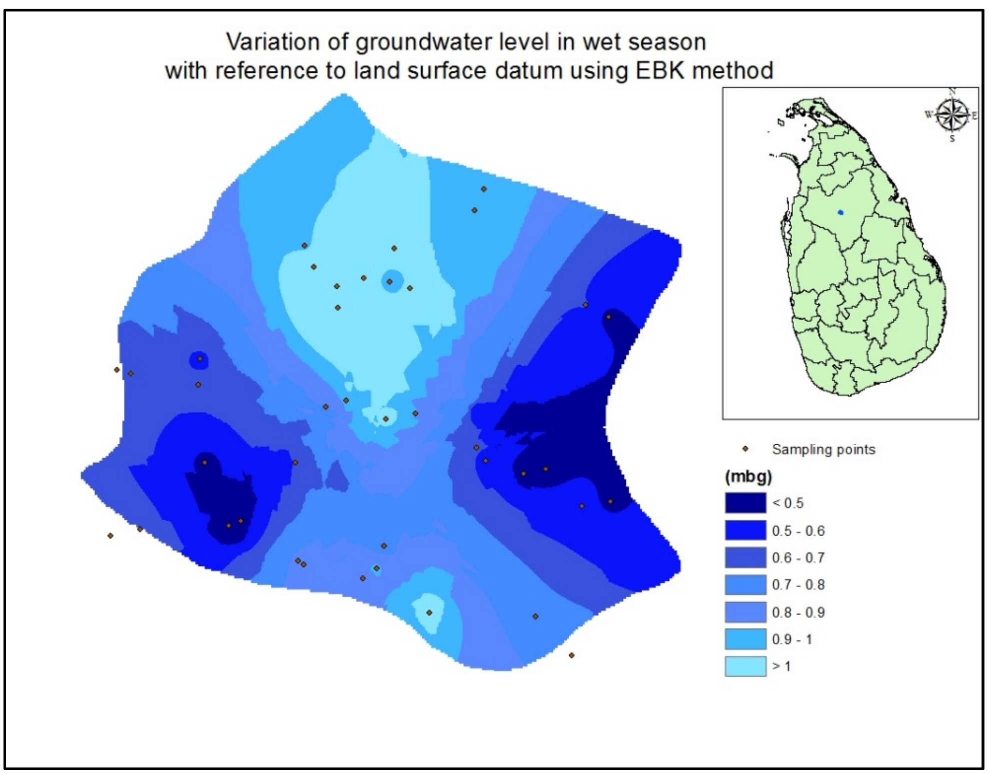

Figure-5
Variation of groundwater level in wet season with reference to land surface datum using EBK method (mbg; meters below ground)

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