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Water-table Control Using Ordinary Kriging in the Southern Part of Cameroon

[1]Jorelle Larissa Meli'i, [2]Dieudonné Bisso, [1]Philippe Nouck Njandjock,
[3]Théophile Ndougsa Mbarga, [4]Alain François Banga and [5]Eliézer Manguelle-Dicoum
[1]Department of Physics,
[2]Department of Earth Sciences, Faculty of Science, University of Yaounde I, Cameroon
[3]Department of Physics, Advanced Teachers Training College, University of Yaounde I, Cameroon
[4]Institute for Geology and Mining Research, Cameroon
[5]Cameroon Academy of Science, Cameroon

Abstract: In this study, application of the kriging technique for the spatial analysis of groundwater levels is shown. The data set consists of measured elevations of the water table at about 70 points during the last five years (2009-2012) in Sangmelima region (South-Cameroon). From these measurements, an experimental variogram was constructed to characterize the spatial variability of water level. Pentaspherical, spherical, exponential, power, linear and gaussian variogram models were fitted to the experimental variogram. The model having the least error 1.77 and 0.001 according to the cross validation criteria was selected by comparing the observed water-table values with the values predicted by empirical variograms. It was determined that, linear model is the best fitted model for the studied area and can be used as tool to conduct desertification control process in this equatorial zone.

Key words: Water-table, geostatistics, groundwater levels, semivariogram, kriging, Cameroon

INTRODUCTION

Many researches have worked on development of water table (Dingman, 2002; Maurer *et al*., 2002; Wolock, 2003: Fan *et al*., 2007). Management of this concept is very important to meet the increasing demand of water for domestic, agricultural and industrial use. Various management measures as discharge and industrial implementation zones, require the spatial behaviour of water-table. According to Isaaks and Srivastava (1989) and Kumar and Ramadevi (2006), Kriging is an optimal and unbiased spatial method used to evaluate regionalized variables at unsampled locations using an initial data set values and various variogram models such as: pentaspherical, spherical, exponential, gaussian, power, linear, etc. As the selected model influences the prediction of the unknown values, this study is an attempt to determine which theoretical variogram, can give acceptable results to predict the water-table values based on the water-table observations for the last three years in Sangmelima (South-Cameroon) region.

MATERIALS AND METHODS

Description of the study area: The Sangmelima city area is located from longitudes 11°57' to 12°01' and latitudes 2°54' to 2°58' in the southern region of Cameroon, on the northern part of the Congo craton (Fig. 1-3).

The study area has equatorial humid climate characteristics. Annual average minimum and maximum temperatures are 28 and 40°C, respectively while annual average temperature is 34°C. Annual average relative humidity is 81.6%. Rainfall is observed in all seasons. Maximum rainfall is often observed in the time-period from June to October, while minimum rainfall is from December to March. Average annual rainfall is about 150.2 cm. Drainages are intermittent and structurally controlled by foliation and faulting. The main water source of the region is the Afamba River belonging to the Nyong basin system (Fig. 1). The electrical conductivity of the river water ranges from 0.56 to 0.73 dS m^{-1} and the corresponding range in sodium absorption ratio is from 0.65 to 2.00. There are more than 60 observation wells in this region, geologically covered by various rocks types such as gneiss, shales, dolerite, gabbro and peridotites (Klitgord and Schouten, 1986; Fairhead, 1988; Guiraud and Maurin, 1992; Manguelle-Dicoum *et al*., 1992; Meli'i *et al*., 2011, 2012). According to the same authors, lateritic, gravel, granite, clay and fractured granite structures are also observed in this region. According to the population encountered in this area, rainfall behaviour, rivers regime, wells and boreholes recharge process have been

Corresponding Author: Jorelle Larissa Meli'I, Department of Physics, Faculty of Science, University of Yaounde I, Cameroon

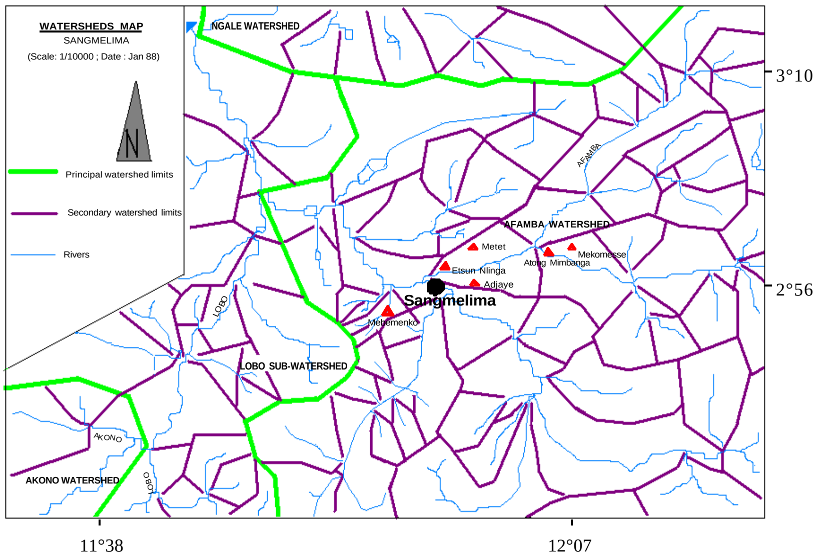

Fig. 1: Watersheds map of Sangmelima region

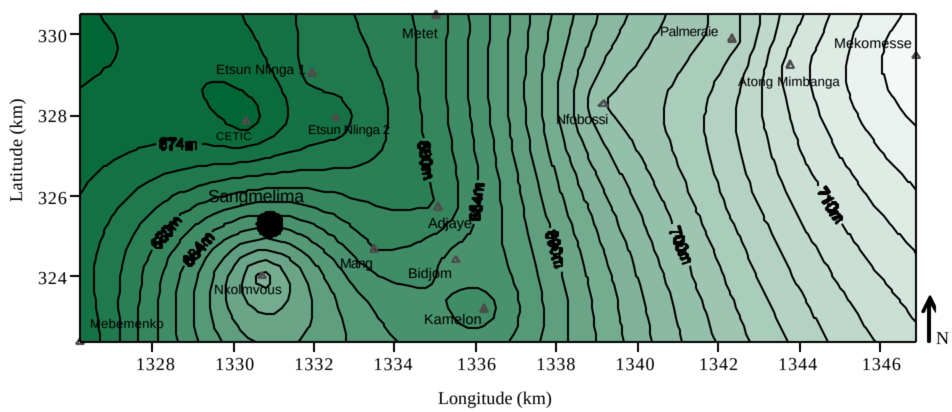

Fig. 2: The simplified topographical map of Sangmelima region

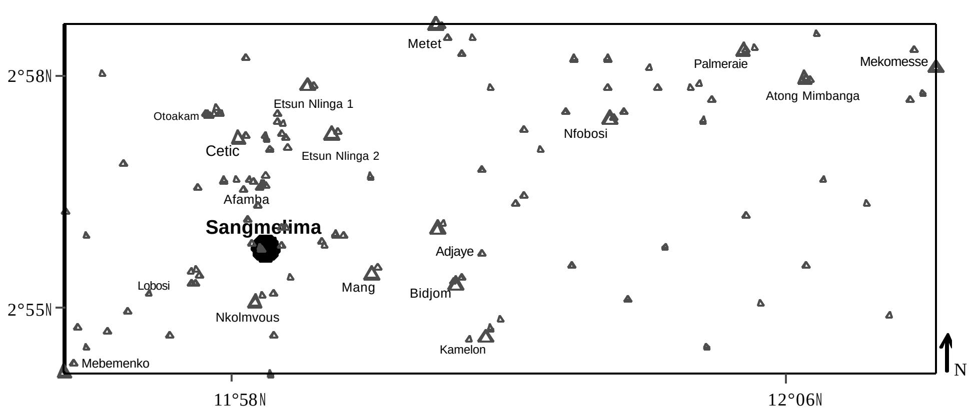

Fig. 3: Stations location map of of the studied area

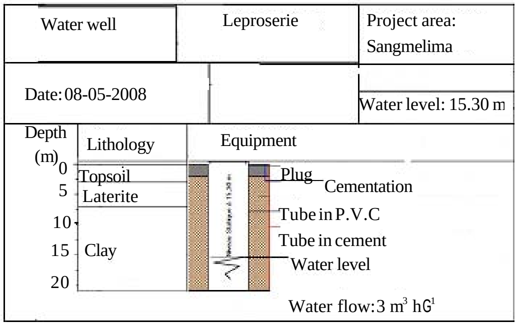

Fig. 4: Well sample obtained in the Leproserie area

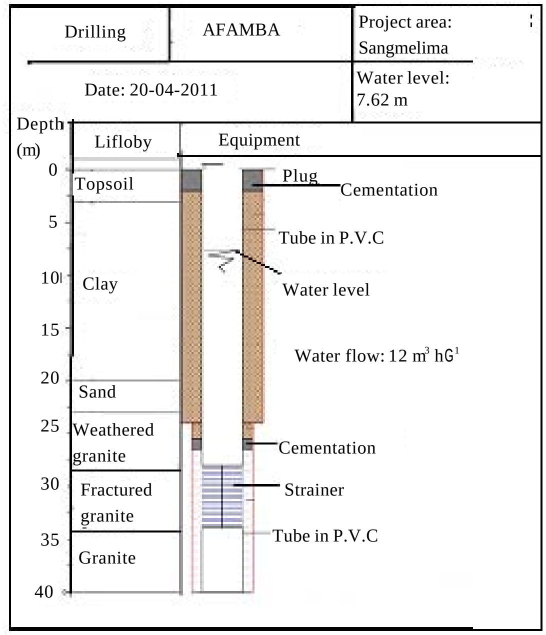

Fig. 5: Drilling sample obtained in the Afamba area

considerably modified during this recent years and are probably due to the climate change and human activities.

Origin of the data: The mean data used in this study (70 samples) were collected between 2009, 2010, 2011 and 2012, with drilled piezometers from rivers, swamps and water wells, generally constructed by the municipality city council (Fig. 3-5).

Geostatistical method: The variogram measures the squared difference between values as a function of distance. It's defined according to Isaaks and Srivastava (1989) and Kumar and Ramadevi (2006) by the following equation:

$$\gamma(h)^* = \frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z(x_i) - Z(x_{i+h})\right]^2 \tag{1}$$

where, $\gamma(h)^*$ represents the estimated value of the semivariance for lag h; N(h) is the number of experimental pairs separated by vector h; $Z(x_i)$ and $Z(x_{i+h})$ are values of variable z at x_i and x_{i+h}, respectively. x_i and x_{i+h} represent the position in two dimensions.

In the linear kriging method, the interpolated value of z at any point x_i is given as the weighted sum of the measured values:

$$Z^*(x_0) = \sum_{i=1}^{N}\lambda_i Z(x_i) \tag{2}$$

where, λ_i is the weight for the observation z at location x_i, calculated by Eq. 3 so that $Z^*(x_0)$ is unbiased and optimal (minimum squared error of estimation):

$$\begin{cases}\sum_{j=1}^{N}\lambda_i\gamma(x_j, x_i) + \mu = \gamma(x_0, x_i)\, i = 1, 2, 3, ..., N\\ \sum_{j=1}^{N}\lambda_j = 1\end{cases} \tag{3}$$

where, μ is the Lagrange multiplier and $\gamma(x_j, x_i)$ the semivariogram between two points x_i and x_j:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left[Z(x_i) - Z^*(x_i)\right]^2 \tag{4}$$

where, N is the number of samples, $Z(x_i)$ and $Z^*(x_i)$ are, respectively the estimated value and observed value at the point (x_i).

RESULTS AND DISCUSSION

Experimental and fitted variograms models: The experimental variogram and the fitted variograms (Fig. 6) are calculated using Eq. 1 and values of Table 1 with the data collected from 70 samples. The analytical variograms results obtain are follow (Eq. 5-8):

- **Spherical model:**

$$\gamma(h) = 31\left[0.4h - 5\left(\frac{h}{10}\right)^3\right] \tag{5}$$

- **Gaussian model:**

$$\gamma(h) = 31\,[1.2\text{-}\exp(-0.2\,h^2)] \tag{6}$$

Table 1: Values obtained with various variogram models

Distance (km)	Experimental model	Spherical model	Gaussian model	Exponential model	Logarithmic model	Penta spherical model	Linear model
1.0	10.6	11.8	10.9	8.9	0.3	740.6	10.4
1.5	16.0	17.9	16.3	12.2	12.5	7142.9	15.9
2.1	22.5	24.4	22.8	15.6	22.8	39859.0	22.4
2.5	27.4	28.6	27.0	17.7	28.5	102053.6	26.9
3.0	32.3	32.8	30.8	19.7	34.0	250070.9	32.2
3.5	36.9	36.1	33.2	21.2	38.2	495075.4	36.8
4.0	41.8	39.2	35.2	22.8	42.7	1040472.5	42.7
4.4	45.8	40.9	36.0	23.9	45.9	1746624.5	47.3
5.0	51.5	41.9	36.6	25.1	49.6	3211271.3	53.5
5.5	56.5	41.5	36.8	26.0	52.5	5075248.1	58.6
6.1	60.2	39.6	36.9	26.8	55.4	8202439.4	64.5

Table 2: RMSE values obtained with various variogram models

Variogram model	Linear model	Spherical model	Gaussian model	Exponential model	Logarithmic model	Pentaspherical model
RMSE	1.67	8.40	10.90	19.42	30.94	3130512.5

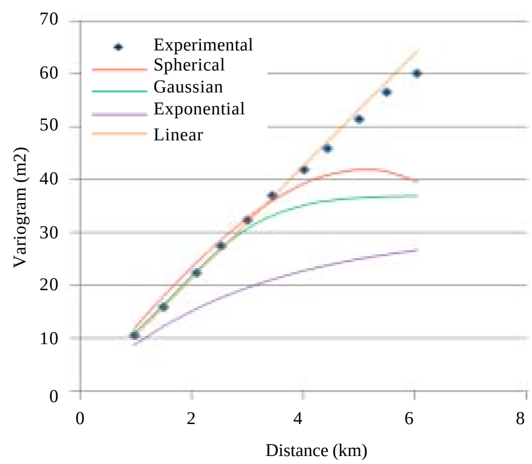

Fig. 6: Experimental and fitted variogram models

Exponential model:

$$\gamma(h) = 31\ [1\text{-}\exp(-0.3)] \tag{7}$$

and linear:

$$\gamma(h) = 10\,h \tag{8}$$

The analysis of experimental values and those obtained with various analytical variograms (Fig. 6, Table 1) shows that, results of linear model present the best approximation with those of experimental model. But in the last line, the value of the linear model increases when the experimental model value remains constant. Comparison with other models shows that, the linear model is followed by the gaussian, spherical and exponential models. This Table 1 also shows that, the pentaspherical model values present very bad correlation with those of the experimental model.

Validation of the variogram models: The RMSE values obtained with various variograms models (Table 2) shows that, the linear model presents the lowest RMSE 1.67. This result is similar to those obtained previously. According to Marcotte (1995), (Eq. 8) must be used to map the water table level in the studied region).

Predicting the water table map: The variograms (Eq. 5-8) are then used to construct the water table map by kriging with Golden Software, 2002, at the nodes of the 1 km x 1km square grid from the collected depth of some wells and depth of topsoil at some stations where shallow aquifer was detected. These estimated level values are used to draw the iso-depth maps. In Fig. 7-11, the water table appears to be continuous in all the study area with some contrasted observations. The depletion varies with space from 0 to 20 m according to the maps generated by linear, spherical and exponential variograms and from 0 to 160 m according to the map obtained with the logarithmic variogram. If the predicted water table is generally close, the maps are different from one variogram model to another. The figures confirm that, the selected model influences the prediction of the unknown values. In Fig. 7, the isocontours present features of the hills and valleys in relative good correlation with the topography (Fig. 3). The water level is low where the surface of the ground is low and higher where the surface is high. The minimum corresponds to the rivers or swamps whereas the maximum corresponds to the region where soils and weathered rocks are thick.

But, the results of the Fig. 8-11 are not the same. In fact, according to these figures, the isocontours are close but they do not present good correlation with the topography.

Cross validation criteria: The comparison between the measured in field and predicted values of water table by kriging using several analytical model is presented in

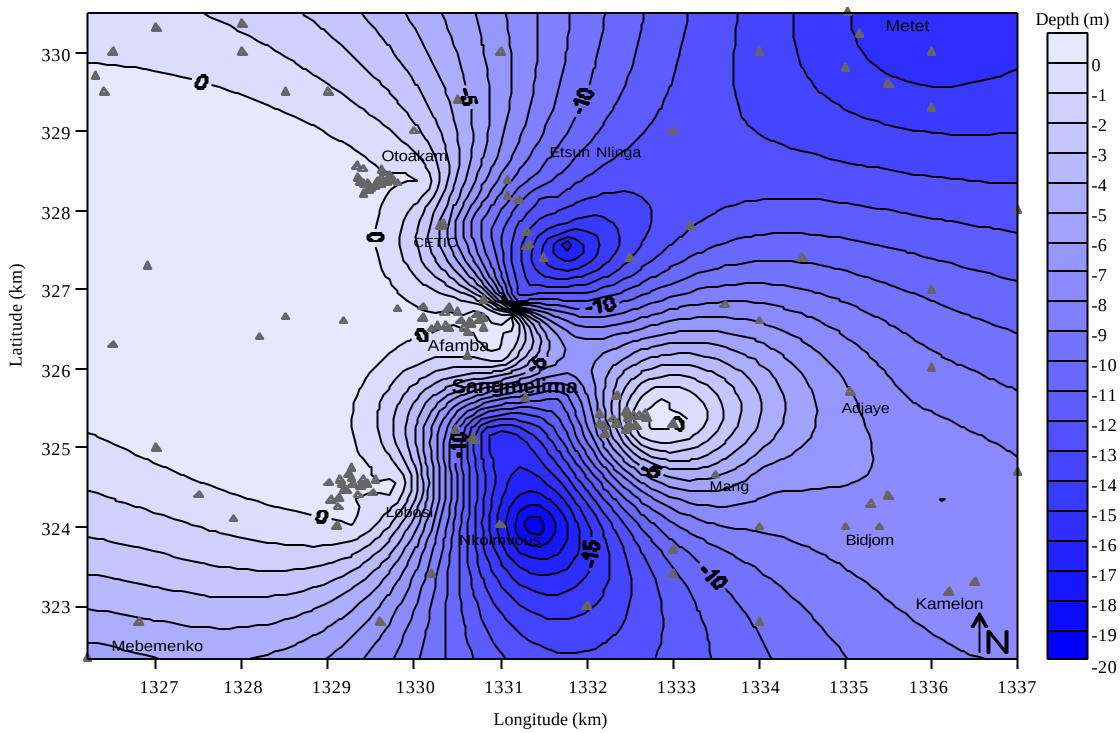

Fig. 7: Water table level (m) map above mean sea level obtained by kriging using linear variogram model

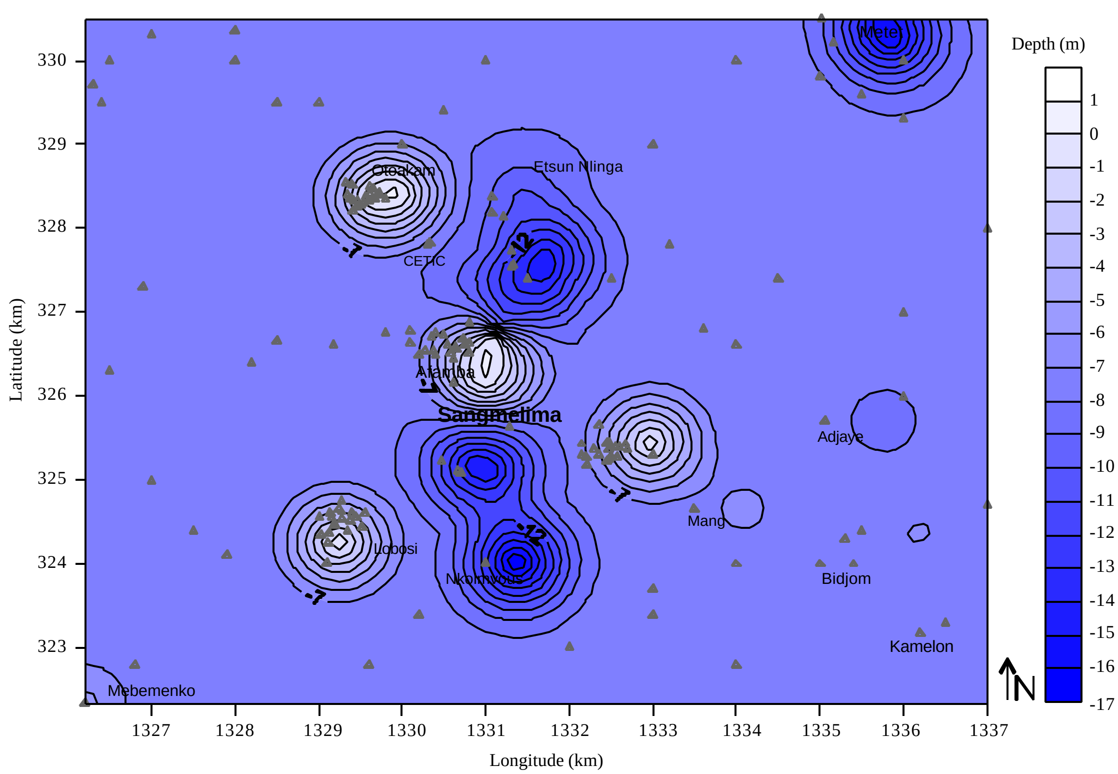

Fig. 8: Water table level (m) map above mean sea level obtained by kriging using spherical variogram model

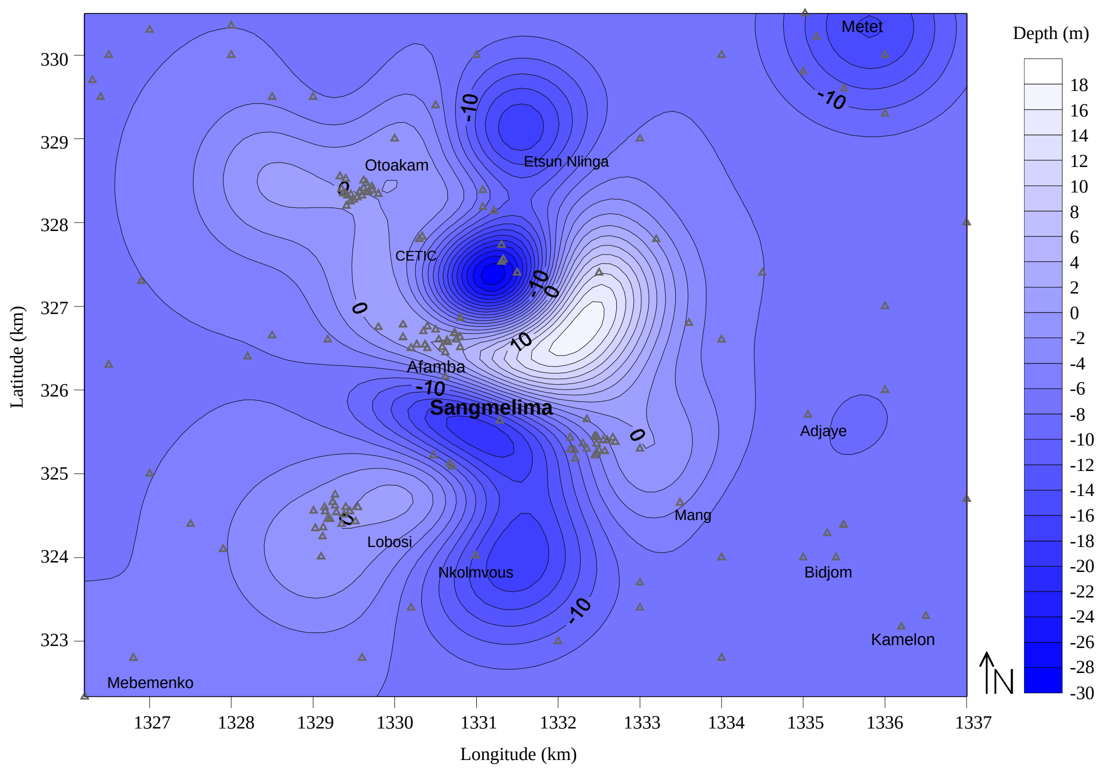

Fig. 9: Water table level (m) map above mean sea level obtained by kriging using gaussian variogram model

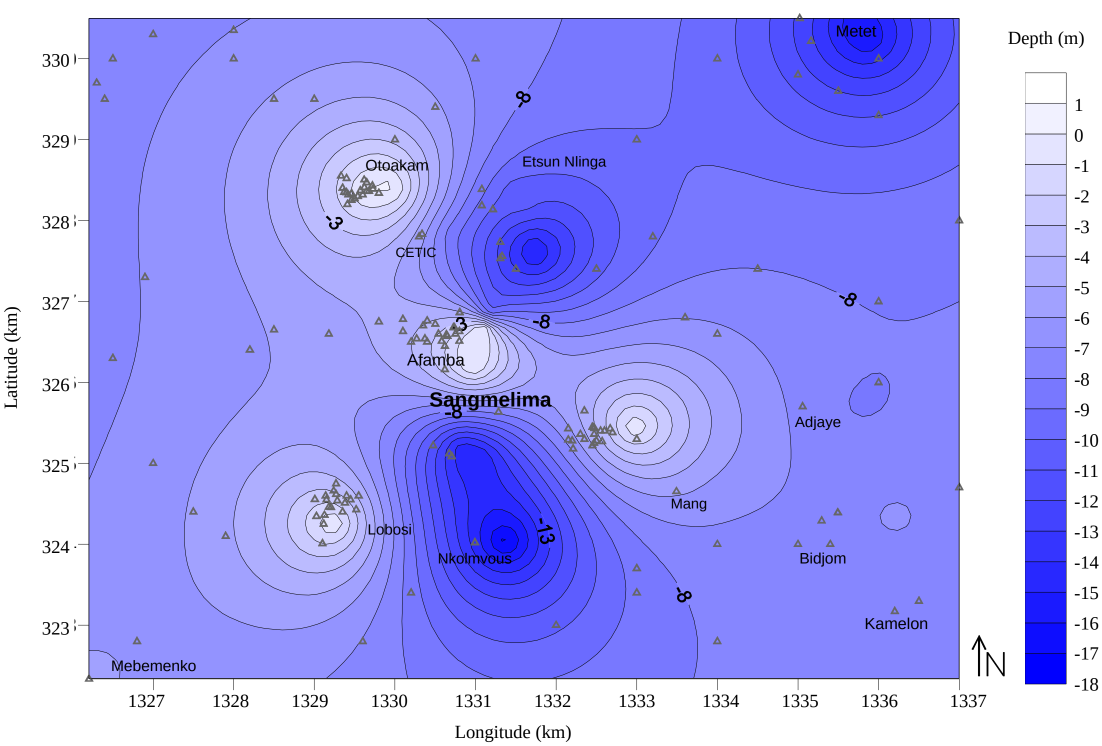

Fig. 10: Water table level (m) map above mean sea level obtained by kriging using exponential variogram model

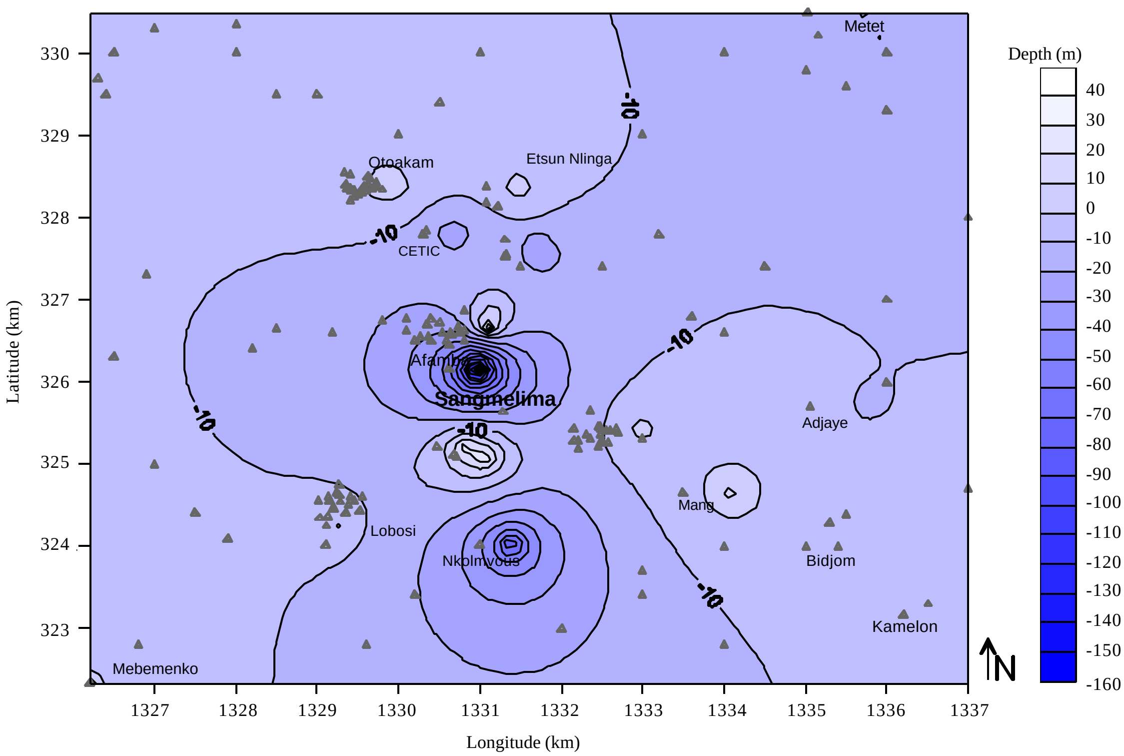

Fig. 11: Water table level (m) map above mean sea level obtained by kriging using logarithmic variogram model

Table 3: RMS values obtained from various variogram models according to the cross validation criteria

Variogram model	Linear	Spherical	Gaussian	Exponential	Logarithmic
RMSE	0.001	2.171	1.406	1.657	5.101

Table 4: Comparison between observed data and those obtained by kriging

Longitude	Latitude	Experimental	Linear	Spherical	Gaussian	Exponential	Logarithmic
1328.12	327.47	0.61270	0.61870	-7.851360	-4.29632	-5.68949	-9.995080
1328.02	324.55	-0.13690	-0.13728	-7.851360	-3.62224	-4.73967	-9.116576
1327.52	330.19	-0.83200	-0.83110	-7.851360	-5.98645	-7.06345	-7.848410
1330.34	326.47	-0.66690	-0.66707	-2.435440	2.82611	-1.76297	-41.691760
1329.44	326.57	-1.43376	-1.43380	-7.851360	-1.95699	-4.98192	-20.225730
1329.13	328.78	-0.06800	-0.06828	-5.377660	-1.23914	-2.53949	-3.842040
1326.51	329.89	-0.24990	-0.25221	-7.851361	-6.08491	-7.34838	-8.197650
1326.8	324.55	-0.81280	-0.81154	-7.851361	-6.01358	-6.56839	-8.088400
1328.33	325.56	-0.22990	-0.23169	-7.851361	-5.64475	-5.63704	-11.880480
1326.21	325.06	-0.55100	-0.55086	-7.851361	-6.09103	-7.05012	-8.109330

Table 3 and 4. These results also confirm that, the linear variogram has the low RMSE 0.001 values and appears to be best one. In addition, the map obtained with the linear model Fig. 7, enables to highlight swamps in the area and tests made on wells and boreholes data present a good correlation with kriging results. However, rivers don't clearly appear, probably due to the narrowing of their courses according to the scale of data.

CONCLUSION

The water table influences soil moisture climatology, continental climate dynamics and is very important for peoples in the rural areas, particularly when they need to know at what depth below the surface they can tap far enough into the ground to get a functioning wells or which way pollutants may or may not flow to come to wells or boreholes. The results obtained confirm the usefulness of applying the geostatistic method to investigate water table. This study also shows that, the best fitted variogram in the Sangmelima rural region is the linear model. The map obtained by kriging allows to control the spatial behaviour of water-table in the context of climate dynamics and can guide the urbanization process while preserving the water quality in this region.

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