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Assessment of Spatial Variability of Groundwater Levels in Moroto District, Uganda

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ABSTRACT

Globally, the variation of groundwater levels is increasingly overwhelming due to over exploitation resulting from population growth. The dynamic nature of socio-economic activities in Moroto District such as agriculture, settlements and increased trends in irrigation technology has been well-known worldwide as common parameters triggering groundwater variability. Nevertheless, determination of groundwater levels for groundwater management and development purpose is a challenge due to spatial variability in levels across Moroto District. In this study, geostatistical technique in Geographical Information System (GIS) was used to analyze spatial variability of water levels in the study area. The analysis utilized ordinary Kriging method to predict the spatial variation of groundwater levels for 189 measured boreholes. The resultant groundwater level variation map generated using Gaussian model depicts change in groundwater levels varying significantly across the study area dropping by 12 m to 50 m. Significant variations of groundwater levels were observed in the western, central and south eastern part of the study area which are highly populated areas and therefore, the potential of overexploitation. Generated map can be used as first-hand information for decision makers and water managers in management of groundwater resources in Moroto District.

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INTRODUCTION

Globally, the demand for groundwater resources continues to rise due to population growth and industrialization leading to variation in groundwater levels resulting from different modes of extraction (Jamaa et al., 2020; Thapa and Gupta, 2017). Abdullahi and Garba (2015) in their publication pointed out that extreme abstraction coupled with changes in precipitation due to climatic variability have influence on groundwater which leads to variations. Further, Wada et al., (2010) elucidated that, the consequence of low groundwater levels has an effect on wetlands, river flows and eco systems. They further mentioned that, at the estuary, a decrease in groundwater can cause soil degradation and salt water intrusion. Giordano (2014) stated that, excessive abstraction of groundwater resources has created difficulties that have led to uncertainty in groundwater due to variations. Delbari et al., (2013) mentioned that, for proper exploitation of groundwater resources, prior knowledge on the spatial variability of the resource is significant. In addition, the outcome helps in proper identification and guidance on groundwater resource exploration.

Consequently, prediction of spatial variability of groundwater levels needs to be achieved from the measured water levels. In line with Ahmadi & Sedghamiz, (2007), the primary root of facts on impact of hydrologic pressure on groundwater is usually associated with monitoring of groundwater levels. However, most areas lack effective groundwater monitoring networks (Alexander et al., 2017; Egwu et al., 2017). Geostatistics as a tool within GIS given methods has proven to be useful in interpolating discrete spatial data in order to generate optimum surfaces (Alexander et al., 2017; Delbari et al., 2013; Egwu et al., 2017; Sastre-Merino, 2011; Taghizadeh-Mehrjardi et al., 2008). The study by Egwu et al., (2017) utilized this technique to analyse the spatial variability connected with groundwater levels in Darab plains of southern Iran. Furthermore, Taghizadeh-Mehrjardi et al., (2008) used this method in order to predict the spatial distribution regarding groundwater parameters of Yazd-Ardkan in Iran. The end result revealed that, the method may be appropriate throughout in preparation of groundwater variability maps. Also Egwu et al., (2017) recommended that, to understand the variations in groundwater level measurements as a result of excessive extraction, it is significant to measure the spatial pattern of groundwater levels. Equally, Bohling & Wilson, (2012) employed the geostatistical technique to analyse the variations in water levels of 70 water points in Kansas high plains during winter season and it presented a drop-in groundwater level. The technique is convenient in assessment of groundwater level changes where the spatial pattern of groundwater levels can be analysed and mapped to identify risky areas for abstraction of groundwater (Cay & Uyan, 2019).

In Moroto District, there has been development of rural water supply through drilling of boreholes in recent past. Moreover, there is less data on hydrogeological situation and potential areas to aid the exploration of groundwater. Further, over abstraction due to rapid population growth coupled with changes in precipitation, natural and human factors has resulted into variations in groundwater levels and high rate of dry boreholes (Nsubuga et al., 2014). Therefore, this study looked at assessment of spatial variability of groundwater levels to develop maps that will give clear representation of changes in groundwater levels and aid decisions and design appropriate measures for groundwater exploration by using geostatistical technique in Geographical Information System.

METHODS AND MATERIALS

Description of the study area

Moroto District is located in the north eastern part of Uganda. It is composed of four sub counties such as Nadunget, Katikekile, Rupa and Tapac. It has an altitude between 1356 m to 1524 m above sea level, land area of approximately 3,532.92 km^2 and lies between latitude 1º 53' N, 33º 56´ E and longitude 3º 05' N, 34º 56' E as shown in Figure 1.

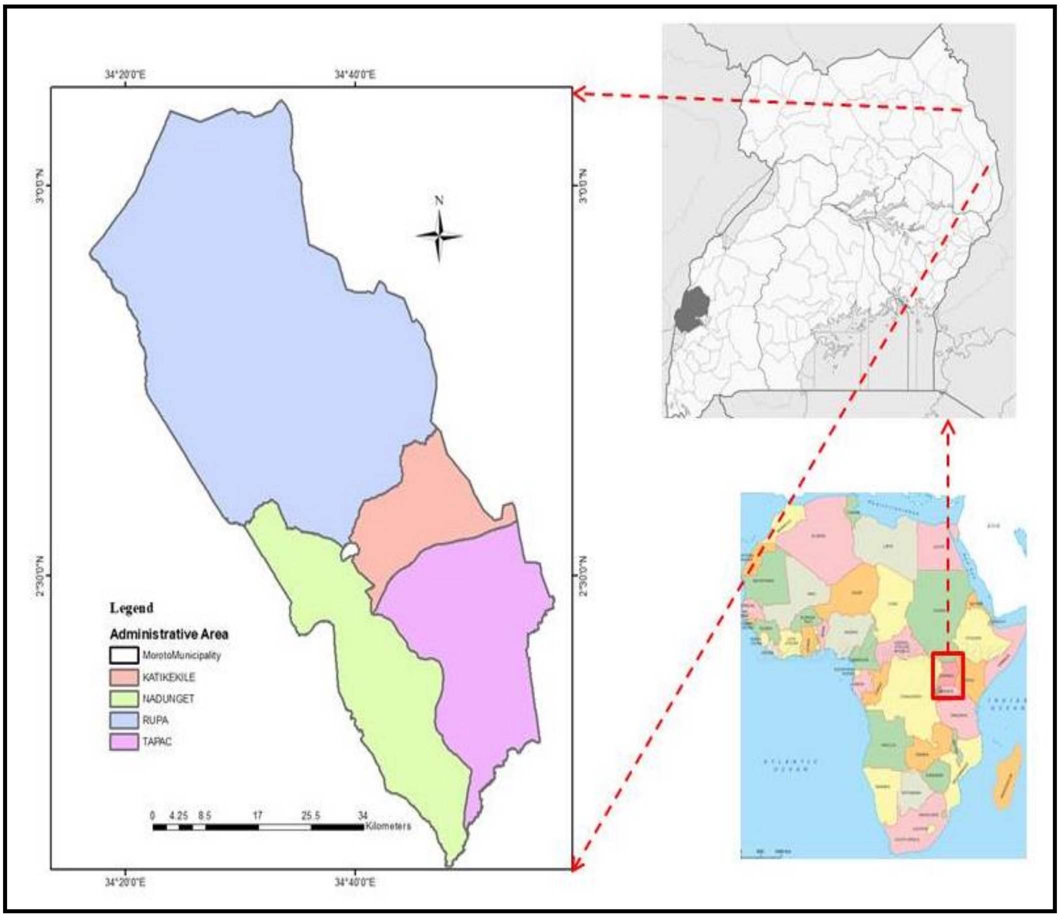

Figure 1: Location of the study area.

The study area is mostly leveled with semi-arid form of vegetation primarily thorny trees. The temperatures are high above 30ºC in January and February with minimum temperature between 15ºC to 17ºC; and in October to December, the average extreme temperature is 29ºC. Furthermore, it experiences relative humidity of 63% in the morning hours and 46% afternoon hours, and low humidity is observed during drought and sharp values noted in morning hours (Moroto District Local Government, 2013). According to Ferreri et al., (2011), Moroto District is predominantly agropastoral community and is highly dependent on groundwater resources for domestic use, watering of livestock and agriculture.

Data Acquisition

Obtained boreholes information comprised of static water levels which were measured by use of electric depth gauge, location coordinates that were obtained by use of the Global Positioning System, and dynamic water levels were obtained from the driller's log. From data obtained, the variation in water levels were found by subtracting static water levels from the dynamic water levels, which were then considered for analysis in order to determine the prediction of water level variation. Figure 2 shows spatial distribution of boreholes points in Moroto District.

Spatial Interpolation

In geostatistical technique, ordinary kriging (Equation (1)) was used to interpolate water levels data for 189 boreholes. The tool uses autocorrelation amongst the points to predict the pattern. It assumes that, the distances between the sampled points reflect the spatial correlation that can explain the variability of the levels (Alexander et al., 2017; Hasan et al., 2021). It also assumes that, levels near each other have related characters than those that are far. According to Gundogdu & Guney, (2007), ordinary kriging uses semivariogram models as key in geostatistical analysis of data (see equation (1)).

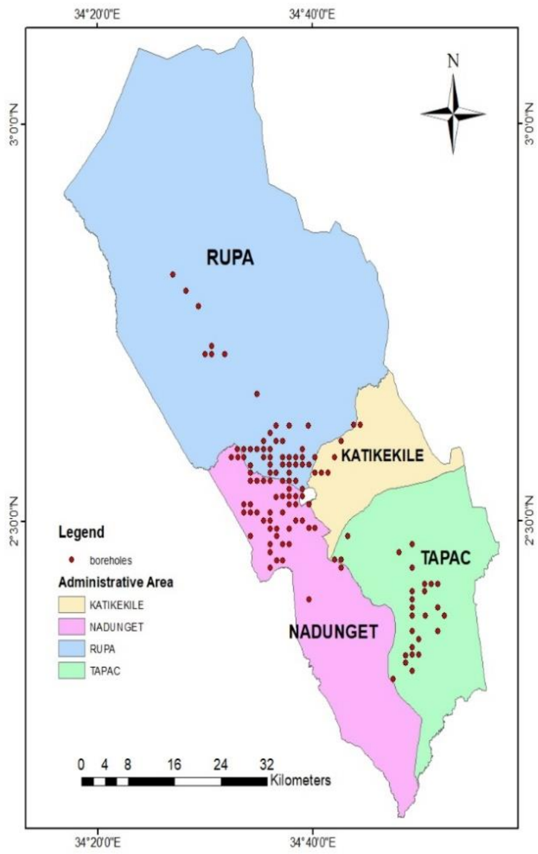

Figure 2: Distribution of boreholes.

$$\gamma^{(h)} = \frac{1}{2N^{(h)}} \sum_{i=1}^{N(h)} [Z(xi + h) - (xi)]^2 \quad (1)$$

where $Z(x_i)$ is the value of variable Z at point x_i ; $N^{(h)}$ is the sample point separated by h; h is the lag and $\gamma^{(h)}$ is the semivariogram model for interpolated water levels.

Spatial analysis of groundwater levels

In analysing of groundwater levels, the difference between dynamic water levels and static water levels were used as an indication of groundwater level variations. Cay & Uyan (2019) equally used this variable in their study. Through comparison of semivariogram models (Spherical, Exponential, Gaussian and Circular) by cross validation in ordinary kriging method, the mean standard error (MSE) and root mean square standardized error (RMSSE) were considered in determination of model performance. As outlined by Johnstone et al. (2001), for the predicted standard errors to be acceptable after cross validation, the root mean square standardized error should be close to 1. The best fit model is selected and used to generate groundwater level map for the study area. The spatial dependency of the water levels involved was determined using the nugget-to-sill ratio. The spatial structure is considered strong when the ratio is <0.25, moderate at 0.25–0.75, and weak when >0.75 (Alexander et al., 2017). Steps for the generation of spatial map for groundwater level involves spatial interpolation of water level data as described in the flow chart presented in Figure 3.

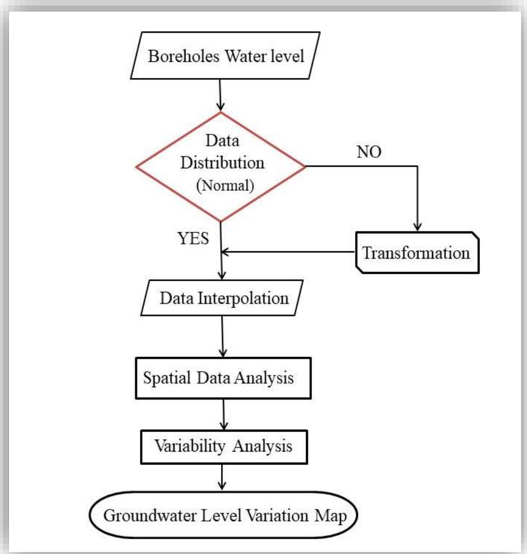

Figure 3: Flow chart for mapping of groundwater level variation.

RESULTS AND DISCUSSIONS

Exploratory data analysis

Prior to geostatistical modeling, normality of data was carried out using Quantile-Quantile (QQ) plot to understand the normality of the data used. As shown in Figure 4 and Figure 5, the distribution of the transformed and non-transformed water level data displayed normality of transformed data as positively skewed symmetrically. Table 1, clearly indicates that, the coefficient of skewness for transformed data of -1.185 is highly skewed than that of non-transformed (0.089), and thus all the analysis this was achieved with non -transformed data.

Groundwater level prediction

Table 2 shows the cross-validation results for ordinary kriging. The resultant indicated that Gaussian model was the best model selected as it gave a predicted root mean square standardized Error (RMSSE) value of 0.777 which is near 1 and mean standardized value of 0.003 close to 0 (Kevin *et al*., 2001). Gaussian model was then used to generate the groundwater level map. The nugget/sill ratio (Table 2) indicated a weak spatial dependency of observed water levels (> 0.75) for all models suggesting that water levels in observed boreholes are highly influenced by external factors such as error introduced during recording of the water level.

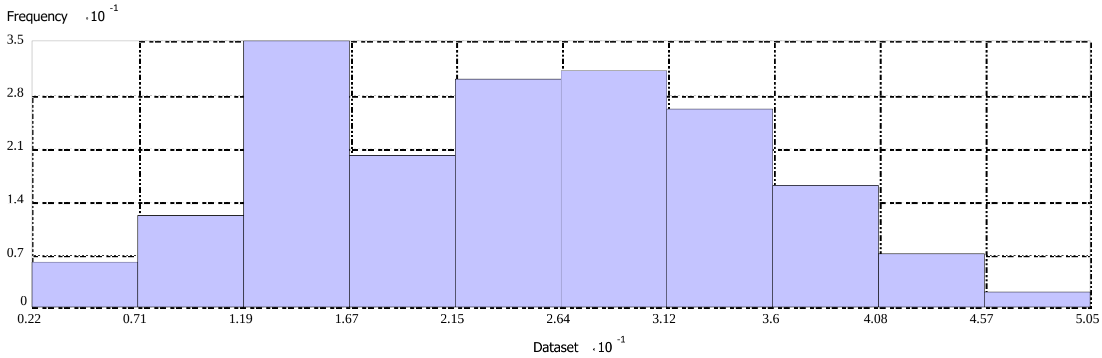

Figure 4: Histogram Non-Log normal.

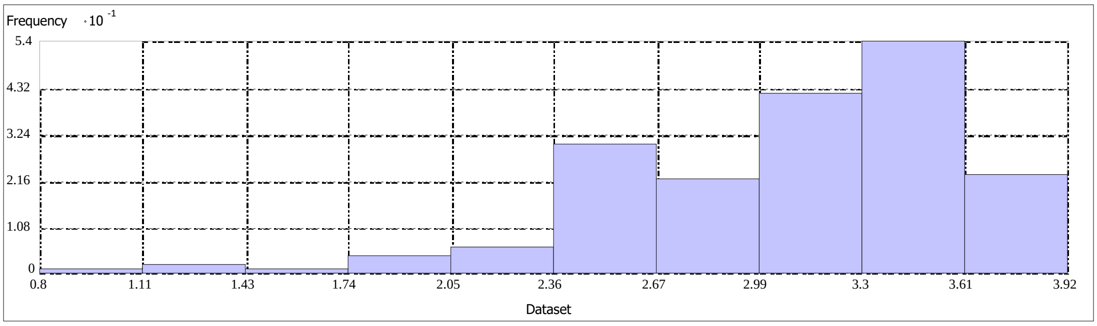

Figure 5: Histogram log-normal.

Table 1: Statistical summary for transformation

	Mean	Median	Min	Max	Std Dev	Skewness
Non-Transformed	24.369	24.86	2.23	50.5	10.299	0.089
Transformed	3.079	3.468	0.802	3.922	0.524	-1.185

Table 2: Summary of cross validation results

Model	Spherical	Exponential	Gaussian	Circular
Mean	0.635	0.644	0.691	0.406
MSE	0.001	0.002	0.003	-0.010
RMSSE	0.752	0.753	0.777	0.744
Nugget	0.143	0.127	0.153	0.136
Sill	0.148	0.162	0.145	0.135
Nugget/ Sill Ratio	0.964	0.781	1.057	1.007

MSE: Mean Standardized Error; RMSSE: Root Mean Square Standardized Error

In Figure 6, the scattered points represent the measured values plotted against the predicted values of the model. The blue line expressed by the regression function 0.01978*X + 24.0767 indicates the best fit line through the scattered points and the black line, signifies an ideal case of 1:1 relationship that exists between the predicted and measured errors. Figure 7 shows that, some points lie above the normal line while some fall below the line. However, many points are close to the normal line which indicates that the predicted errors are close to being normally distributed. This is indicated that given data shares characteristic of normal curve and the model can be used to estimate spatial water level

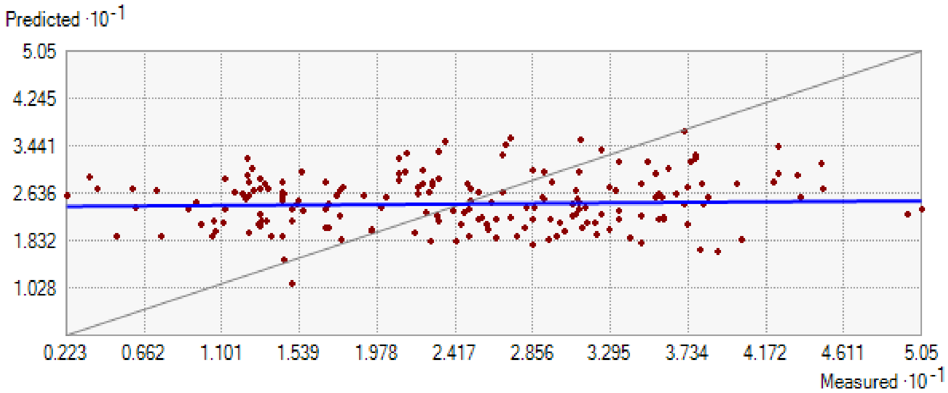

Figure 6: Predicted QQ plot.

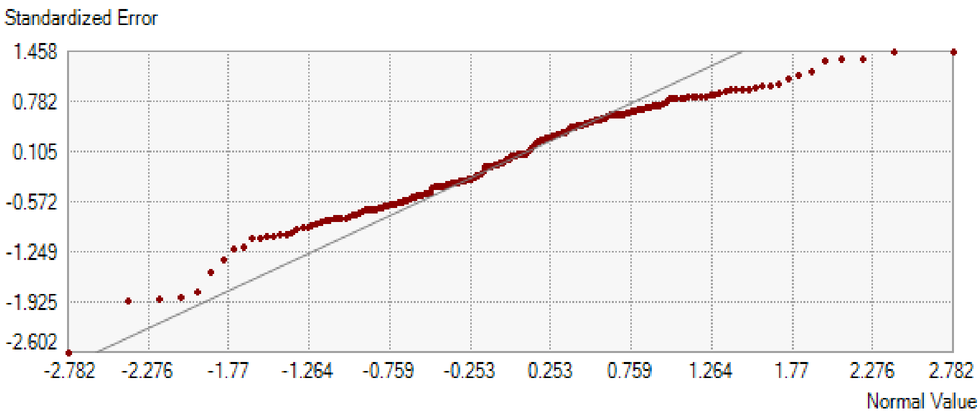

Figure 7: Normal QQ plot.

Spatial variability of groundwater level

Figure 8 and 9 present the spatial distribution of static and dynamic water level in Moroto District, respectively. The static water level map indicated the water table for largest part of Moroto to be below 45 m, deeper water table was observed on the Northern –East and the Southern-West part as seen in Figure 8. The dynamic water level map depicts a significant dropping of water level to as deep as 90 m (Figure 9), except for the Northern part which is mostly covered by forest reserve and therefore less developed.

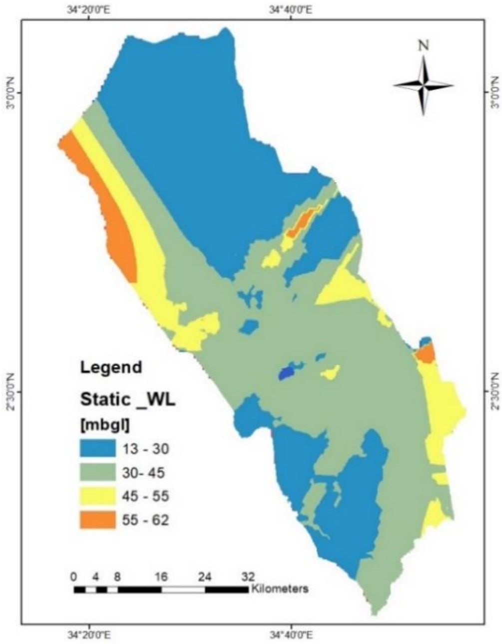

Figure 8: Static water level map.

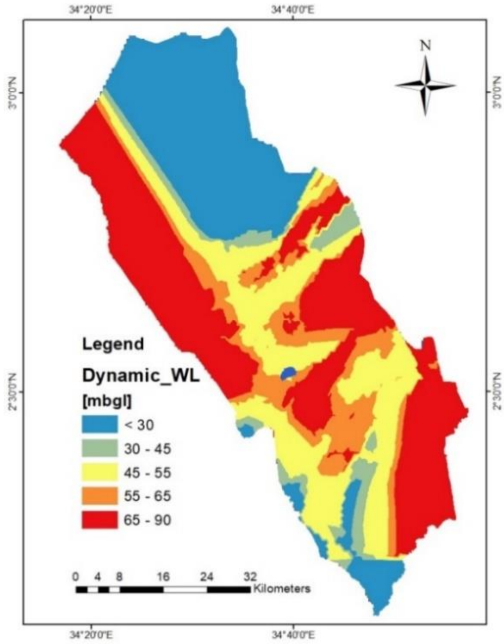

Figure 9: Dynamic water level.

Figure 10 presents the water level variation map generated using Gaussian model. The map depicts the change in groundwater levels varying significantly across the study area. Generally, groundwater levels in the study area have dropped by 12 m to 50 m when comparing the static water level against the dynamic water level. On the eastern, northern and southern part of the study area where few boreholes were observed, groundwater level variation range from 12 to 30 m. Moreover, significant variations of groundwater levels were observed in the western, central and south eastern part of the study area. This can be linked with abstraction of groundwater as more boreholes are located in this area (Figure 2). These results give an indication of potential groundwater overexploitation especially in highly populated areas like the western and central part (Nsubuga et al., 2014). Slight to moderate changes in groundwater levels are spatially distributed on eastern, northern and southern parts which are less exploited.

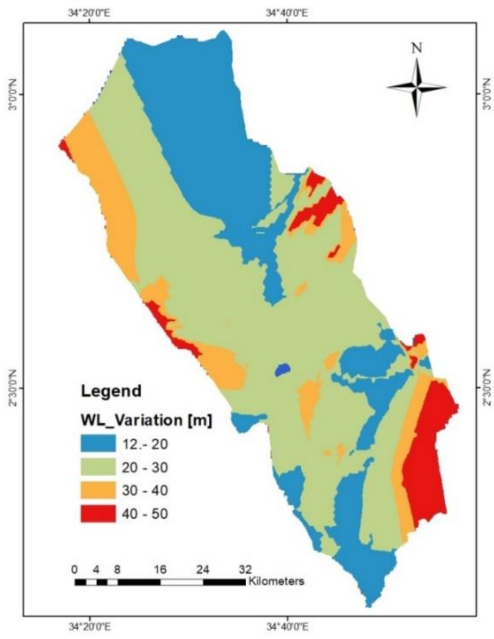

Figure 10: Groundwater level variation map.

CONCLUSION

The demand for water continues to escalate in the Moroto District which has resulted into increasing trend of groundwater development. However, uncontrolled abstraction of groundwater can lead to significant dropping of groundwater level and depreciation of groundwater storage. Management of groundwater level variation is challenged by the lack of an effective monitoring system. This study make use of geostatistical tools in the GIS to determine the spatial variation of groundwater levels using the static and dynamic water level measured in 189 boreholes in Moroto District. The best fit model is a semivariogram of Gaussian model which depicted a strong spatial dependency of the observed water levels. The spatial variation of groundwater levels across the study area indicated a significant drop spotted on the western, central and south-western part of the study area. The drop can be related to the population increase water demand in the area which may have resulted into over exploitation of groundwater. The observed variations of water levels call for continue monitoring of groundwater level for effective management of the resource. Generated map of the study area can be used as firsthand information for decision makers and water managers in management of groundwater resources in Moroto District. The proposed approach was able to relatively estimate the spatial variation of the groundwater levels from available data, however; confidence of the estimation depends on the quality of the data and the spatial distribution of observation points. Therefore, based on the problem at hand and the accuracy of the data, GIS can contribute immensely to the understanding of groundwater level variations. Thus, generated map from the study can be used as firsthand information for decision makers and water managers in management of groundwater resources in Moroto District.

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