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GIS based Groundwater Level Mapping in Ashanti Region of Ghana

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Abstract

Groundwater is an essential resource for sustainable development all over the world. It is the most important source of domestic, industrial and agricultural water supply in Ghana. Notwithstanding the numerous contributions of groundwater resources in human development, groundwater causes problems and can be considered as a nuisance rather than a blessing in infrastructural development. Available depth to groundwater level information can be used to determine the effects of groundwater on civil engineering structures during the preliminary investigations. Borehole information on groundwater level across Ashanti Region was used to predict the depth to groundwater level. The data was interpolated using the kriging interpolation techniques in a GIS environment. The study shows that groundwater levels are spatially distributed and the depths range between 13m to 74m with an average depth of 43.5m, also groundwater level in districts where no information was obtained can be predicted from the map. Based on the map, the implications of groundwater level on construction activities and geotechnical design can be evaluated during the preliminary stage of projects implementation.

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Keywords: Geographical Information Systems; Groundwater; Kriging; Interpolation; Semivariogram

1. Introduction

Groundwater is an essential resource for sustainable development all over the world. The welfare of every society is tied to the sustainable exploitation of water resources [1]. Groundwater is the most important source for the domestic, industrial and agricultural water supply in the Ghana [2]. Notwithstanding the numerous contributions of groundwater resources in human development, in certain circumstances, groundwater causes problems and can be considered as a nuisance rather than a blessing. Groundwater levels have significant effect on the bearing capacity of soil which can lead to building failures. It can also cause liquefaction when in contact with loose fine soil that is subjected to high ground vibrations. There are cases where excessive ingress of groundwater in excavation during construction has led to major modification of initial project design or abandonment of entire project. In order to mitigate the difficulties posed by groundwater on engineering construction, there is the need for readily available depth to groundwater level information which can be used during the feasibility stage in infrastructural development. Such information is very vital in planning and execution of civil engineering projects and landuse planning.

A number of studies have been conducted to determine the depth to groundwater level in other parts of the world, [3 - 11] . Regional maps of ground water depth are commonly used in environmental decision making such as locating landfills and wastewater disposal sites [8]. Snyder [3] stated that the information describing the depth to groundwater is useful for many applications, including evaluation of groundwater contamination, contributing areas to groundwater or evaluation of effects of groundwater on infrastructural development. It is also required typically in construction of buildings, roads, and the design of ground water monitoring programs. Snyder [3] used water-level data from shallow wells and available water-level measurements in reports filed by well constructors to map the configuration of the water table in the Portland metropolitan. The purpose of water table map was to address concerns about various water resource issues, especially with regard to potential effects from storm water injection systems such as UIC (underground injection control) systems that are either existing or planned. Buto and Jorgheran [6] developed geospatial database of ground-water-level altitude and depth-to-ground-water data for state of Utah. The database was used to generate a surface describing the depth to groundwater. Aslan and Gundogdu [10] used GIS to develop a depth to groundwater maps for irrigation purposes in Turkey. This paper presents the use of GIS tools to generate a groundwater level map from measured groundwater levels in boreholes across the Ashanti Region of Ghana.

1.2 The Role of GIS in Groundwater Research

GIS as defined by Burrough and McDonnell [12] is a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. GIS provides a means for data processing, such as geo-referencing, integration, aggregation, or spatial analysis [12]. The benefits of GIS are enormous and application in groundwater studies have been increasing over the years. Fathy [13], Hans [14], Tahir [15] and Atiqur [16] have successfully applied GIS in groundwater studies. The main strength of GIS is its ability to integrate data from different sources together and allow spatial analysis; this makes it possible to bring different sources of data together with groundwater data for spatial analysis. GIS provides a variety of tools such as Spatial Analyst and Geostatistical Analyst which can be used to explore spatial data and interpolate data to create a map for efficient decision making in geo-hydrology [17].

1.3 Geostatiscal Analysis of Data

The semivariogram is used to analyse the spatial dependencies in geostatistics. The semivariogram provides a means by which the spatial dependencies between the measured sample points can be ascertained. It is based on the assumption that for a given point dataset those that are close to each other are more correlated whereas those at a further distance are less correlated [17]. It is calculated by determining the variance of each data point in the data set with respect to all other data points and by plotting the variances (or semivariance) against the distance between the points. It is then used to compute the weights that are used in the interpolation [18]. Practically the semivariance is calculated by using equation 1.

$$\gamma(h) = \frac{1}{2n(h)} \sum (d_i - d_j)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where n is the number of samples, d_i and d_j are the variables being measured (depth of groundwater. Mathematically, regionalized data are modeled by three variogram models [20]. These are the linear model, the De Wijsian model and the spherical model. The spherical model is the most preferred by geostatisticians and defined mathematically as

$$\gamma(h) = \begin{cases} c\left(1.5\frac{h}{a} - 0.5\frac{h^3}{a^3}\right) + C_0 & when\ h \geq a \\ c_1 + c_0 & when\ h > a \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where $C_1 + C_0 = \gamma\ (C_0)$ is called the sill value, C_0 is the nugget effect (usually present) and a is the range or the maximum zone of influence [21]. The spherical model is represented graphically as shown in Figure 1.

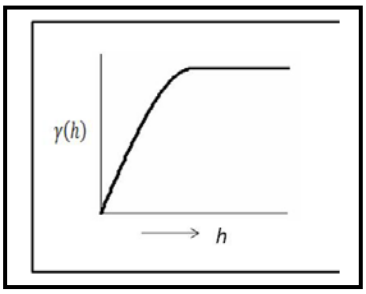

Fig. 1: Diagrammatic representation of the Spherical (Mattron) Model

2. The Study Area

The Ashanti Region is centrally located in the middle belt of Ghana. It lies between longitudes 0.15W and 2.25W, and latitudes 5.50N and 7.46N. Figure 2 shows the location of the study area with the various districts. The region shares boundaries with four of the ten political regions, Brong Ahafo in the north, Eastern region in the east, Central region in the south and Western region in the Southwest [22]. The area is within the moist semi deciduous forest which occurs in the wet semi – equatorial climatic region of Ghana. Annual rainfall is between 125 and 175cm and dry seasons are clearly marked. Relative humidity is low throughout the year and accounts for the heavy rainfall [23]. According to Kesse [24], Ashanti Region falls within three main geological systems; Birimian, Tarkwain and the Voltain formations. Majority of the area consists of the Birimian Formation. The Birimian has two main divisions, the lower and upper Birimian series, with the lower Birimian series dominating the entire area. The Birimian formation is greatly intruded by large masses of granites and basic intrusive of uncertain age but probably of post-Birimian and Pre-Tarkwaian age. Due to the intrusive relationship with granitoids, they are usually strewn with quartz veins. The water-bearing and yielding capacity is high due to the faults, fractures and quartz veins.

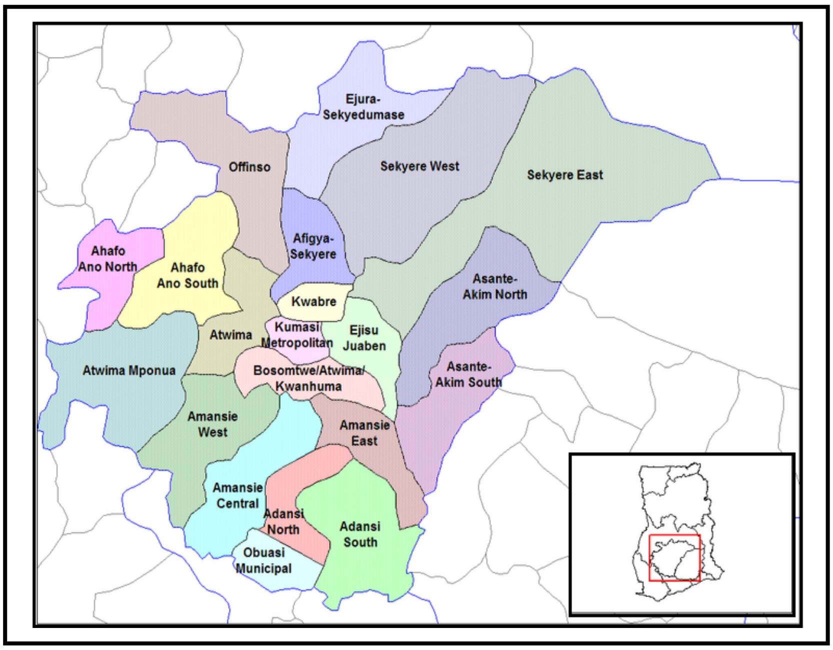

Fig.2: Map of the Study Area showing the various Districts in Ashanti Region

3. Materials and Methods

The data for the study consist of borehole information which was gathered from a number of boreholes that were drilled across some districts in Ashanti Region. The data comprised of two main categories, the spatial data which is made up of the geographical location of each borehole in the form of coordinates, the coordinates were projected in UTM Zone 30N coordinate system and the attribute data which is made up of the borehole characteristics including groundwater level measurements. Outline of study area including the districts were digitised and included in the database. Figure 3 shows the outline of the study area and locations of the boreholes within the districts. Using this information a spatial database was created in GIS to facilitate the interpolation process. Table 1 shows a typical database created in GIS for the borehole information.

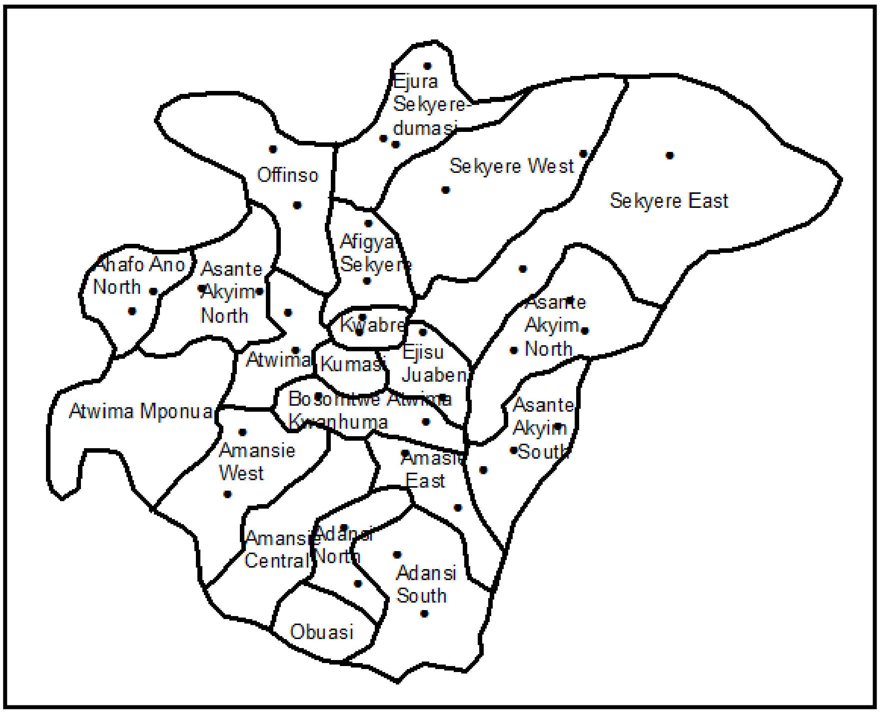

Fig. 3: Locations of the Boreholes with the Districts

3.1 Analyses of Spatial Dependencies

The Geostatiscal Analyst which is a tool of the GIS software was used to carry out the spatial analysis of depth to groundwater level; the data was treated as regionalized variable. Based on the analysis point kriging was used to develop the interpolated surface for the study area. It has been established that, a normal distributed data which is spatially dependent produces results with less uncertainty when interpolated with geostatistical techniques; it is prerequisite for any geostatistical interpolation [17]. Therefore the depth to groundwater (d_i) was investigated to ascertain its distribution and spatial dependency. The summary statistics of the data is presented in Table 2, it is clear from the mean, median and skewness values that, the data is not a normal distribution; therefore it was transformed using the log transformation. The depth to groundwater (d_i) was then used to calculate the semivariogram based on equation 1. The semivariogram plotted as a spherical model is shown in Figure 3, the semivariance is on the y axis and the distance (m) is on the x axis. The semivariogram parameters are presented in Table 2.

Table 1: Database of Borehole Information Created in GIS

Attributes of Boreholes_Water Events

OBJECTID *	X_Cordinates	Y_Cordinates	Community	District	Depth_to_Gr
1	593111	743785	Asuofua	Atwima	22
2	590968	754399	Anhwiafotu	Atwima	21
3	553003	760114	Suponso	Ahafo Ano	31
4	547288	754807	Konkori	Ahafo Ano	30
5	566474	760931	Bonkwaso	Asanti Akyem North	35
6	582788	760114	Mpasaaso	Asanti Akyem North	17
7	638730	699239	Asamama	Amansie East	52
8	623626	714801	Feneso	Amansie East	40
9	578313	720516	Adimposo	Amansie West	25
10	573822	703371	Nkaasu	Amansie West	13
11	586886	800120	Kwapanyin	Offinso	63
12	593417	784608	Dwendadi	Offinso	44
13	613420	779301	Asamang	Afigya Sekyere	21
14	613012	763380	Boamah Maase	Afigya Sekyere	25
15	611787	753174	Maase Brofoyedru	Kwabre	48
16	610971	748684	Amanfrom	Kwabre	23
17	629749	723782	Nweneso	Bosomtwi Atwima Kwahoma	48
18	599316	730722	Trabuom	Bosomtwi Atwima Kwahoma	21
19	654283	715618	kyempo	Asanti Akyem South	20
20	645670	709903	Saabo	Asanti Akyem South	29
21	654243	743785	Dwease	Asanti Akyem Nouth	20
22	674246	749092	Woramponso	Asanti Akyem East	15
23	666798	722525	Nobewan	Asanti Akyem South	22
24	669953	757561	Domakwai	Asanti Akyem East	27
25	628933	748684	Adadientem	Ejisu Juaben	31
26	634240	730314	Hwereso	Ejisu Juaben	17
27	673761	799114	Atonsoagya	Sekyere West	40
28	635056	788690	Birem	Sekyere West	39
29	698331	798690	Asesewa	Sekyere East	74
30	656692	766646	Seneso	Sekyere East	70
31	617911	803386	Bema	Ejura Sekyere Dumasi	38
32	630157	823791	Dromankoma	Ejura Sekyere Dumasi	42
33	621176	801345	Ejura	Ejura Sekyere Dumasi	40
34	621585	686226	Pipiiso	Adansi South	58
35	629341	669488	Nsokote	Adansi South	27
36	606480	693982	Kramokrom	Adansi North	46
37	610563	678061	Wamase	Adansi North	46

Table 2: Semivariogram Parameters

Count	Min	Max	Mean	Median	Std. Dev.	Skewness
37	13	74	34.5	31	15.5	0.8

Table 2: Semivariogram Parameters

Model Type	Range	Sill	Lag	No. of Lags	Nuggets
Spherical	65.0km	0.22	12km	12	0.09

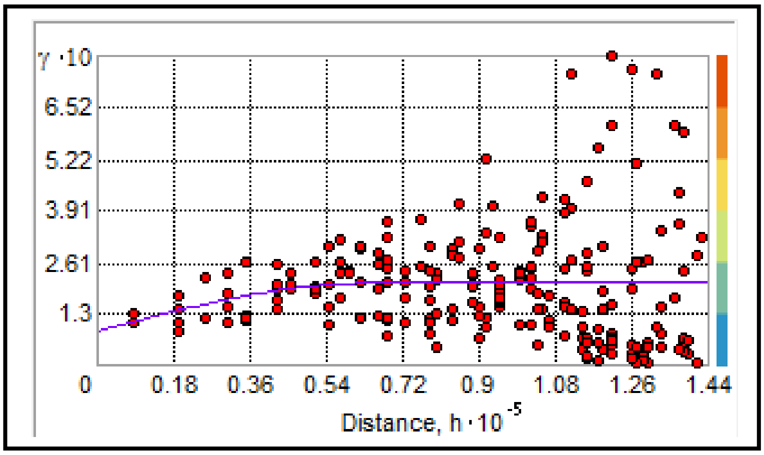

Fig.4: Semivariogram of the Borehole Depth Data

3.2 Developing the Interpolated Surface

The parameters that were derived from the semivariogram analysis were then fed into kriging module of the software to interpolate values of depth to groundwater levels within the various districts from the measured depths. Using the combined measured and interpolated values, an interpolated surface for the whole region was produced showing areas of similar depth to groundwater surface. This GIS module uses the concept of point kriging to interpolate values based on measured groundwater levels. The basic kriging equations are:

$\sum_{i=1}^{n} a_j \sigma_{xi} + \lambda = \sigma_{x_0 x_i}$, $i = 1, \ldots \ldots \ldots . n$...3

$\sum_{i=1}^{n} a_i = 1$ 4

Where a_i, a_j are the weighting coefficients

$\sigma_{x_i x_j}$ is the covariance between the samples x_i and x_j

$\sigma_{x_o x_i}$ is the covariance between the points x_o being considered and sample point x_i

λ is the Lagrange Multiplier. From these equations, best linear unbiased estimation of the of the groundwater level were interpolated at predetermined distances between measured samples to produce an interpolated surface for the whole area.

4. Results and Discussions

4.1 Overall Spatial Variability of Depth

The average depth to groundwater in the Ashanti Region was found to be 35.4m with a minimum depth of 13m and the maximum depth of 74m. These maximum depths are recorded in the Voltain areas which are known to contain very little water. This is because the Voltain System consist of sedimentary rocks mainly siltstone with high transmissivity hence it is often very difficult to locate. In the Birimian areas where there is high intrusive of quartz veins, groundwater occurs near the surface and is usually intersected at very shallow depths especially in low lying areas.

Spatial analysis of the data established that correlation between samples exist within a distance (range) of 65.0 km irrespective of the general geology of the region. Hence the variation in depth of groundwater in the district will have influence on water lying in wells that lie in a 65.0 km radius from that well. Beyond 65 km, the water levels shows no correlation but could be influenced by similarity in geology and soil profile.

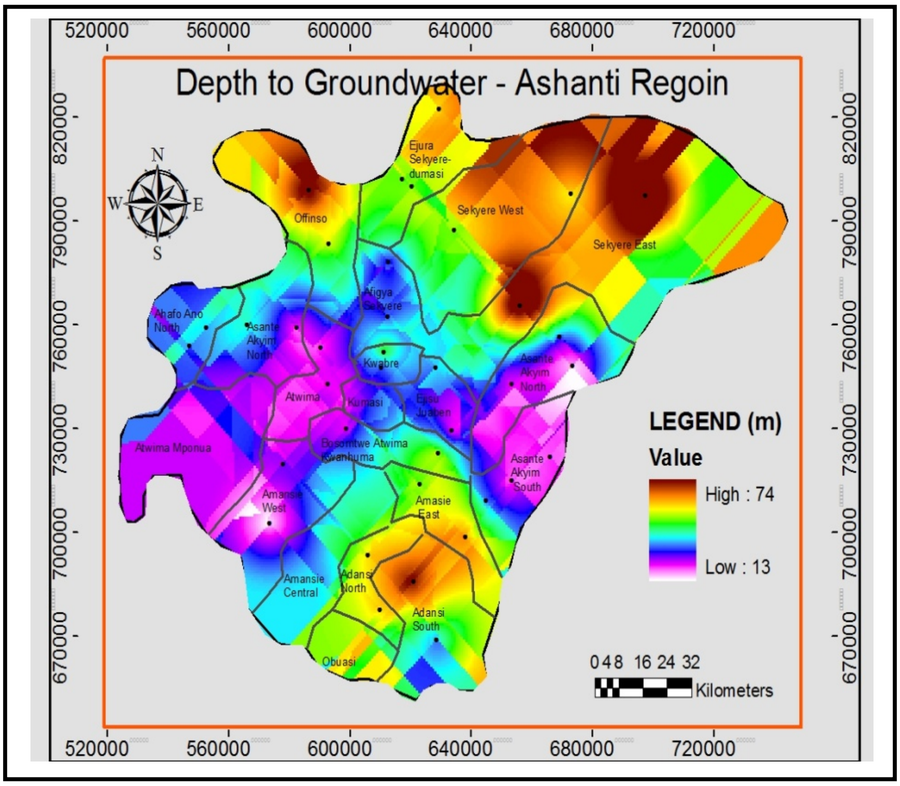

Fig. 5: Depth to Groundwater Level Map for Ashanti Region

Based on this map, the implications of groundwater level on construction activities and civil engineering structures can be evaluated during the preliminary stage of civil engineering projects. This will aid engineers and planners to know if groundwater will interfere with construction activities or foundation of structures and design against it before detail projects commence. It will go a long way to reduce the cost of construction and avert foundation failures.

5. Conclusions

The study has successfully demonstrated how groundwater level can be mapped integrating GIS with borehole data. The map shows that groundwater level is spatially distributed. Additional boreholes can be located and included in any future study to improve the accuracy of the map. A national groundwater database should be developed based on past and current groundwater exploitation to monitor the position of the groundwater table for infrastructural development and landuse planning in the Ashanti Region. This map will be very useful during the preliminary stage of projects and should not be an alternative to detail ground investigations to determine the actual position of the groundwater level.

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