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Derivation of Equations for Ground Level, Water Surface Depth and Well Depth and Determination of Flow Directions of Shallow Aquifers

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Abstract
Water is essential to maintain and sustain human life, animal and water therefore is important in that it is essential for growing food, for household water uses, as a critical input into industry, for tourism and cultural purposes, and for its role in sustaining the earth's ecosystem. The study is to determine the direction of ground water flow and also establish the parametric relationship of the measured topographical and derived data for the management of exploration and exploitation of groundwater in shallow aquifers of the study area. The methods involve the selection of ten wells within the University campus. The wells were used to obtain information on ground water topographical information. Data was acquired using a Global Positioning System (GPS) Garmin 76csx which is a satellite based equipment for position determination. The data acquired were wells coordinates and the elevation of the well location above mean seal level (amsl), while the water level values of wells as measured with the aid of an Electronic Water Level Indicator was used to measure the water surface depth from the ground surface.The relative positions of the wells were plotted using AutoCAD 2012 version and it was superimposed on the base map of the area. Suffer for window (version 8, topographical analysis software) was used to produce the contour of the Ground Level, Water surface Level and the Well Level water flow direction. Simple regression analysis was applied to the computed values according to their functional relationships, ground level-water surface level, ground level-well level and depth of well-depth of water surface. The derived equations from the measured and derived parameters were of the linear, power, exponential, logarithmic and 2nd degree polynomial types. The coefficient of determination (R^2) obtained from the various analysis ranges from 0.8485 to 0.9834. The coefficient of determination (R^2) of 0.98 is close to unity which is the highest theoretically possible thus indicating that whenever the values of the independent variables or assigned variables are known exactly, the corresponding values of the dependent or derived variables can be evaluated with a high degree of accuracy. In all the relationships the 2nd degree polynomial is consistent with higher values of the coefficient of determination. The results of the equations derived from this study indicate that there was an explanatory independent variable for ground level in predicting water surface level with a coefficient of determination r^2=98% and also the results of well level prediction of r^2 of 94% - 95% and depth of well prediction of 85% - 97% for all the five different equations considered in the study. The equations established can be a useful and essential tool in the development of sound groundwater management plans, formulation of policies for exploration and exploitation of shallow aquifers.
Keywords: Coefficient of determination, Shallow Aquifer, 2nd degree polynomial, Power equation, Exponential equation

INTRODUCTION

Water is essential to maintain and sustain human life, animal and plant (Patil and Patil, 2010). Water therefore is important in that it is essential for growing food, for household water uses, as a critical input into industry, for tourism and cultural purposes, and for its role in sustaining the earth's ecosystem (Mark *et.al*, 2002). However, access to safe drinking water and sanitation is critical in terms of health, especially for children. For instance, unsafe drinking water contributed to numerous health problems in developing countries such as the one billion or more incidents of diarrhoea that occur annually (Mark *et al.*, 2002). According to Asonye et al. (2007), availability of safe and reliable source of water is an essential prerequisite for sustained development. The availability and purity of groundwater are affected by location, construction and operation of wells (Egbulem, 2003). Adekunle *et al.* (2007) has established the contamination of wells sited close to dumping sites in southwest, Nigeria.

Of all sources of freshwater on the earth, groundwater constitutes over 90% of the world's readily available freshwater resources (Boswinkel, 2000) with remaining 10% in lakes, reservoirs, rivers and wetlands.
Groundwater differs from surface water because of the contrasting physical and chemical environment in which it occurs, although the water itself is essentially part of the same overall hydrological cycle. An increased awareness of groundwater in the hydrological cycle would result in better understanding of the resource, its susceptibility to pollution, and the need for increased efforts to protect its quality. In evaluating groundwater risk

from pollution, several methods have been used that produce groundwater vulnerability maps of varying reliability (Piscopo, 2001; Rupert 2001; Radig, 1997). Groundwater moves through aquifers from areas of recharge to areas of discharge (determined by the geological structure), normally at slow rates. These slow flow rates and long residence times, consequent upon large aquifer storage volumes, are amongst the numerous distinctive features of groundwater systems. Groundwater forms the 'invisible part' of the hydrological cycle, which can lead to misconceptions amongst stakeholders. The study is to determine the direction of ground water flow and also establish the parametric relationship of the measured and derived data for the management of exploration and exploitation of groundwater in shallow aquifers of the study area. The result of the study will provide time saving and cost effective models as a tool to use for groundwater exploitation and information on how to ensure that land use activities in the recharge area will not pose a threat to the quality of the ground water.

STUDY AREA

The University lies on latitude 7°25´N and longitude 3°25´E and it has a landed area of 9,700 hectares which is situated northwest of Abeokuta Township. It is bounded to the west by Abeokuta- Opeji-Eruwa road and to the east by Osiele-Alabata road. The site falls within the geographical region of Odeda Local Government (UNAAB Master Plan, 1991). Ten Hand-Dug wells were selected within the University campus for study. It was ensured that the ten wells selected were best representative of the area.

MATERIALS AND METHODS

This involves the selection of ten wells within the University campus. The wells were used to obtain information on ground water. The geometry data was acquired using a Global Positioning System (GPS) Garmin 76csx which is a satellite based equipment for position determination. The data acquired were wells coordinates and the elevation of the well location above mean seal level (amsl) Table 1, while the water level values of wells as measured with the aid of an Electronic Water Level Indicator was used to measure the water surface depth from the ground surface Table 2, to know the depth of the well. From these three parameters, the water surface level and Well level were deduced using the following relations

(i) Well Level = Ground Level -Depth of Well

(ii) Water Surface Level = Ground Level –Water Surface Depth

The relative positions of the wells were plotted using AutoCAD 2012 version and it was superimposed on the base map of the area (i.e. FUNAAB Map) Figure 1. Suffer for window (version 8, topographical analysis software) was used to produce the contour of the Ground Level, Water surface Level and the Well Level water flow direction Figure 2. Microsoft Excel and Notepad, were used to prepare the data in the format that is acceptable to both the AutoCAD and Suffer for window software. Simple regression analysis was applied to the computed values according to their functional relationships, ground level-water surface level, ground level-well level and depth of well-depth of water surface. The computed values were subjected to scatter plot and various trend lines, the trend lines were used to graphically display trends in data to obtain appropriate models for each functional relationship (Figures 3-5).

RESULTS AND DISCUSSION

The relative positions of the ten wells in are as shown in Figure 1 with reference to the longitude and latitude. The contour map of water level showing flow direction (Fig. 2) is a powerful tool for determination of appropriate location for the construction of wells, septic tank, grave, burial-ground and dumpsites. Pollution producing activities such as septic tank, grave, burial-ground and dumpsites must be sited downstream of a well. The flow directions in Fig. 2 is in the West-East and East-West direction, pollution producing activities must be sited downstream of a well.

The derived equations from the measured parameters are of the linear, power, exponential, logarithmic and 2nd degree polynomial types. The coefficient of determination (R^2) obtained from the various analysis (Figures 3-5 and Tables 3-5) ranges from 0.8485 to 0.9834. The coefficient of determination (R^2) of 0.98 is close to unity which is the highest theoretically possible thus indicating that whenever the values of the independent variables or assigned variables are known exactly, the corresponding values of the dependent or derived variables can be evaluated with a high degree of accuracy. The coefficients of determination (R^2) can also be described as the ratio of the explained variation to the total variation that gives an indication of how well the regression line fits the observed data.

From the summary detailed in Tables 3-5 the three different relationships were summarized and the coefficient of determination was used to categorize the equations in order of higher value of coefficient of determination. In all the relationships in Tables 3-5 the 2nd degree polynomial is consistent with higher values of the coefficient of determination. The equations 5, 10 and 15 in Tables 3-5

$$y = -0.0093x^2 + 3.283x - 141.17 \cdots\cdots\cdots\cdots r^2 = 0.9834 \cdots\cdots\cdots 5(Table3)$$

$$y = -0.0093x^2 + 3.233x - 138.75 \cdots\cdots\cdots\cdots r^2 = 0.9542 \cdots\cdots\cdots 10(Table4)$$

$$y = 0.0602x^2 - 0.0043x + 0.877 \cdots\cdots\cdots\cdots r^2 = 0.9728 \cdots\cdots\cdots 15(Table5)$$

Despite the fact that the results are derived from a small sample size, the strength of the correlations provides evidence that there is a relationship between the parameters considered and their functional relationship established.

CONCLUSION

It can be concluded that knowledge of the direction of ground water flow can be a useful tool in the management of exploration and exploitation of shallow aquifers and in the reduction or minimization of groundwater contamination. It can be used as a guide to map out the land use of the study area and thereby take steps to ensure that land use activities in the recharge area will not pose a threat to the quality of the ground water. The flow directions in Fig. 2 is in the West-East and East-West direction, pollution producing activities must be sited downstream of a well.

The results of the equations derived from this study indicate that there was an explanatory independent variable for ground level in predicting water surface level with a coefficient of determination r^2=98% and also the results of well level prediction of r^2 of 94% - 95% and depth of well prediction of 85% - 97% for all the five different equations considered in the study. The equations established can be useful and essential in the development of sound groundwater management plans, formulation of policies for exploration and exploitation of shallow aquifers. The derived equations are time saving and cost effective models that can be used for groundwater exploration, exploitation. The groundwater study is generally site specific, the range of coefficients of correlation and determination obtained for the study area are universally acceptable.

Table 1**:** Coordinates and Elevations of Wells

Wells	Coordinates		Elevation Above Mean Sea Level(amsl) (m)
W_1	N7° 13′ 29.6′′	E3° 25′ 26.8′′	150
W_2	N7° 13′ 31.4′′	E3° 25′ 27.2′′	148
W_3	N7° 13′ 34.0′′	E3° 25′ 27.1′′	144
W_4	N7° 13′ 40.0′′	E3° 25′ 29.0′′	136
W_5	N7° 13′ 24.6′	E3° 25′ 54.3′′	122
W_6	N7° 14′ 11.7′	E3° 26′ 12.7′′	126
W_7	N7° 14′ 09.2′′	E3° 26′ 11.4′′	125
W_8	N7° 14′ 08.8′′	E3° 26′ 11.7′′	126
W_9	N7° 14′ 08.6′′	E3°26′ 15.5′′	127
W_{10}	N7° 13′ 58.3′′	E3° 26′ 12.7′′	144

Table 2: The water level values of wells as measured with the aid of an Electronic Water Level Indicator

Wells	Ground level at mean sea level(amsl)(m)	Depth of Well (m)	Average Water Surface Depth (m)	Water Surface level above mean sea level(amsl) (m)	Well level above mean sea level(amsl) (m)
W_1	150	10.87	8.81	141.19	139.13
W_2	148	10.35	6.85	141.15	137.65
W_3	144	9.92	6.16	137.84	134.08
W_4	136	4.94	2.27	133.73	131.06
W_5	122	6.13	3.86	119.73	115.87
W_6	126	2.67	1.40	124.6	123.33
W_7	125	2.02	.88	124.12	122.98
W_8	126	3.41	1.65	124.35	122.59
W_9	127	6.70	3.09	123.91	120.3
W_{10}	144	11.15	8.26	135.74	132.85

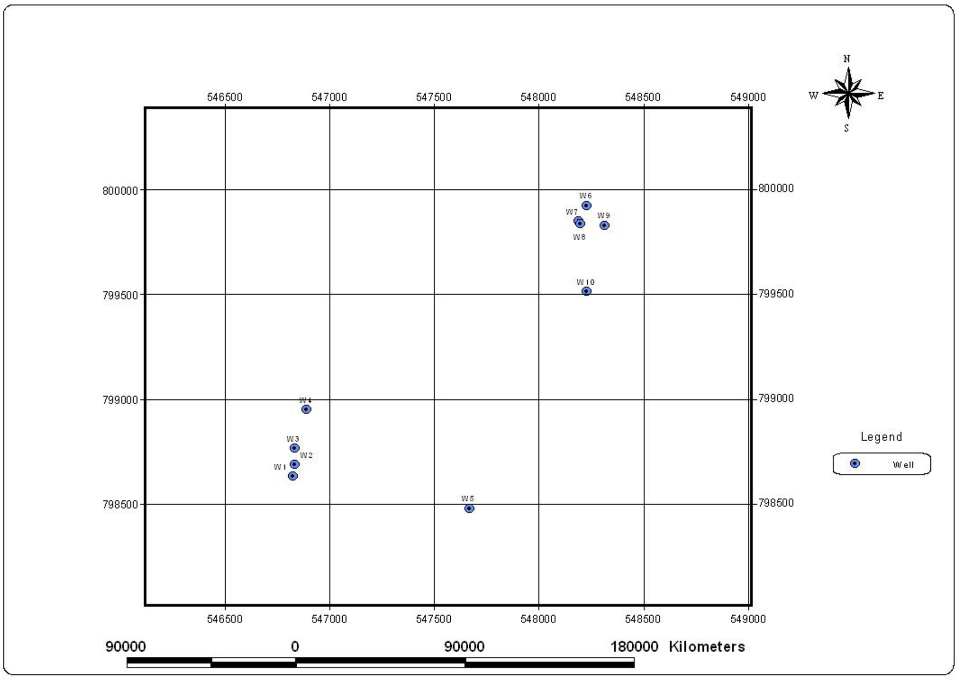

Fig. 1: Relative Positions of the Ten Wells with the Longitude and Latitude

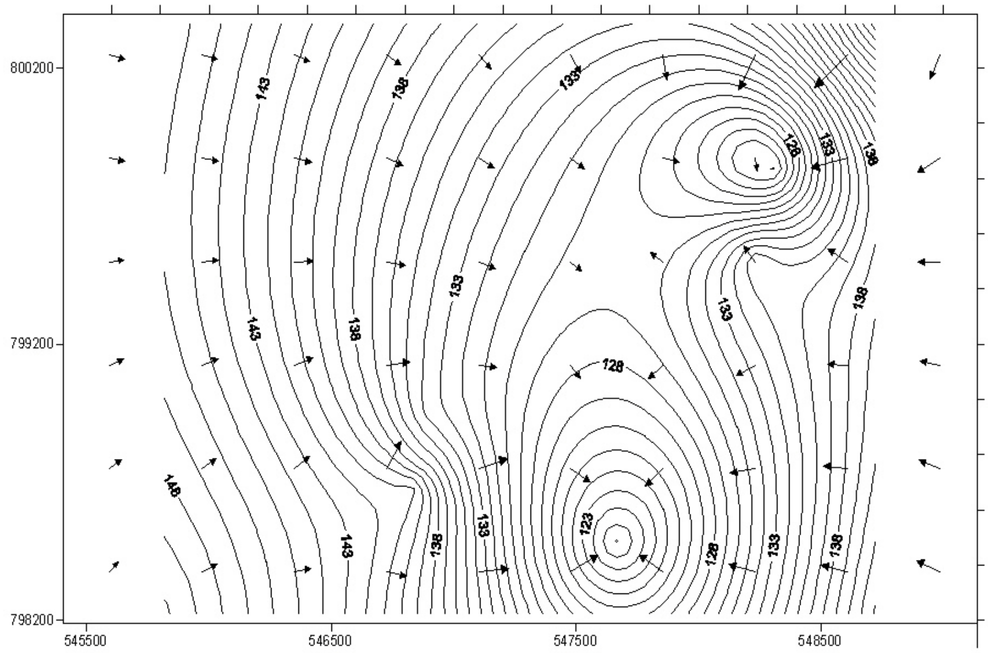

Fig. 2: Contour Map of Water Level Showing Flow Direction

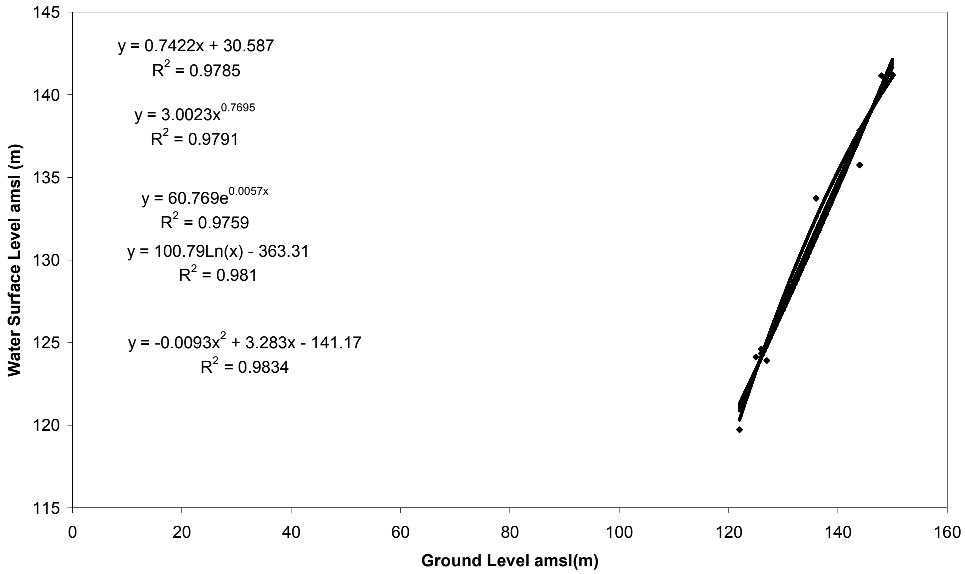

Fig 3 : Ground Level amsl and Water Surface Level amsl

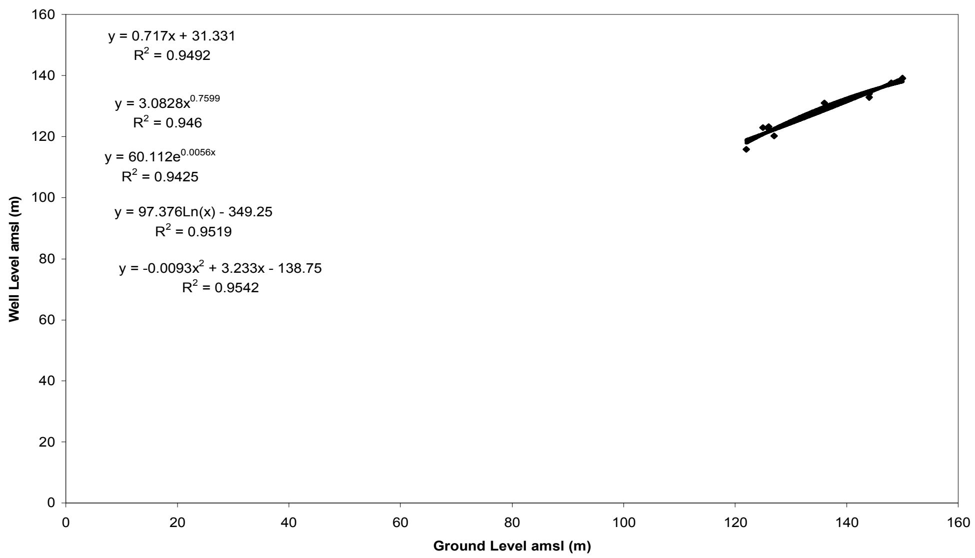

Fig. 4: Ground Level amsl and Well Level amsl (m)

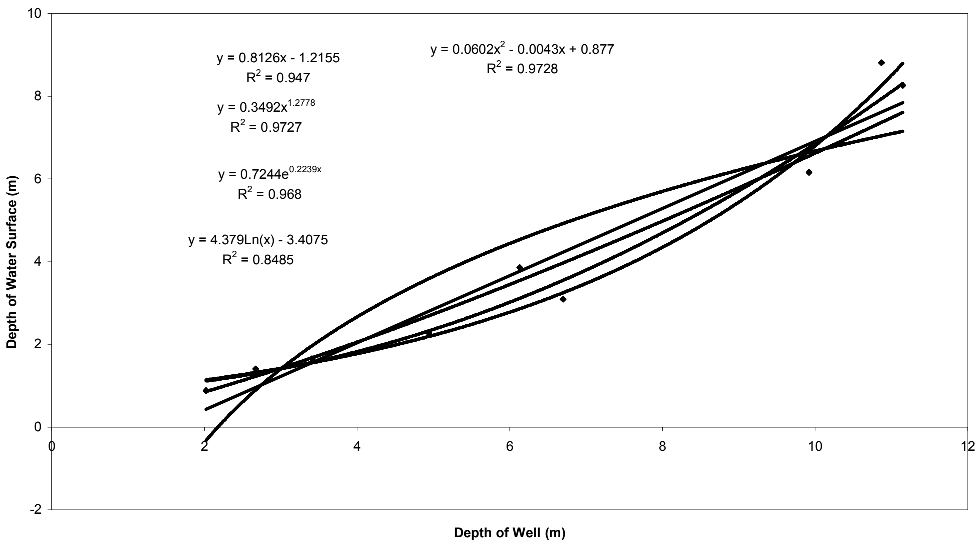

Fig 5: Depth of Well and Depth of Water Surface (m)

Table 3: Summary of various trend line equations for Ground Level (amsl) and Water Surface Level (amsl)

Equations	Equation Number	Type of Equation	Coefficient of Determination R^2
$y = 0.7422x + 30.587$	1	Linear	0.9785
$y = 3.0023x^{0.7695}$	2	Power	0.9791
$y = 60.769e^{0.0057x}$	3	Exponential	0.9759
$y = 100.79Ln(x) - 363 - 31$	4	Logarithmic	0.981
$y = -0.0093x^2 + 3.283x - 141.17$	5	2nd degree polynomial	0.9834

Table 4: Summary of various trend line equations for Ground Level (amsl) and Well Level (amsl)

Equations	Equation Number	Type of Equation	Coefficient of Determination R^2
$y = 0.717x + 31.331$	6	Linear	0.9402
$y = 3.0828x^{0.7599}$	7	Power	0.946
$y = 60.112e^{0.0056x}$	8	Exponential	0.9425
$y = 97.376Ln(x) - 349.25$	9	Logarithmic	0.9519
$y = -0.0093x^2 + 3.233x - 138.75$	10	2nd degree polynomial	0.9542

Table 5: Summary of various trend line equations for Depth of Well and Depth of Water Surface

Equations	Equation Number	Type of Equation	Coefficient of Determination R^2
$y = 0.8126x - 1.2155$	11	Linear	0.947
$y = 0.3492x^{1.2778}$	12	Power	0.9727
$y = 0.7244e^{0.2239x}$	13	Exponential	0.968
$y = 4.379Ln(x) - 3.4075$	14	Logarithmic	0.8485
$y = 0.0602x^2 - 0.0043x + 0.877$	15	2nd degree polynomial	0.9728

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