PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (6) 1789-1798 June 2024

Spatial Model for Predicting the Cost of Constructing Hand-Dug Wells in Abeokuta City, Nigeria

***[1]OYEDEPO, JA; [2]OYEDEPO, EO**

*[1]*Institute of Food Security, Environmental Resources and Agricultural Research, Federal University of Agriculture, Abeokuta, Nigeria*
[2]*Department of Economics, Augustine University, Ilara-Epe, Lagos Nigeria*

**Corresponding Author Email: oyedepoja@funaab.edu.ng*
**ORCID: https://orcid.org/0000-0001-7394-1416*
**Tel: +2348038648941*

Co-Author: lolaoyedepo1@gmail.com

ABSTRACT: The heavy reliance on groundwater sources, the high cost and difficulties in accessing groundwater from a basement complex in Abeokuta necessitate the development of a simple prediction model. Hence, the objective of this paper was to develop a spatial model for prediction of the cost of constructing hand-dug wells in Abeokuta city, Nigeria, using geographic information systems. The static water level (SWL) of wells was measured across the city, and the digital terrain model (DTM) of the city was created in the GIS. Map algebra was applied to determine the depth and predict the overall cost of well construction. The map of the overburden removed was derived as the algebraic difference between the DTM and SWL extended down by the height of four concrete rings (OVERBURDEN = DTM – SWL+ 4 rings below the SWL). The map of the total cost of well construction in any part of the metropolis was produced by multiplying the sum of the cost of one unit of concrete ring and excavation of the depth of one concrete ring with the map of overburden. The model was validated by an empirical investigation of eight randomly selected wells. The results revealed relatively good accuracy, with correlation coefficients of 0.94, R2 values of 0.76, RMSE values of 0.27 and mean absolute percentage errors of 9.24 and 3.23 for the SWL and construction cost, respectively. The paper concludes that such spatial decision support is good for municipal water planning.

DOI: https://dx.doi.org/10.4314/jasem.v28i6.18

Cite this Article as: OYEDEPO, JA; OYEDEPO, E. O. (2024). Spatial model for predicting the cost of constructing hand-dug wells in Abeokuta city, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (6) 1789-1798

Dates: Received: 21 February 2024; Revised: 22 March 2024; Accepted: 20 April 2024 Published: 09 June 2024

Keywords: Spatial system, Predictive assessment, Hand-dug wells, Correlation coefficient

People worldwide will be willing to pay for an uninterruptible clean water supply (Ahsan *et al.*, 2021; Amoah and Moffatt, 2021 Alaerts, 2022). Many feel that the provision of potable water is the obligatory and exclusive responsibility of the government, but when this expectation fails, the improvement of access to a continuous supply of water in private capacities becomes inevitable (Gadebo *et al*., 2010). The heavy dependence of the people of the Abeokuta metropolis on boreholes and shallow (hand-dug) wells clearly illustrates the above assertion. As of 2007, there were more than 2,280 hand-dug wells and 38 boreholes in the city (Oluwasanya *et al.*, 2011). The ability to excavate shallow wells and access year-round water supplies has removed the reliance on the government provision of pipe-borne water in many towns and cities. Today, most homes in Nigeria obtain water from shallow or tube wells, and this brings great relief to the people. However, the cost of establishing these wells, particularly deep wells ranging from geophysical surveys to actual drilling and excavation of overburdens, is far beyond the reach of the common man. As suggested by Ufoegbune *et al*. (2010), the total daily water requirement of the Abeokuta

**Corresponding Author Email: oyedepoja@funaab.edu.ng*
**ORCID: https://orcid.org/0000-0001-7394-1416*
**Tel: +2348038648941*

populace exceeded 163 million litres daily supplied by the government as of 2000. Although the city is "laced" by many rivers and streams, they are highly polluted and unfit for domestic use in their untreated form (Oyedepo *et al*., 2015). Although groundwater is free, the cost of removing the overburden (earth) before accessing it is high. In many cases, underlying obstacles have led to well project abandonments. Tools aiding in determining the feasibility and cost of completing hand-dug wells could alleviate this burden. A tera-meters are particularly useful, where the underlying materials consist of hard pans or rock formations at shallow depths (Salati and Adeyemo, 2021). The challenge, however, is the cost and the technicality of handling such equipment. There should therefore be a cheaper and effective alternative in this age of digital technologies and artificial intelligence.

Geographical information systems (GISs) have been useful in many spatial decision-support applications (Yousif, 2020; Cerreta *et al.,* 2021; Saadi et al., 2021; Aykut, 2021). As a useful tool in several aspects of subsurface exploration, GIS can also be useful in groundwater prospecting and costing.

MATERIALS AND METHODS

Data types and data processing: The geographic coordinates of representative samples of hand-dug wells and their corresponding static water levels were obtained across the city. A geologic map, recent cloud-free satellite images and digital elevation images of the city were acquired. The URLs for these data are presented below. The elevation data were obtained from https://www.earthdata.nasa.gov/sensors/srtm, city boundaries from Google Earth Studio; https://www.google.com/earth/studio/, and the geology map was obtained from the Nigerian Geological Survey Agency; https://ngsa.gov.ng/geological-maps/

Base map production: The perimeter of the city conurbations was captured through on-screen digitization of a high-resolution Google Earth (GE) image for 2003 and exported as a .kml file. The GE kml file was imported into ArcGIS, where it was converted to a shapefile as the base map into which other datasets were fitted. Similarly, the scanned geology map was georeferenced into a unified unprojected coordinate system (WGS 1984). The geology map was digitized head-up in ArcGIS, similar to the basemap. All vector maps were then converted to raster format using the same grid cell size of 2.78E-04. A grid form of the boundary map was produced and used as a template for subsequent surface interpolations performed in the study. A map of the city boundary is presented in Figure 1.

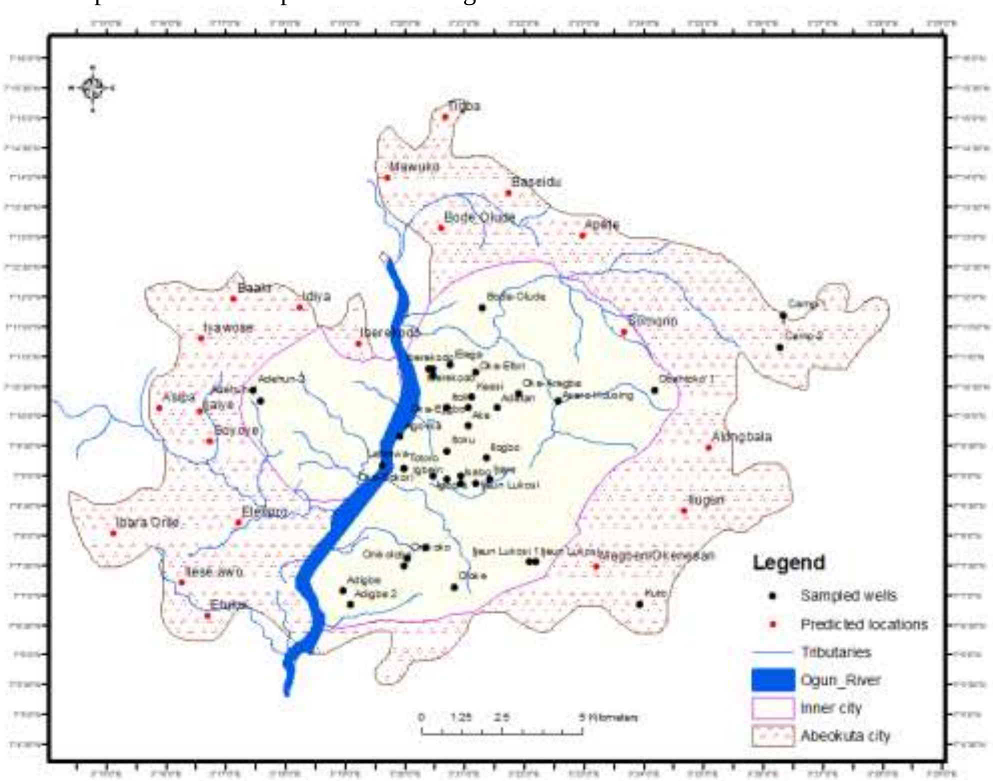

Fig 1: Map of Abeokuta Metropolis, with sampled wells

Well Inventory: The geographical coordinates of each well were obtained, and more than 2,000 wells were identified in the city of Abeokuta. The spatial distribution of the comprehensive list of wells guided the selection of wells where measurements were eventually taken. The geographical coordinates of the 40 randomly selected wells based on the proportion of wells to human population density were obtained with the aid of Garmin etrex 10 Global Positioning System (GPS) hand-held receivers. The coordinates of each sampled well were recorded in a Microsoft Excel worksheet from each well and were tabulated in a spreadsheet against their respective names and assigned serial numbers of static water levels and other parameters.

Static water level determination of wells: The wetted tape method was adopted for the SWL. A 100-meter steel measuring tape with a lead weight attached to the end was lowered into the well. Eight to ten feet of the tape were dried and covered with carpenters' chalk before each measurement. The tape was lowered into the well until a portion of the chalk was below the waterline. An even foot mark on the tape at the top of the casing was aligned and marked such that when the tape was pulled to the surface to read the mark where the line was wet, the wetted mark was easily subtracted from the mark at the casing to determine the actual depth of the water table. The depth of the water table was taken to be the depth of the overburden to be removed before reaching the water table, as shown in the illustration in Figure 2.

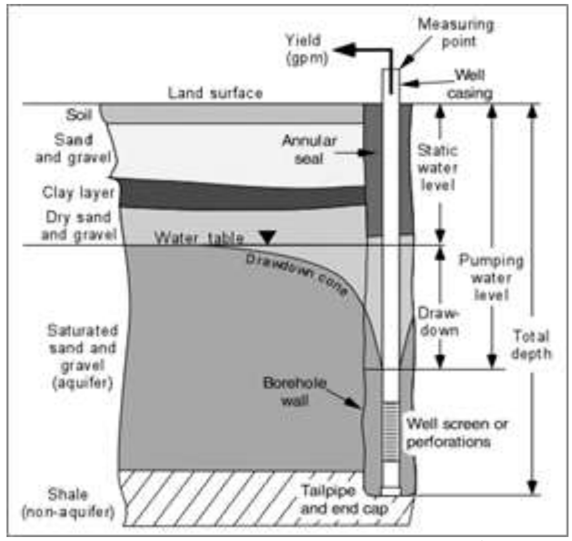

Fig 2: SWL illustration by Montana Ground-Water Information Center - MBMG, 2018)

Normally, excavation in hand-dug wells does not terminate at the static water level; it is further excavated approximately 4 to 5 meters below the SWL. The well holes are protected with 1-m tall concrete rings to prevent the well from caving in and burying the human excavators alive. An atypical concrete cement ring costs N5,000 ($15.00) per unit, while the cost of excavations of the volume of earth that contains one ring is approximately the same as that of N5,000 ($15.00) samples of the protective ring.

Plate 1: 1 m high concrete rings for lining the wells and excavation of a hand-dug well

Digital Terrain Analysis: Although groundwater levels follow surface topography (Mulyadi *et al*., 2020; Frey *et al*., 2021), for correctness, this assumption does not always hold true in all cases. As such, it was necessary to combine empirical measurements to investigate the actual static water levels, especially at the peak of the dry season, when hand dug wells are known to be constructed. This implies that the distance of the static water level from the ground surface can provide a rough estimate of the amount of the overburden to be removed before obtaining water. Then, the actual depth of the well can be determined from the number of rings below the static water level. Shuttle radar topographic mission (SRTM) data are available for digital terrain models (DTMs). These data are very useful for providing hydrological information (Sirisena *et al*., 2020; Jayaprathiga *et al*., 2022). For instance, it was possible to determine the water table across the entire city by subtracting the surface interpolated map of the SWL from the DTM. It was also possible to determine the total depth of the overburden to be removed by adding the heights of the 4 rings to the difference between the DTM and the SWL. **Spatial interpolation**: Any phenomenon occurring as continuous data can be modelled into surfaces (Antal *et al*., 2021). In a GIS, such a data manipulation exercise is broadly regarded as spatial interpolation. In this study, the iso-concentration map(s) of the desired water parameters, such as the static water levels, are produced by the kriging technique (Navas and Machin, 2002). The interpolation of the SWLs of the selected wells, which were predicted for locations that were not sampled. MBMG (2018) regarded the SWL as the water table at that point. The groundwater table, also known as the water table or phreatic surface, is the level below which the ground is saturated with water. It represents the upper boundary of the saturated zone, where pore spaces in the soil or rock are filled with water. The groundwater table fluctuates seasonally and in response to changes in precipitation, evaporation, and groundwater pumping. Since digital terrain modelling has been applied for terrain analysis of heights and depths (McLaren and Kennie, 2020), it is possible to interpolate various static water levels to determine the water table at different positions across a city.

Map algebra: The two surfaces (static water level and digital terrain model) were produced via the same method with a grid cell size of 2.78E-04; thus, the algebraic operations were quite easy. The map algebra started with the generation of a grid map for the cost of rings as follows: $Map\ of\ cost\ ring = [(DTM\ x\ price\ of\ 1\ ring)/DTM]$. The result was a grid map with a uniform ring price across the city.

The price of the concrete rings is assumed to be constant throughout the metropolis. Similarly, the cost of overburden excavation at one ring depth is assumed to be constant across the city, so the grid map of the excavation cost for one ring was also produced in the same way that the map of the cost of one ring was produced. The map of excavation is simply produced by first interpolating the static water levels (obtained empirically along with the geographic coordinates during the field data collection). The obtained grid map of the SWL was then imported into the map calculator in ArcGIS, and the heights of the 4 rings were added to the map. The grid map produced here is the thickness of the overburden to be removed. Thus, in the map calculator, we have

$$Map_{(overburden)} = Map_{(SWL)} + height\ of\ 4\ rings\ below\ SWL\ \ldots\ldots (1a)$$

$$\text{Or, Total overburden} = \text{grid map of DTM} - \text{grid map of SWL} + \text{No of rings below SWL} \ldots (1b)$$

Our assumption here again is that well excavators normally stop digging when the well bottom becomes soft, clayey and muddy. This is because of the fear that the well might cave in from this point and bury them alive. This point is usually approximately 4 rings below the static water level. The map of the water table is simply obtained by subtracting the grid map of the SWL from the grid map of the DTM

$$\text{Water table map} = \text{grid map of DTM} - \text{grid map of SWL} \ \ldots\ldots (2a)$$

In this paper, our focus is on the prediction of the cost of excavating wells up to the water table in newly developing sites or where there are no existing wells. The cost elements therefore come in through the manipulation of the map of overburden in equation 1. To actualize this, a new algebraic equation will be formulated for the cost of removal of overburden up to the water table, as stated in equation 2b:

$$Map_{(overburden\_cost)} = Map_{(overburden)} * cost\ of\ 1\ meter\ depth\ \ldots\ldots (2b)$$

Equation 2 was modified since the excavation will go beyond the static water level. The constant depth of 4 m in our assumption that the well excavators do not extend beyond 4 m after the water table has been reached was integrated into the equation. With this assumption, equation 2 becomes modified to produce equation 3:

$$\text{Cost Map}_{(\text{H-dug well})} = (Map_{(o'burden)} + 4) * (Unit\ cost\ of\ excarvation) + cost\ of\ 1\ concrete\ ring) \ldots\ldots (3)$$

Equation 3 produced a predictive cost map for developing a hand dug well in any part of the city metropolis. From this map, it was possible to extract a cost table for hand-dug wells even in locations where wells have not been dug.

Validation of the results: Validation of the results of our predictive models was performed at 8 locations with new wells to empirically obtain the data to be used for checking the goodness of fit of the model. One commonly used measure is the coefficient of determination, also known as the R-squared (R^2). The figure shows how well the model explains the variation in the actual data points.

When $R^2 = 1$, we have a perfect prediction,
When $R^2 = 0$, the model does not explain any of the variability in the data.

However, when $R^2 < 0$, the prediction performance of the model decreases. High R^2 values indicate a better fit of the predicted values to the actual data. The R^2 was computed as follows: $R^2 = 1 - \left(\frac{SS_{res}}{SS_{tot}}\right)$

Where SS_{res} is the sum of squares of residuals (differences between the predicted and actual values) and SS_{tot} is the total sum of squares, which measures the total variance in the actual data. Higher

Kumar *et al*. (2022) and Nasirtafreshi (2022) suggested that it is more reliable to use R^2 in conjunction with other measures, such as correlation (r), mean absolute error (MAE), root mean square error (RMSE) and mean absolute percentage error (MAPE). The mean absolute error (MAE) is the average of the absolute differences between the predicted and actual values. $MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$ where yi is the actual measurement, $\hat{y}_i$ is the forecasted value, and n is the total number of samples. The root mean square error (RMSE) is the square root of the MSE. $RMSE = \sqrt{MSE}$

RESULTS AND DISCUSSION

Spatial Distribution of Suitable Locations: Figure 3 shows that Abeokuta is underlain by hornblende biotite gneiss, granite, porphyritic granite and porphyritic gneiss. Excavating hand-dug wells in areas such as Iberekodo and Idiya is challenging due to the presence of granite formations. In central areas such as Itoko and Kuto, dynamite needs to be blasted through granite and porphyritic granite for well construction. This increases the cost. However, in the eastern parts, such as Obantoko and Asero, reaching the water table is easier. Geological properties such as permeability and weathering affect well construction and groundwater availability. Granite formations are typically impermeable and can still facilitate groundwater flow through fractures and weathered zones; hence, dynamite is used when it is encountered in wells. These materials provide stable substrates for well construction. Hornblende biotite gneiss, with its layered structure and moderate permeability, allows easy drilling and excavation. Porphyritic granite, with large crystals, potentially enhances permeability, aiding in groundwater movement.

Digital terrain model and relative depth of the water table: Analysing hand-dug well data overlaid on a digital terrain model (DTM) revealed a correlation between terrain elevation and water table depth. Spatial interpolation techniques applied to static water level measurements can predict depths at locations lacking direct data.

Figure 3 shows the 3D city terrain, while Figure 4 shows the digital terrain map of the Abeokuta metropolis. The highest points (coffee brown) and the lowest points (pink/white) were visualized. Areas of low elevation or depressions in the terrain coincide with shallow water tables, while higher elevations may indicate deeper water tables. Figure 5, however, is the map of static water levels across the metropolis.

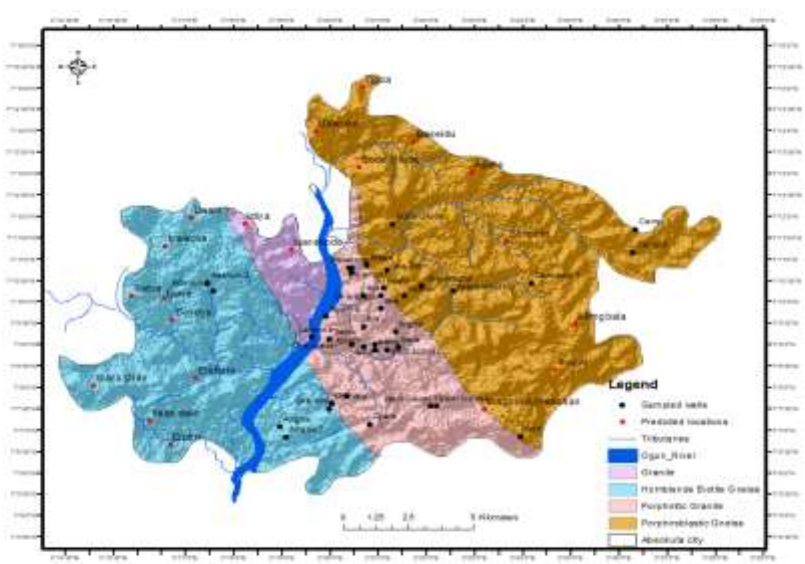

Fig 3: Map of the geology of Abeokuta showing basement complex formation.

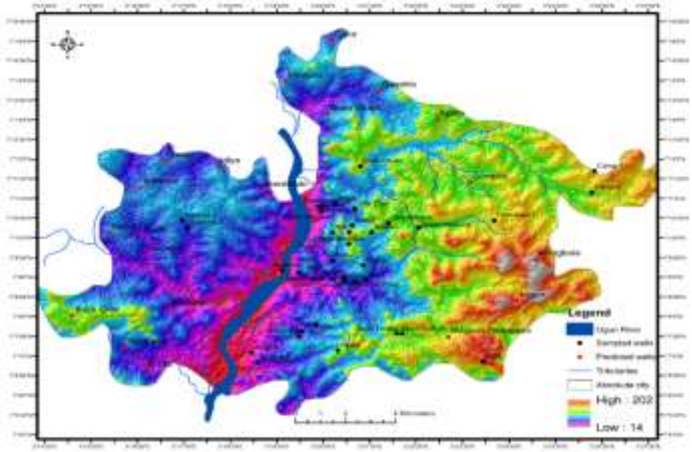

Fig 4: Map of the digital terrain of the Abeokuta metropolis

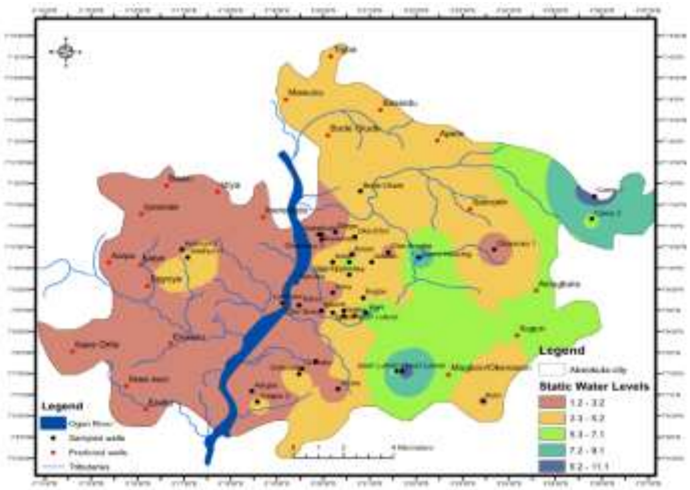

Fig 5: Map of spatially interpolated static water levels of known wells in the city

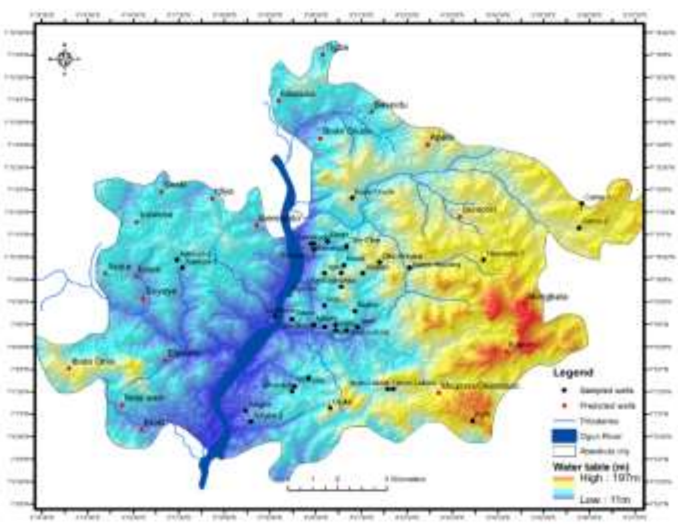

Fig 6: Map of the relative depth of the water table in the metropolis

The SWL map was derived from the spatial interpolation of the empirically measured SWLs of wells with known coordinates and geographic locations. The map reveals that the western part of the city has the shallowest set of wells, as depicted by the SWL range of 1.3-3.2 meters. The geology and the DTM maps in Figures 3 and 4 explain the results of the SWL. The eastern and central portions of the city have the lowest points in the city, which includes the inland valleys of the Ogun River and its tributaries. The eastern part of the city has the highest locations and, incidentally, the deepest set of wells. By applying the algebraic function of GIS, the map of static water levels can provide further information on the relative depth of water tables. Subtracting the SWL from the digital terrain produces a new map of the relative depth of the water table across the city, as shown in Figure 6. At a glance, this kind of map can aid in decision making, as it provides a rough estimate of how deep one prospecting for groundwater from shallow aquifers may be before water access. Beyond mere visualization, it is possible to develop a cost prediction model that will provide insight into the financial implications of constructing hand dug wells in any part of the Abeokuta metropolis. This decision support is quite easy if the costs of labour and materials are determined.

Cost Prediction Models: The predictive models considered two variables, namely, the cost of concrete rings and labour for excavation, which are both dependent on the depth to the water table. Soil type, geology and accessibility and other variables were deliberately excluded from the computation because excavators put labor charges on depth. The total cost of constructing a well cost map (complete hand-dug well) = (map (overburden) + 4) * (cost of 1 (meter excavation) + cost of 1 concrete ring)) is determined by the total overburden excavated, which is congruent with the well depth multiplied

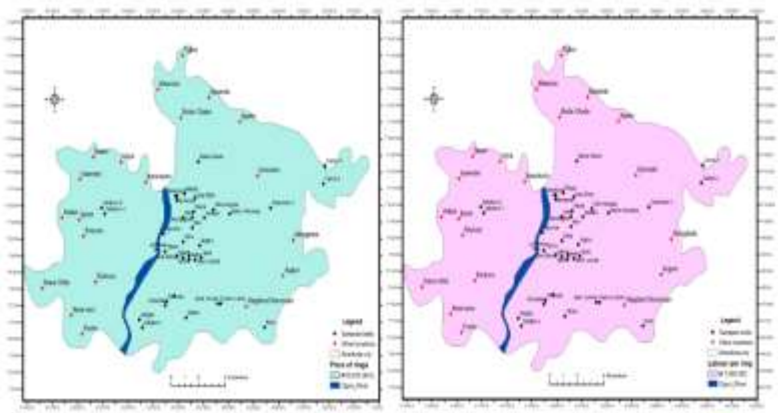

Fig 7: Map of the unit cost of ring and labor

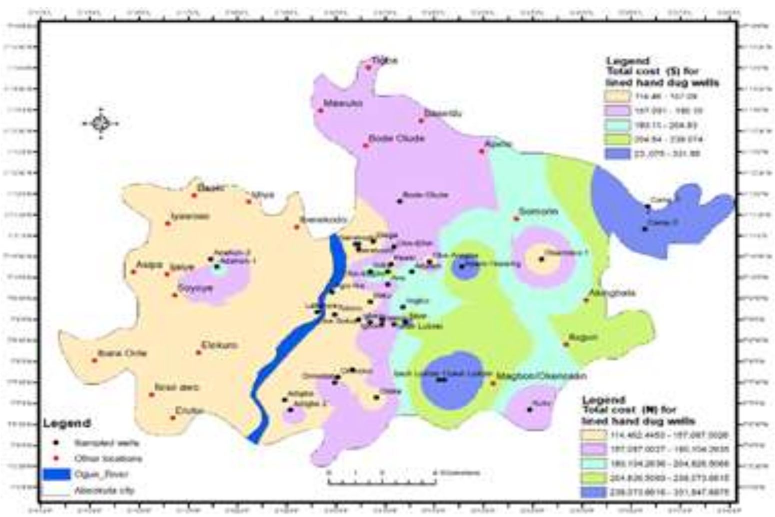

Fig 8: Map of the variability distribution of the total overburden to be removed to access water

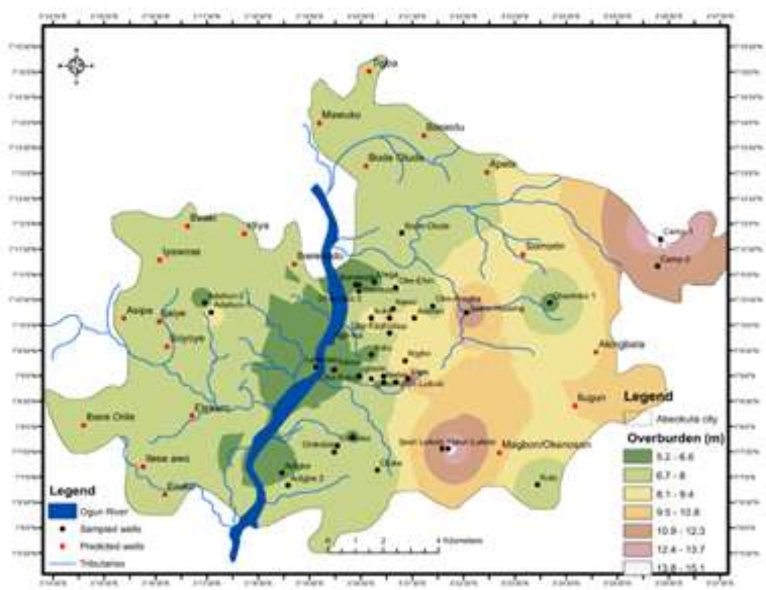

Fig 9: Variability distribution of the cost of hand-dug wells across Abeokuta

Figure 8 is the map of overburden removed, while Figure 9 presents the map total cost. Locations close to the Ogun River flood plain are shallow and require less excavation—between 5.2 and 6 meters. The western part of the city requires more excavation up to 15 meters. The spatial distribution of the cost of constructing hand-dug wells across the Abeokuta metropolis reveals that it is less expensive to construct hand-dug wells in the western part of the city than in the eastern part. This is because the water table in the west is shallower than that in the east of the city. Table 1 presents the cost of construction of wells as predicted across 40 locations in which the wells were previously sampled. Table 1 computes costs based on well depth, concrete ring usage, and labor expenses for overburden removal. Ijeun Lukosi had the highest cost at N332,200 due to the 15.1-meter well. Costs correlate directly with well depth. On average, 3.7 rings are below the static water level, approximately 4 meters deep. The model assumes that adding 4 meters to the static water level depth provides the well depth at any location within the Abeokuta metropolis. In Table 2, however, the predicted cost extracted from the map of total cost in Figure 9 was validated to determine the accuracy of the GIS-supported prediction model. The correlation analysis between the predicted and actual SWL and total cost yields an r value of 0.94. This is close to unity and thus indicates that the forecasting is good. The R^2 value of 0.76 is also high, indicating a very good fit of the prediction to the actual value. The mean absolute percentage error value of 3.23% in the predicted cost of hand-dug well drives home the accuracy level of the GIS-based predictive models for this study is high and therefore can be recommended.

Table 1: Predicted cost of well construction across 40 locations

S/N	Location	Lat	Long	S/water level	Spot heights	Total Over burden	Total Cost for lined well (N)
1	Adatan	7.169	3.359	5.2	97	9.2	202400
2	Adehun-1	7.171	3.293	5	68	9	198000
3	Adehun-2	7.174	3.291	1.8	76	5.8	127600
4	Adigbe	7.118	3.316	1.57	40	5.57	122540
5	Adigbe 2	7.114	3.318	3.68	49	7.68	168960
6	Ago-Ika	7.161	3.332	1.2	43	5.2	114400
7	Ake	7.164	3.351	3.35	107	7.35	161700
8	Asero Housing	7.171	3.376	8.42	110	12.42	273240
9	Bode-Olude	7.197	3.355	3.65	111	7.65	168300
10	Camp-1	7.195	3.439	10.36	105	14.36	315920
11	Camp-2	7.186	3.438	6.95	105	10.95	240900
12	Elega	7.181	3.346	2.05	68	6.05	133100
13	Ibara Housing	7.13	3.339	2.46	81	6.46	142120
14	Iberekodo	7.18	3.341	1.64	57	5.64	124080
15	Iberekodo	7.18	3.34	1.67	50	5.67	124740
16	Igbein	7.149	3.345	4.8	49	8.8	193600
17	Igbore	7.15	3.341	1.8	49	5.8	127600
18	Ijaye	7.149	3.357	8.3	71	12.3	270600
19	Ijeun Lukosi	7.148	3.353	2.94	117	6.94	152680
20	Ijeun Lukosi	7.126	3.37	11.1	113	15.1	332200
21	Ijeun Lukosi 1	7.126	3.368	6.2	117	10.2	224400
22	Ilogbo	7.155	3.356	5.1	95	9.1	200200
23	Isabo	7.148	3.349	2.6	60	6.6	145200
24	Ita Oshin	7.081	3.185	1.7	75	5.7	125400
25	Itoko	7.169	3.345	5.1	96	9.1	200200
26	Itoku	7.157	3.345	1.6	65	5.6	123200
27	Keesi	7.172	3.352	2.3	90	6.3	138600
28	Kuto	7.1142	3.399	3.14	170	7.14	157080
29	Lafenwa	7.153	3.327	1.85	26	5.85	128700
30	Obantoko 1	7.174	3.403	2.41	143	6.41	141020
31	Obantoko 2	7.178	3.341	3.3	50	7.3	160600
32	Oke-Aregba	7.173	3.365	2.55	116	6.55	144100
33	Oke-Bode	7.15	3.349	4.27	62	8.27	181940
34	Oke-Efon	7.179	3.353	4.2	89	8.2	180400
35	Oke-Ejigbo	7.169	3.351	7.2	108	11.2	246400
36	Oke-Sokori	7.152	3.333	2.58	57	6.58	144760
37	Oloke	7.119	3.347	2.75	99	6.75	148500
38	Onikoko	7.127	3.334	2.4	64	6.4	140800
39	Onikolobo	7.125	3.333	4.28	69	8.28	182160
40	Totoro	7.152	3.333	2.18	57	6.18	135960

Unit labour cost = N7,000; cost of rings = N15,000. The value in USD is obtained by dividing the total cost by 1000

Table 2: Validation of the predicted depth and total cost for wells in other locations

S_N	Validation sites	Longitude	Latitude	Static water levels (m)		Total cost of hand -dug well (N)	
				Actual	Predicted	Predicted	Actual cost
1	Sabo 1	3.3165490	7.1786560	2.41	2.72	141020	147882
2	Sabo 2	3.2994540	7.1786700	3.42	3.11	163240	156407
3	Gbagura	3.3312680	7.1604510	1.12	1.25	112640	115501
4	Akomoje	3.3380610	7.1879680	2.12	2.59	134640	145031
5	Elega	3.3598962	7.1889898	3.70	3.70	169400	169470
6	Ago-Odo 2	3.3324770	7.1581820	2.23	1.83	137060	128346
7	Obantoko 1	3.4030000	7.1740000	2.41	2.41	141020	141028
8	Obantoko 2	3.3410000	7.1780000	3.30	3.29	160600	160342
	Model Fitness test			**Static water levels**		**Total cost hand -dug well**	
1	R-squared (R^2)			0.76		0.76	
2	Correlation coef. (r)			0.94		0.94	
3	Mean Absolute Deviation (MAD)			0.20		4,499.63	
4	Root mean square Error (RMSE)			0.27		5,978.51	
5	Mean Absolute Percentage Error (MAPE)			9.24		3.23	

Insights from the study: Predictive models can be enhanced to incorporate variables such as material costs and excavation resistance. Spatial decision support systems help optimize well placement for improved water accessibility and reduced construction expenses. Future studies can explore socioeconomic impacts. Policymakers and water managers can utilize these insights to enhance well planning and maintenance for a sustainable water supply in Abeokuta city.

Conclusion: This study illustrates how GIS aids in the predictive cost assessment of hand-dug wells by correlating terrain elevation with water table depth. This suggests that deeper wells incur greater construction expenses, emphasizing the role of GISs in optimizing well placement. This research recommends socioeconomic impact assessments and advocates for policymakers' use of GISs for informed decision-making.

REFERENCES

Akinse, AG; Gbadebo, AM (2016). Geologic Mapping of Abeokuta Metropolis, Southwestern Nigeria. *Int. J. Sci. Eng. Res.* 7(8): 979 - 983.

Alaerts, GJ (2022). Water, physically connected yet institutionally fragmented-Investing in its strategies, asset classes, and organizations, In: Leflaive, X; Dominique, K; Alaerts, G (Eds.) Financing investment in water security: Recent Developments and Perspectives. ScienceDirect, Elsevier p. 17

Ahsan, MN; Hadiujjaman, S; Islam, MS; Nasrin, N; Akter, M; Parvin, GA; Hossain, MS (2021). Willingness to pay for improved safe drinking water in a coastal urban area in Bangladesh. *Water Policy* 23 (3): 633 - 53.

Amoah, A; Moffatt, PG (2021). Willingness to pay for reliable piped water services: evidence from urban Ghana. *Environ. Econs. Policy Studies*, 23 (4): 805 - 829.

Antal, A; Guerreiro, PM; Cheval, S (2021). Comparison of spatial interpolation methods for estimating the precipitation distribution in Portugal. *Theor. Appl. Clim.,* 145 (3): 1193 - 1206.

Aykut, T (2021). Determination of groundwater potential zones using geographical information systems (GIS) and analytic hierarchy process (AHP) between Edirne-Kalkansogut (northwestern Turkey). *G,water, Sust Devt,*, 12: 100545.

Cerreta, M; Panaro, S; Poli, GA (2021). Spatial decision support system for multifunctional landscape assessment: a transformative resilience perspective for vulnerable inland areas. *Sustainability*, 13 (5): 2748.

Frey, SK; Miller, K; Khader, O; Taylor, A; Morrison, D; Xu, X; Berg, SJ; Hwang, HT; Sudicky, EA; Lapen, DR (2021). Evaluating landscape influences on hydrologic behavior with a fully-integrated groundwater–surface water model. *J. Hydrol.*, 602:126758.

Gbadebo, AM; Oyedepo, JA; Taiwo, AM (2010). Variability of nitrate in groundwater in some parts of Southwestern Nigeria. *Pacific J. Sci. and Technol.* 11 (2): 572 - 584.

Jayaprathiga, M; Cibin, R; Sudheer, KP (2022). Reliability of hydrology and water quality simulations using global scale datasets. JAWRA *J. American Water Res. Assoc.* 58 (3): 453 - 470.

Kumar, S; Kolekar, T; Kotecha, K; Patil, S; Bongale, A (2022). Performance evaluation for tool wear prediction based on Bidirectional, Encoder–Decoder and Hybrid Long Short-Term Memory models. *Intern. J. Qual. Reliability Manage.* 39 (7): 1551-1576.

McLaren, RA; Kennie, TJ (2020). Visualization of digital terrain models: techniques and applications. *3D appl. in GIS* 24: 79-98.

Mulyadi, A; Dede, M; Widiawaty, MA (2020). Spatial interaction of groundwater and surface topographic using geographically weighted regression in built-up area. In: IOP conference series: Earth and environmental science, 477, 1: p. 012023, IOP Publishing.

Nasirtafreshi, I (2022). Forecasting cryptocurrency prices using recurrent neural network and long short-term memory. *Data Knowl. Eng.* 139, 102009.

Odjegba, EE; Amori, AA; Ojekunle, ZO; Awomeso, JA; Adetula, BA (2015). Water quality and socio–economic appraisal of public water supply in Abeokuta, South West, Nigeria. *Gashua J. Irrig. Desert Studies* 1: 12 ISSN: 2489 – 0030

Oluwasanya, G; Smith, J; Carter, R (2011). Self-supply systems: Urban dug wells in Abeokuta, Nigeria. Water Science and Technology: *Water Supply*, 11, (2): 172 - 178.

Oyedepo, JA; Adegboyega, J; Oluyege, DE; Babajide, EI (2021). Weighted linear combination procedures with GIS and remote sensing in flood vulnerability analysis of Abeokuta Metropolis in Nigeria. *Nig. J. Environ. Sci. Technol.* 5, (1): 240 - 257.

Saadi, O; Nouayti, N; Nouayti, A; Dimane, F; Elhairechi, K (2021). Application of remote sensing data and geographic information system for identifying potential areas of groundwater storage in middle Moulouya Basin of Morocco.*Groundwater. Sust. Develop.* 14: 100639.

Salati, LK; Adeyemo, JT (2021). A study on the physical and mechanical properties of a granite outcrop for a quarry at Onikoko community, Oyo State, South-Western Nigeria. *Mining Mineral Deposits.* 15 (1): 27 – 34

Yousif, M (2020). Combination of remote sensing, GIS and palaeohydrologic remarks for promoting the exploitation of water resources in the Sahara: cases from the Red Sea Coast, Egypt. *Environ. Earth Sci.* 79 (10): 222.

Sirisena, TJG; Maskey, S; Ranasinghe, R (2020). Hydrological model calibration with streamflow and remote sensing-based evapotranspiration data in a data poor basin. *Remote sens.* 12 (22): 3768