Geostatistical Assessment for Ground Water Resources Development: A Case Study of Bende Local Government Area Abia State, South Eastern Nigeria

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Abstract: ***The aim of this paper was to develop a geostatistical model for the identification of ground water resources development priority zones. The model was developed based on the important hydrogeologic factors that determine the availability of groundwater and the vulnerability of aquifers to surface contamination. The relevant input parameters namely depth to water table (d), aquifer thickness (h), transmissivity (τ) and protective capacity (p_c), were integrated to develop the Ground Water Potential Index (GWPI) and Ground Water Vulnerability Index (GWVI) rating scales. The Groundwater Development Index (GWDI) model was formulated as the ratio of GWPI to GWVI. The GWDI values range from 0.22 to 0.97. The demarcation of the study area based on the results of the GWDI assessment delineated the study area into six ground water development priority zones: (i) Very Low Potential & Extreme Vulnerability (5.2% of the study area) (ii)Low potential & Extreme vulnerability (15.7% of the study area) (iii)Medium potential & Extreme vulnerability (31.5% of the study area). (iv) Medium potential & High vulnerability (5.2% of the study area). (v) High potential & Extreme vulnerability (36.8% of the study area). (vi) High potential & High vulnerability(5.2% of the study area). The results of this study may be used for sustainable development of groundwater resources by identifying areas that have high groundwater development values. It is recommended that the priority for groundwater exploration and exploitation be based on high GWDI values.***

Keywords: Groundwater Potential Index (GWPI), Groundwater Vulnerability Index (GWVI), Groundwater Development Index (GWDI), Development Priority Zones,

1. Introduction

Economic growth in Nigeria is largely dependent on water, more specifically groundwater which is widely used for domestic, agricultural and industrial supplies. Presently, there is tremendous pressure to exploit groundwater and this has resulted in the continuous depletion and deterioration of groundwater quality. Zhou et al.[1] cited in Groundwater Governance (2013) that the last few decades have witnessed an increased pressure on groundwater resources globally, which has in many cases induced abstraction beyond sustainable levels and increased levels of pollution. Furthermore, Sililo et al. [2] affirms that the pollution of groundwater resources is often a consequence of poor land-use planning, especially, locating high risk activities in areas where they will have a negative impact on groundwater resources . As a response to this problem, hydrogeologists as well as decision makers have been forced to focus on implementing management and protection plans in order to sustainably safeguard water resources for current and future generation.

Geostatistical estimates of groundwater characteristics could be useful for the development of management strategies aimed at sustainable use of the groundwater resources. As noted by Focazio et al [3], the use of statistical methods to assess ground water vulnerability, represents a reasonable compromise of model complexity and cost, in order to produce scientifically-defensible products. The existing techniques for such estimates are based on either a single indicator/factor that may not be adequate to reflect several aspects of groundwater development or too many indicators which may not be readily available for a target area. This study was therefore undertaken to propose geostatistical models for (i) the estimation of groundwater potential and groundwater vulnerability (ii) formulation of groundwater development index (GWDI) to determine the suitability of target areas for any groundwater resources development projects.

2. The Study Area

The study area (Fig. 1) is located on latitudes $5°\,24'$ to $5°\,52'N$ and longitudes $7°\,28'$ to $7°46'E$ in Bende LGA Abia State, Southeastern Nigeria. The towns and villages under the study area include Okayitem, Akanu, Amankalu, Alayi, Eluokwe, Onu-Ibina, Okafia, Amankalu Igbere, Ezi-Igbere, AmaobaElu, Umuhu-Ezechi, Ozuitem, NgwuAmankwo, Okputong, Etitu-ulo, Amankwo and Bende.

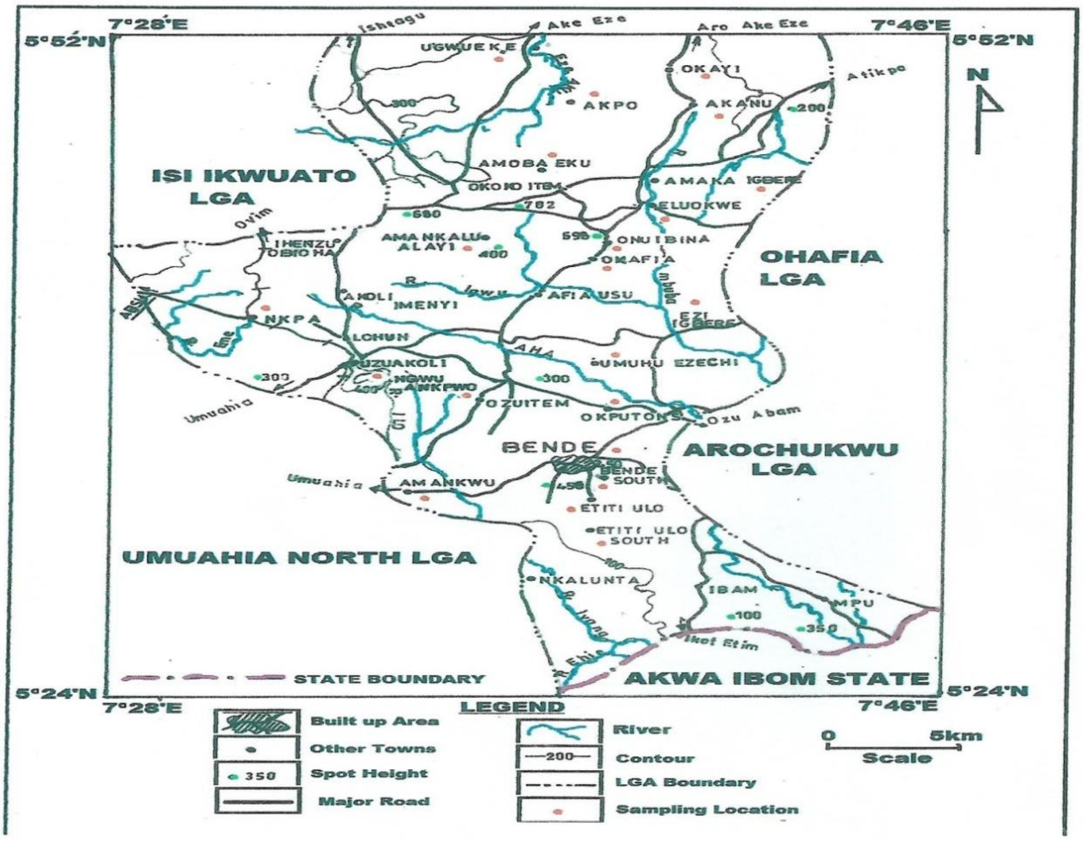

Figure 1: Map of Study Area

The physiographic information on Abia State reveals that the area is a humid zone and has a tropical climate with two major seasons, the rainy and dry seasons. The prominent topographic feature is generally undulating topography made up of highlands which consist of sandstones and the lowlands which consist of shale. The major water bodies that drain the area are River Inyong, Okwanka stream, River Ehie, River Igwu and River Idonyi.

Geologically, the major stratigraphic units encountered in the area include the coastal plain sands (the Benin formation), the Ogwashi-Asaba and Bende – Ameki formations[4] . The lithology of the Benin formation is unconsolidated fine-medium-coarse grained, cross-bedded sands occasionally pebbly with localized clays and shales [5]. The Ogwashi-Asaba formation is made up of variable succession of clays, sands and gnits with seams of lignite. It is directly underlain by Bende-Amaki formation. The Bende-Ameki formation consists of medium to coarse-grained sandstone, silt with mottled clays and thin limestone. The lower part of the formation consists of fine-coarse-grained lenses of sandstone with abundant calcareous shales and thin shelly limestone. The Bende-Ameki formation overlies the impervious Imo shale group, which is characterized by lateral and vertical variations in lithology[6]. It is underlain in succession by Nsukka formation, Ajalli sandstone, Mamu formation, Nkporo shale group, Ezeaku shale group and Asu river group (Fig. 2).

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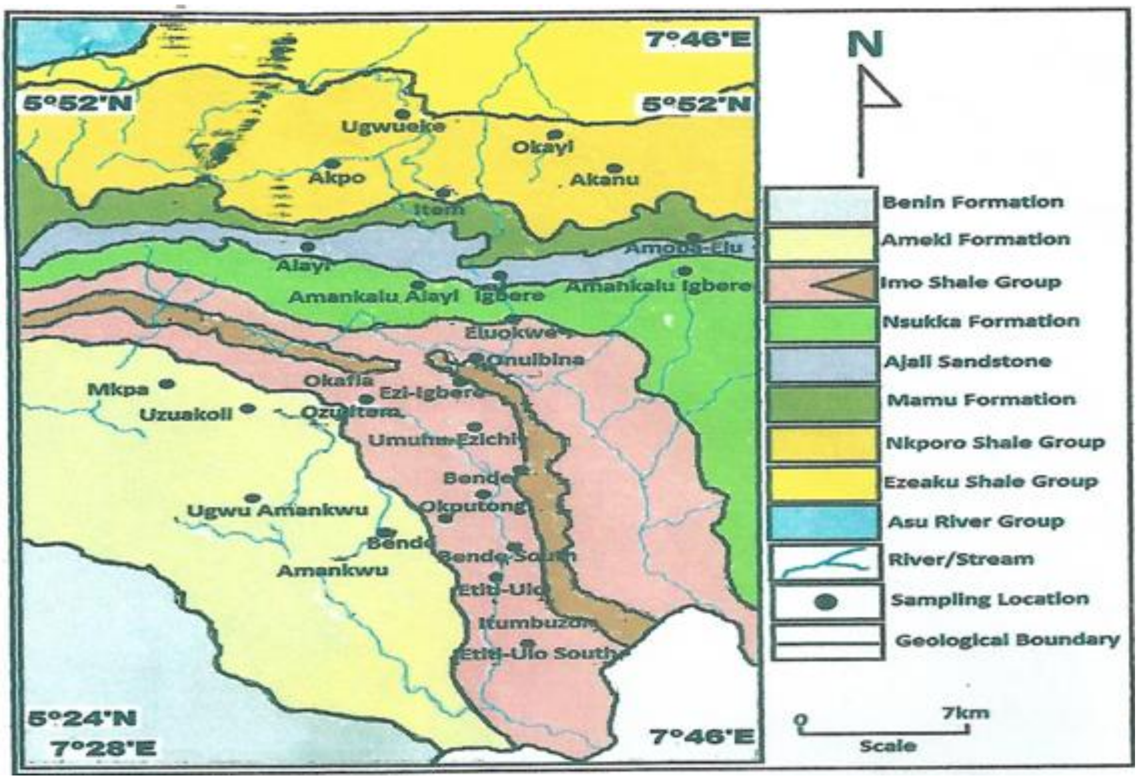

Figure 2: Geology and hydrogeology map of the study area

3. Methodology

The datasets employed for the development of the geostatistical models (GWPI, GWVI and GWDI) were obtained from the summary of the results of geoelectric investigation of aquifers in the study area by the author [7] for 19 VES stations (Table 1).

Table 1: Lithological Characteristics, Hydraulic and Geoelectric Parameters of Aquifers in Bende LGA Abia State

S/N	Longitude /Latitude	Location	VES NO	Lithology	Aquifer layer Lithology	Aquifer protective capacity	Aquifer resistivity	Aquifer depth	Aquifer thickness	Aquifer transmissivity	Aquifer hydraulic conductivity	Aquifer longitudinal conductance
1	N5^{0} 50.512’ E 7^{0} 41.382’	Okayitem	C1	KQHA	SAND	0.00086	1340	0.9	1.6	0.74	0.46	0.0011
2	N 5^{0} 48.483’ E 7^{0} 42.092’	Akanu	C2	KHKQ	SAND	0.0093	2010	62.1	39.9	0.033	0.00082	0.019
3	N 5^{0} 47.307’ E 7^{0} 37.829’	Amankalu Alayi	C3	KHKQ	SAND	0.0078	4190	87.8	60.2	0.025	0.00041	0.014
4	N 5^{0} 43.343’ E7^{0} 34.868’	Amankalu Alayi	C4	KHKQ	SHALE	0.26	197	3.9	57.3	160.26	2.79	0.29
5	N 5^{0} 41.990’ E 7^{0} 40.197’	Eluokwe	B1	AKH	SHALE	0.30	225	6	44.1	108.96	2.47	0.19
6	N 5^{0} 40.367’ E 7^{0} 39.842’	Onu-Ibina	C5	HAKH	SILT	0.44	1810	4.7	24.9	8.79	0.35	0.013
7	N 5^{0} 40.502’ E 7^{0} 36.645’	Okafia	C6	AAKH	SAND	1.66	1390	7.2	20.4	9.22	0.45	0.014
8	N 5^{0} 43.614’ E 7^{0} 41.026’	Amankalu Igbere	C7	HAKQ	SAND STONE	0.10	2110	30.3	74.7	22.87	0.30	0.035
9	N 5^{0} 39.255’ E 7^{0} 38.895’	Ezi-Igbere	C8	AKHA	SAND	0.012	1030	7	14	8.36	0.59	0.013
10	N 5^{0} 45.643’ E 7^{0} 38.540	Amaoba Elu	C9	AAKQ	SAND STONE	0.0092	14700	148	72	3.60	0.05	0.048
11	N 5^{0} 36.715’ E 7^{0} 39.724’	Umuhu-Ezechi	C10	KQQQ	SAND	0.016	1570	0.9	3.9	1.57	0.40	0.0024
12	N 5^{0} 35.903’ E 7^{0} 36.290’	Ozuitem	B2	KHA	SAND	0.0021	1070	0.7	3.4	1.96	0.57	0.0031
13	N 5^{0} 36.444’ E 7^{0} 32.974	Ngwu Amankwo	B3	KHA	SAND	0.0027	1340	1.2	14.2	6.64	0.46	0.010
14	N 5^{0} 34.280’ E 7^{0} 39.487’	Okputong	B4	KQQ	SAND	0.017	234	0.9	1.5	3.57	2.38	0.0064
15	N 5^{0} 32.928’	Bende	B5	QHA	SANDY	0.0013	683	21.7	24.2	21.22	0.87	0.035

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	E 7^0 40.434'				CLAY							
16	N 5^0 31.440' E 7^0 40.730'	Bende (500m South)	B6	KQQ	SANDY CLAY	0.020	548	0.9	8.9	12.3	1.38	0.016
17	N 5^0 29.816' e 7^0 40.434'	Etiti-ulo	B7	KHK	SAND	0.020	1130	21.7	58	31.80	0.54	0.051
18	N 5^0 28.058' E 7^0 41.145'	Etitiulo (500m South)	A1	KH	SAND	0.0018	2040	0.9	46.2	14.60	0.31	0.022
19	N 5^0 28.058' E 7^0 37.474'	Amankwu	B8	AKQ	SILT	0.022	102	0.8	2.6	13.43	5.16	0.025
Mean		-	-	-	-	0.1527	1985	21.45	30.10	**22.63**	**1.02**	**0.042**

Development of GWPI and GWVI Models

The method of computing the GWPI and GWVI involved three steps. The first step was to assign weights to the relevant input parameters with their total units summed up to ten (10). The second was to divide the parameter value into ranges and the third was to compute the index.

Weighting of Relevant GWPI Parameters

The GWPI parameters were assigned weights ranging from 2 to 5 (Table 2) on the basis of their relative importance in groundwater exploration and evaluation.

Table 2: Assigned weights (W) to the GWPI parameters

S/N	Parameter	Weight (Units)
1	Thickness (h)	2
2	Depth (d)	3
3	Transmissivity	5
	Sum	**10**

Aquifer thickness is limited to screen length of the abstraction borehole. Thus it was assigned the least weight of 2. Depth (d) was assigned weight of 3 based on the limitation of current penetration. Maximum depth penetration of the AMNB method is $\frac{1}{3}$ to $\frac{1}{4}$ of the maximum distance of current electrodes. The weight of 5 was assigned to the estimated transmissivity. It was assigned the highest weight among the three factors (τ, h and d) as a major indicator of groundwater availability.

Weighting of Relevant GWVI parameters

The GWVI parameters were assigned weights ranging from 2 to 5 (Table 3) based on their comparative significance with regards to aquifer contamination potential.

Table 3: Assigned Weights (W) to the GWVI Parameters

S/N	Parameter	Weight (Units)
1	Thickness (h)	2
2	Depth (d)	3
3	Vulnerability(v)	5
	Sum	**10**

4. Ratings and Classifications of the Geostatistical Parameters

The proportional relationships of the relevant GWPI and GWVI parameters were established (eqns. 1, 2) and their values divided into different class intervals (Table 4, 5).

$$GWPI \propto \tau \propto h \propto \frac{1}{d} \quad (1)$$

were τ is transmissivity, h is thickness, d is depth

$$GWVI \propto v \propto \frac{1}{h} \propto \frac{1}{d} \propto \frac{1}{P_c} \quad (2)$$

where v is vulnerability, P_c is protective capacity.

Table 4: Assigned rating to GWPI parameters

S/N	Parameter	6	5	4	3	2	1
1	Potential	A	B	C	D	E	F
2	Transmissivity m^2/day	> 1000	1000-100	100-10	10-1	1-0.1	< 0.1
3	Depth (m)	< 50	50-100	100-150	150-200	200-250	> 250
4	Thickness (m)	> 250	200-250	150-200	100-150	50-150	< 50

Table 5: Assigned rating to the categories of GWVI parameters

S/N	Parameter	6	5	4	3	2	1
1	Vulnerability	A	B	C	D	E	F
2	Protective Capacity $(mhos)$	> 0.1	0.1-0.19	0.2-0.60	0.7-4.9	5-10	> 10
3	Depth (m)	< 50	50-100	100-150	150-200	200-250	> 250
4	Thickness (m)	> 50	50-100	100-150	150-200	200-250	> 50

Mathematically,

$$GWPI = h_w h_r + d_w d_r + \tau_w \tau_r \quad (3)$$

$$GWVI = h_w h_r + d_r d_w + v_w v_r \quad (4)$$

$$GWDI = \frac{GWPI}{GWVI} \quad (5)$$

where w = weight and r = rating for the different GWPI and GWVI parameters.

The computed GWPI and GWVI values were used to develop a semi quantitative overall rating scale (R) for the classification of the groundwater potential and groundwater vulnerability at a borehole site (Tables 6, 7)

Table 6: Classification of GWPI values

Class	GWPI (R)	Groundwater Potential
A	≥ 50	Prolific(P)
B	40 – 49	High(H)
C	30 – 39	Medium(M)
D	20 – 29	Low(L)
E	10 – 19	Very low(L)
F	< 10	Negligible (N)

Table 7: Classification of GWVI Values

Class	GWPI (*R*)	Groundwater Vulnerability
A	≥ 50	Extreme (E)
B	40 – 49	High(H)
C	30 – 39	Moderate(M)
D	20 – 29	Low(L)
E	10 – 19	Very low(VL)
F	< 10	Negligible (N)

The summary results of the geostatistical assessment and the GWDI classification for the study area are presented in Tables 8 and 9.

Table 8: Geostatistical assessment for groundwater development priority zones

S/N	Location	VES No	GWPI	GWVI	GWD
1	Okayitem	C1	25L	60 E	0.41
2	Akanu	C2	13VL	57 E	0.22
3	AmankaluAlayi	C3	24L	55 E	0.43
4	AmankaluAlayi	C4	47H	48 H	0.97
5	Eluokwe	B1	45H	50 E	0.9
6	Onu-Ibina	C5	35M	50 E	0.7
7	Okafia	C6	35M	45 H	0.77
8	AmakaluIgbere	C7	42H	53 E	0.79
9	Ezi-Igbere	C8	35M	60 E	0.58
10	Amaoba-Elu	C9	31M	52 E	0.59
11	Umuhu-Ezechi	C10	35M	60 E	0.58
12	Ozuitem	B2	35M	60 E	0.58
13	NgwuAmankwo	B3	35M	60 E	0.58
14	Okputong	B4	23L	60 E	0.38
15	Bende	B5	40H	60 E	0.66
16	Bende (500m South)	B6	40H	60 E	0.66
17	Etiti-Ulo	B7	42H	58 E	0.72
18	Etiti-Ulo (500m South)	A1	40H	58 E	0.68
19	Amankwo	B8	H40	60 E	0.66

L – Low; VL – Very Low; H – High; M – Medium; E - Extreme

Table 9: GWDI Classification of the Study Area

Zone	Rating	Designation	% Distribution in study area
I	0.22	VL Potential & E Vulnerability	5.2%
II	0.38-0.43	L potential & E Vulnerability	15.7%
III	0.58-0.59	M Potential & E Vulnerability	31.5%
IV	0.77	M Potential & H vulnerability	5.2%
V	0.66-0.9	H potential & E vulnerability	36.8%
VI	0.97	H potential & H vulnerability	5.2%

5. Results and Discussion

The thematic maps (Figs.3a,4a,5a) and distribution charts (Figs.3b,4b,5b) provided the means to identify areas suitable for groundwater resources development.

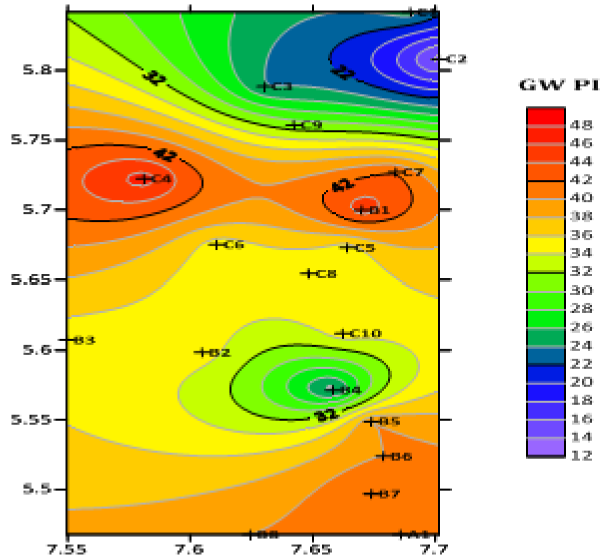

Figure 3a: GWPI Thematic Map

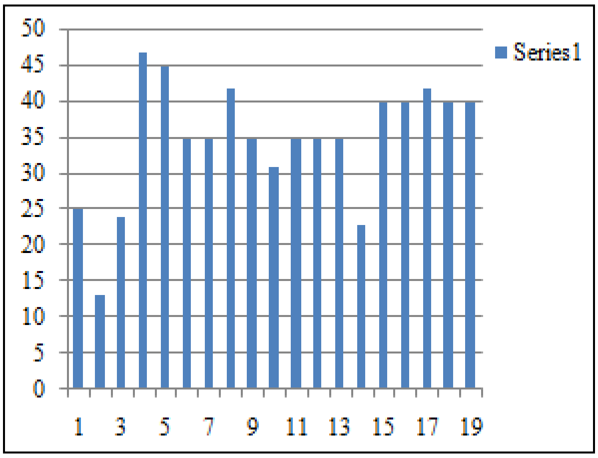

Figure 3b: GWPI Distribution Chart

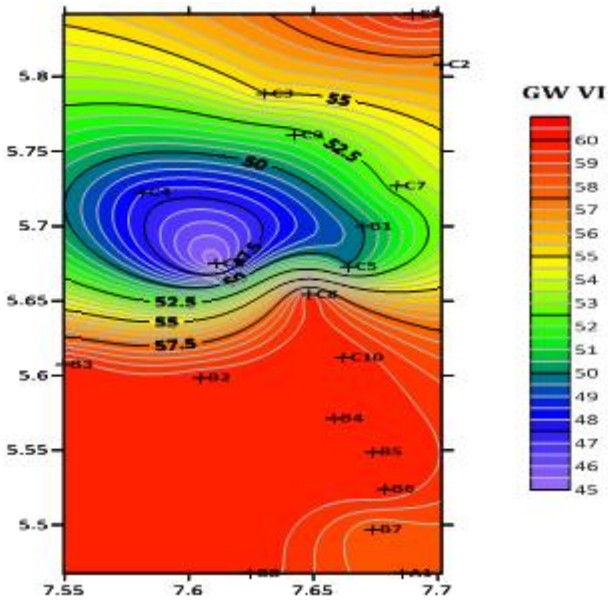

Figure 4a: GWVI Map

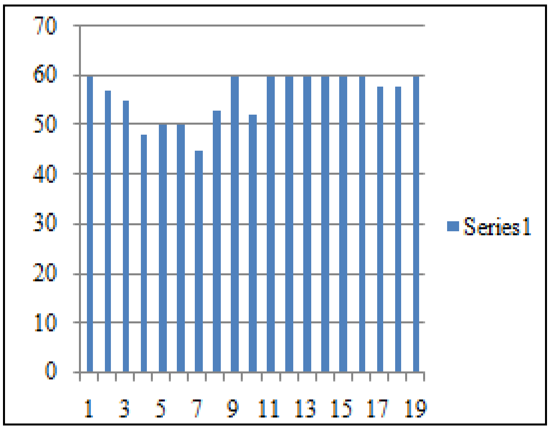

Figure 4b: GWVI Chart

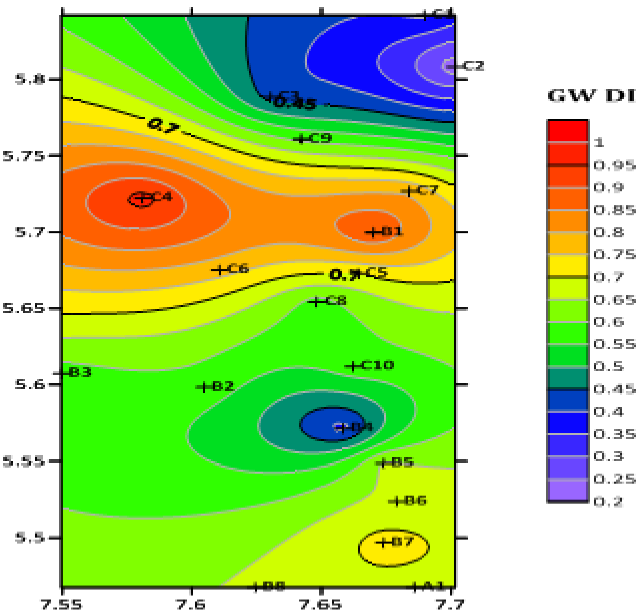

Figure 5a: GWDI Map

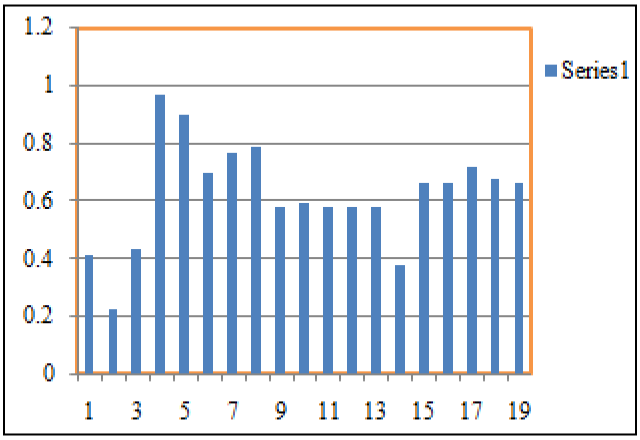

Figure 5b: GWDI Chart

The GWPI values obtained from the area range from 13 to 47. The GWPI map delineated the groundwater prospects of the area into four (4) zones: (I) High (II) Medium (III) Low and (IV) Very low.

The GWVI values obtained from the area range from 45 to 60. Table 8 and the GWVI map which depicted the susceptibility of the aquifers in the area to surface contamination classified the study area into two zones: (i) High (ii) Extreme.

The results of the GWVI assessment revealed that approximately 89.5% of the aquifers in the study area are extremely vulnerable to contamination probably due to low protective capacity of the predominantly sandy overburden units as well as the low values of the aquifer thickness and depths to the water table. The remaining 10.5% had high vulnerability probably due to the increase in the aquitard (shale/clay) content of the overburden units of the aquifers.

The GWDI values range from 0.22 to 0.97. The GWDI map demarcated the study area into six (6) zones: (i) Very Low Potential & Extreme Vulnerability (5.2% of the study area) (ii) Low potential & Extreme vulnerability (15.7% of the study area) (iii)Medium potential & Extreme vulnerability (31.5% of the study area). (iv) Medium potential & High vulnerability (5.2% of the study area). (v) High potential (H) &Extreme vulnerability (E) (36.8% of the study area). (vi) High potential &High vulnerability(5.2% of the study area).

The area with highest GWDI is characterized by high potential (H) and high vulnerability (H), while the area with the lowest value is characterized by very low potential (VL) and extreme vulnerability (E). The results of the GWDI assessment have revealed that the highest value of 0.97 was obtained at VES C4 (Amankalu Alayi) and the lowest value of 0.22 at VES C2 (Akanu).

6. Conclusion and Recommendations

Four input parameters were integrated to develop GWPI, GWVI and GWDI geostatistical models for regional evaluation of groundwater availability, vulnerability and development respectively.

The area with the highest GWDI value is characterized by high potential (H) and high vulnerability (H), while the area with the lowest GWDI value is characterized by very low potential (VL) and extreme vulnerability (E).

Groundwater exploration and exploitation should be prioritized in the most prolific and least vulnerable zones in the study area. The results of this study may be used for sustainable development of groundwater resources by identifying areas that have high groundwater development values. It is expected that the maps produced from the GWPI, GWVI and GWDI models will be useful as a guide for groundwater management and protection to land use planners and water development agencies.

7. Acknowledgement

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