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Application of Legrand pollution correlation in the evaluation of contaminants migration within the groundwater of Ebhoakhuala in Ekpoma and Agbede, Edo State, Nigeria

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The increase in population has led to indiscriminate disposal and mismanagement of waste in the society, resulting to waterborne diseases. As a result, this study was done to determine the efficacy and the efficiency of LeGrand correlation chart in the evaluation of the potential of groundwater of an area to pollution. Ebohkhuala and Agbede were used as a case study. Electrical resistivity tomography (ERT) and hydrogeochemical analysis of groundwater in the two areas were used to validate the result of the correlation chart. The LeGrand correlation chart for Ebohkhuala and Agbede total point value for pollution evaluation were 32.5 and 7, respectively. These values showed that Ebohkhuala's groundwater cannot be contaminated by nearby dump site owing to the result of the correlation which fell within the limits of impossibility, while that of Agbede fell in high possibility. The result of Ebohkhuala's ERT resistivity signature depicts plume, ranged from 35 to 89 Ωm. The low values indicated migration of pollution without infiltrating the groundwater. However, that of Agbede ranged from 1.8 to 56 Ωm, which suggested high plume saturation. Similarly, the result of hydrogeochemical test of the ground water showed that Ebohkhuala did not have bacteria while Agbede has high concentration. The study has shown that LeGrand correlation is very efficient and efficacious in pollution prediction.

Key words: Pollution, groundwater, hydrogeochemical analysis, LeGrand correlation chart, electrical resistivity tomography (ERT).

INTRODUCTION

Legrand pollution correlation chart is a pollution chart that comprises hydrogeological and geological parameters that give information about the groundwater vulnerability to contaminants infiltration in a given area. Many

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correlations have been proposed by several authors. The pitfalls of these correlations are that such correlations do not capture the main parameters that give information about an area's ability to withstand or be prone to contaminant infiltration. The size and shape of pollutant depends on local geology, direction of ground water flow, depth to water table, sorption above water table, and the continual waste disposal.

There are other numerous authors that have done fantastic work on pollution migration monitoring using ERT (Pantelis et al., 2007; Wilkinson et al., 2009; Abdullahi. et al., 2011; Ogungbe et al., 2012; Muhammad et al., 2013; Iyoha et al., 2013; Elijah et al., 2013; Ugbor et al., 2021). However, the disadvantage with ERT is that it can only tell you the presence of contaminants, it cannot predict future occurrence. Treadaway et al. (1999) studied the migration of contaminants in soils using an in situ fibre optic sensor to track the movement of a dye tracer. Water was forced to percolate downwards in a bed of fine sand, with the hydraulic gradient kept constant during any given experiment. A pulse of contaminant was released on the soil surface, and its concentration was subsequently measured using sensors buried at two depths. This permitted the pollution plume to be tracked. It was found that the width was independent of hydraulic gradient, as predicted by the theory of mechanical dispersion for seepage flows with a high Peclet number. Utom et al. (2012) and Tsepav et al. (2015) had used vertical electrical resistivity (VES) to determine the protective capacity of an area against infiltration into the aquifer. However, this method cannot capture accurately the parameter that determines the susceptibility of an aquifer to pollution.

Devlin et al. (2012) mapped out the extent of flood plume water over a 10 year period using quasi-true colour imagery. They were able to predict the long-term frequency of occurrence of the plumes. The total suspended sediments and Photosystem-II herbicides from each source were used to scale the surface exposure maps for each pollutant by using the riverine loads that is proportional to the dissolution from these contaminants. A procedure that is categorized was also applied to satellite imagery from one year of flood event to another year through processing to discriminate the changing characteristics across the water body. This classification is a first step towards characterizing flood plumes. However, these methods can only monitor pollution migration but cannot predict if the groundwater area is prone to pollution or not. Marques et al. (2021) combined ERT and hydrogeochemical analysis to investigate the potential of an area to contaminants infiltration into the groundwater of the area with a fantastic result. This is the reason Legrand pollution correlation (LeGrand, 1964) that uses the parameters that are directly related to factors that initiate soil, surface and groundwater pollution is chosen to determine the possibility of contaminant migration in present time and in the future at Ebhokhuala, Ekpoma, Esan West Local Government Area in Edo State and at Agbede, Etsako West Local Government Area in Edo State, as well as the reliability and effectiveness of the correlation.

Location, geology and hydrogeology of the study area

The study was done in two areas with different geological formation. The first area is located in Ekpoma, Esan West Local Government, Edo State, Nigeria. It covers Ebhokhuala and some parts of Illeh. It is bounded by Latitudes 6°44'N - 6°44'N and Longitudes 6°9' E - 6°10' E. It is accessible by a major road, Royal Market Road, Illeh Road and other minor roads.

The second area is Agbede. It is located in Etsako West Local Government Area of Edo State, boundary Ewu to the south west and south east. It is accessible by one major road, Benin-Auchi Express. The area is underlain by both shallow and deep aquifer, and is underlain by thick sequence of shale, thin sequence of sandstone and siltstone. The two areas fall within Anambra Basin. Ekpoma is underlain by Bende-Ameki Formation while Agbede is underlain by Imo Formation.

Ebohkhuala falls within the Ishan plateau. The landform of the study area is generally highlands, ranging from 1250 to 1280 ft while Agbede is a low land as shown in Figure 1. The groundwater table is deep in Ebohkhuala and consists of sedimentary deposits of Bende-Ameki Formation. The area is just a newly developing settlement which is situated along Illeh Road at Ebhokhuala which is on the outskirt of Esan West Local Government Area towards Esan Central Local Government from the metropolis.

The dumpsite is located along Illeh Road, Ebhokhuala, Ekpoma, Esan West Local Government Area, Edo State (Figure 1). The area is underlain by lateritic sandstone while in some portions of the study area, is generally covered by brown clayey sandstone that is moderately to well-consolidated poorly sorted sandstone. The dumpsite at Ebohkhuala (Figure 2) is an active dumpsite that has lateral extent of about 200 m, and the vertical extent of the waste varies laterally across the area from 1 to 5 m. Agbede dumpsite has about 150 m lateral extent and the heap of the dump is about 15 m (Figure 3). The wastes in the two study areas are generally domestic (mostly garbage and electronic) (Figures 2 and 3).

MATERIALS AND METHODS

The geological and hydrogeological study of two hand dug wells each in Ebohkhuala and Agbede were carried out to determine the parameters used in LeGrand correlation chart to be able to evaluate the potential of the nearby well getting contaminated by the infiltration of contaminants from the nearby dump site. Thereafter, 2-D resistivity imaging of the subsurface and hydrogeochemical study of groundwater in the study area was done to validate the result of the Legrand correlation in order to ascertain its efficacy

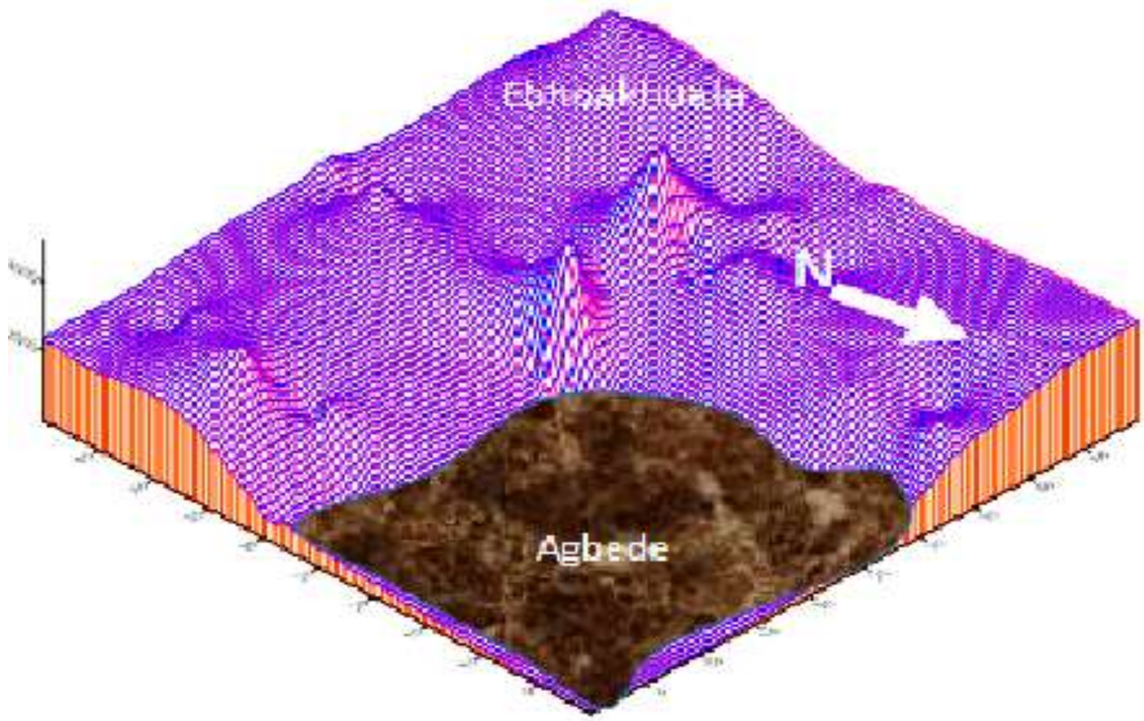

Figure 1. 3-D Geomorphology map of the study area showing their landscape and topography.

Figure 2. Section of the dumpsite in Ebohkhuala, Ekpoma, Edo State.

and efficiency in groundwater pollution evaluation.

Three 2-D resistivity profiles at selected transverses were done at Ebhokhuala in Ekpoma and in Agbedeas shown in Figure 4 to identify the occurrence of plume, the extent of plume migration and its direction of migration. The hydrogeochemical ground water analysis was conducted on the two wells in Ebhokhuala and Agbede respectively using IS standard.

The 2-D resistivity tomography imaging was done using ABEM SAS 1000. The survey was done in an active dump site at Ebohkhuala along Illeh-Ewakhwa Road, Ekpoma, Esan West Local Government, Edo State and in Agbede along Benin-Auchi Road, Etsako West Local Government Area. The transverse of each profile was done 2 m laterally away from the dump site, 50 m away, and 100 m away respectively (Figure 4) in order to be able to determine the lateral extent of plume migration into the groundwater system.

Dipole-Dipole array method (Figure 5) was used. An average number of 144 electrodes were spread in order to have sequence

Figure 3. Section of dump site in Agbede, Etsako West LGA of Edo State, Nigeria.

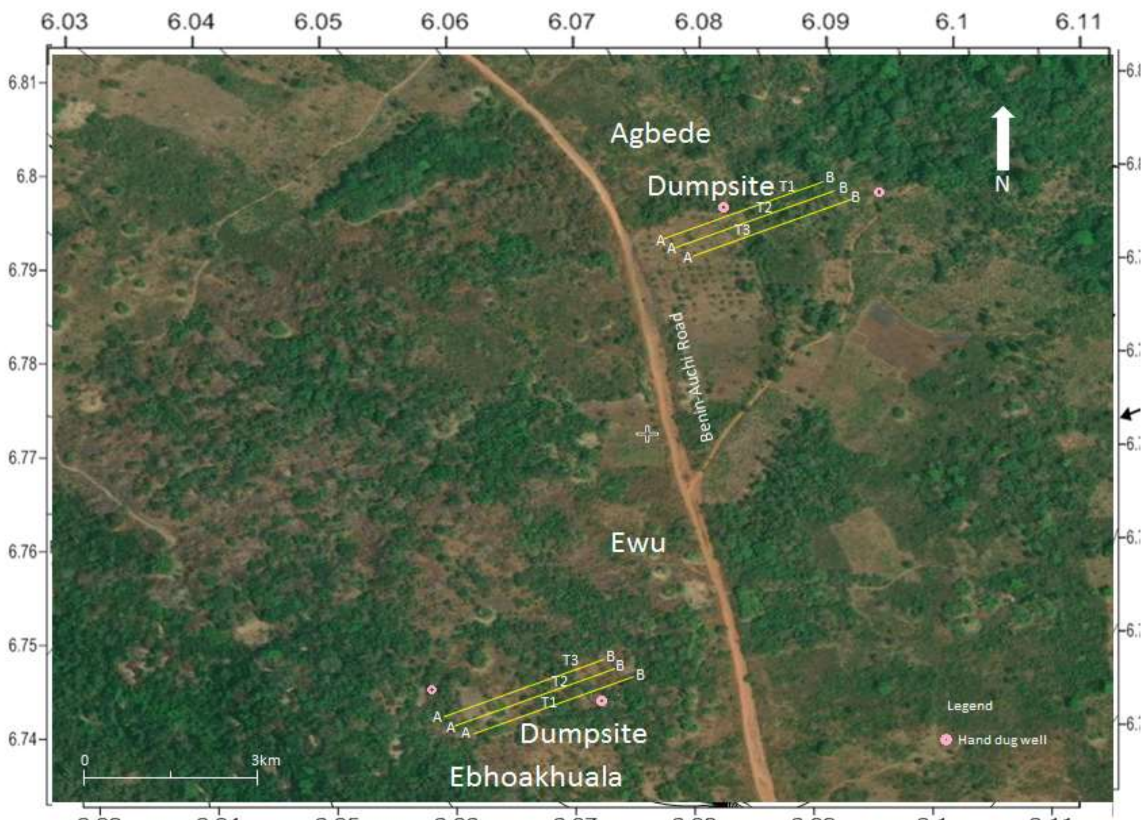

Figure 4. Map showing geophysical survey.

of measurement to build up a pseudo section (Figure 6) using the data level n=1 up to n=3 and a=5 m (Figure 6). The electrodes were spread in such a way that discrete bodies of any material within the subsurface can be easily identified with minimal noise effect.

Immediately after data acquisition, the acquired data were retrieved from the memory of the instrument, using utility software and later converted to RES2Dinvers format with same software. The data was edited as RES2Dinvers bad data point and 0.2 damping factor was used in order to eliminate noise effect. The pseudo section of the subsurface was processed into 2-D images

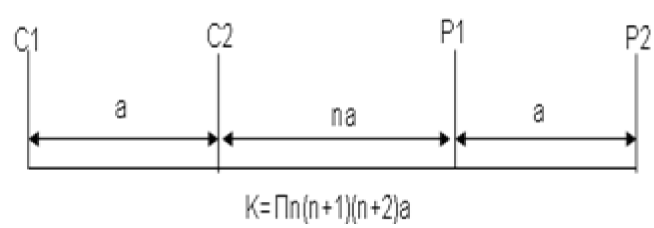

Figure 5. Dipole-Dipole electrode array.

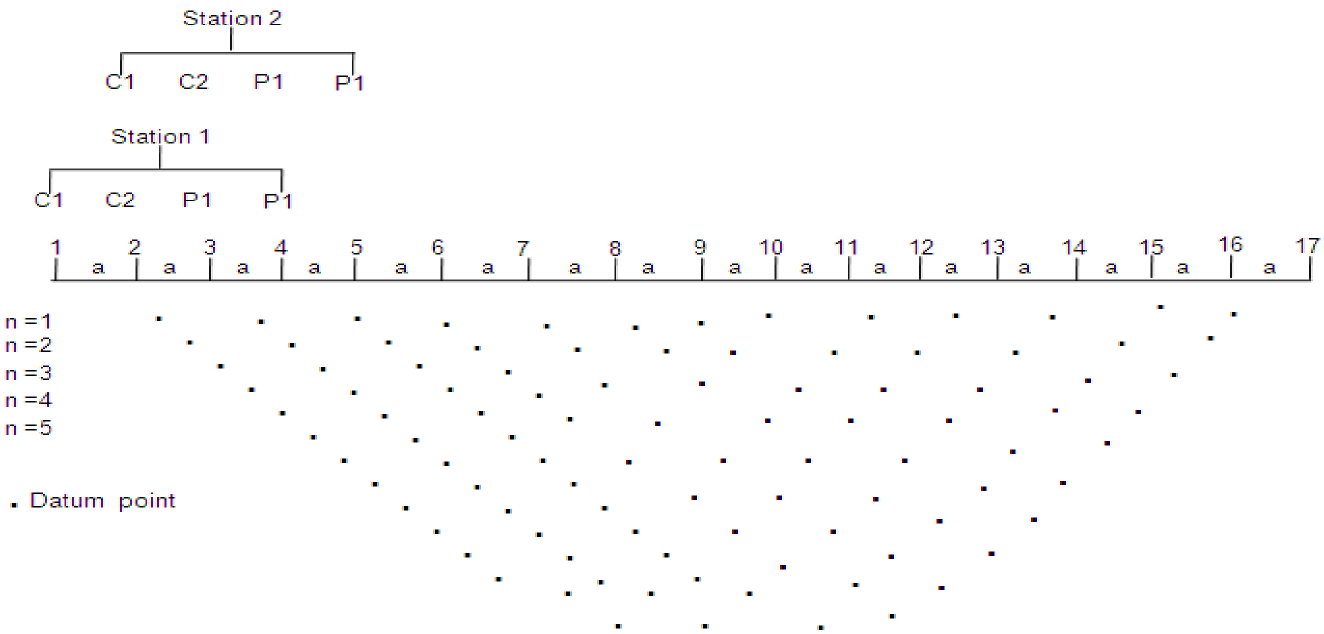

Figure 6. Sequence measurement used to build up pseudo section for the ERT data in the study area.

using smoothness constraint inversion method after the method of deGroot-Hedlin and constable (1990). The inversion method was based on the following mathematical equation:

$$\left(J^{T}J+UF\right)d^{1}=J^{T}g \quad (1)$$

Where,

$$F=f_{X}\,f_{X}T+f_{z}\,f_{z}T \quad (2)$$

T = Transpose matrix; d = model perturbation vector; g = discrepancy vector; J = the Jacobian matrix of partial derivative; f_X = horizontal flatness filter; F = vertical flatness filter; U = damping factor.

RESULTS AND DISCUSSION

Evaluation of pollution potential using LeGrand correlation chart

Evaluation of pollution potential of the groundwater in Ebohkhuala and Agbede was done by first carrying out the geology and hydrogeological study of the areas. The result of the geological study showed that Ebohkhuala is underlain by Bende-Ameki Formation while Agbede is underlain by Imo Formation (Figure 7). The geological unit in Ebhokhuala contains clayey sandstone, lateritic sandstone, kaolin and siltstones while that of Agbede contains sandstone, well sorted clean sandstone and shale (Figure 8). The result of hydrogeology of Ebohkhuala showed that the area contains two sets of aquiferous units. The first unit occurs at depth of 90-110 m and the second unit at 270-300 m (Figure 8) while that of Agbede aquifer is thin and occurs at shallow depth range of 3 to 30 m. Below the first aquiferous unit in Agbede is a thick sequence of shale of over 300 m (Figure 8) with thin beds of evaporates, gypsum and halite with little water that is highly saline.

When the geological and hydrogeological parameters were correlated with the LeGrand Chart (Figure 9), the result showed that Ebohkhuala depth to water table total point value scored in pollution evaluation was 9 while that of Agbede was 1 as shown in Table 1 because depth to water table in Agbede is very shallow. The sorption above water table in Ebohkhuala is very high (4.5) because depth to water table is very deep in Ebohkhuala. The result of permeability correlation on the LeGrand Chart of the subsurface rock in Ebohkhuala was 3 because the rocks are dirty and clayey, that is, it does not allow easy seepage and infiltration of contaminants into the groundwater while Agbede was 1 (Table 1) because the rock units are clean pure sandstone that allows easy infiltration into the aquiferous unit. The total value for pollution evaluation on the LeGrand correlation chart for Ebohkhuala and Agbede was 32.5 and 7 (Table 1), respectively. These values show that Ebohkhuala's groundwater potential to contaminants infiltrations is impossible based on the LeGrand correlation chart's interpretation as shown in Table 2. However, that of Agbede suggests that the groundwater potential to contaminants infiltration is very possible as shown in Table 2. This is due to the nature of Agbede geology and hydrogeological setting.

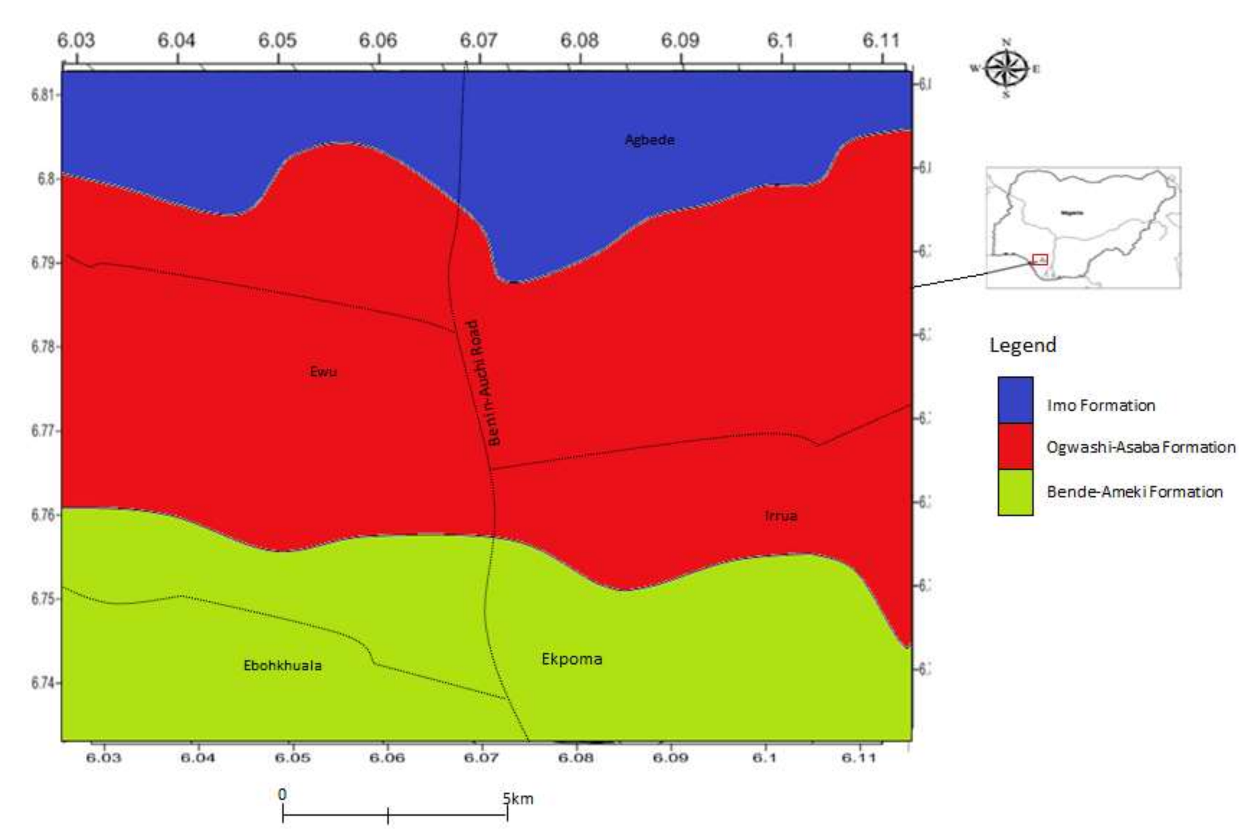

Figure 7. Geologic map showing the geology of Ebohkhuala and Agbede.

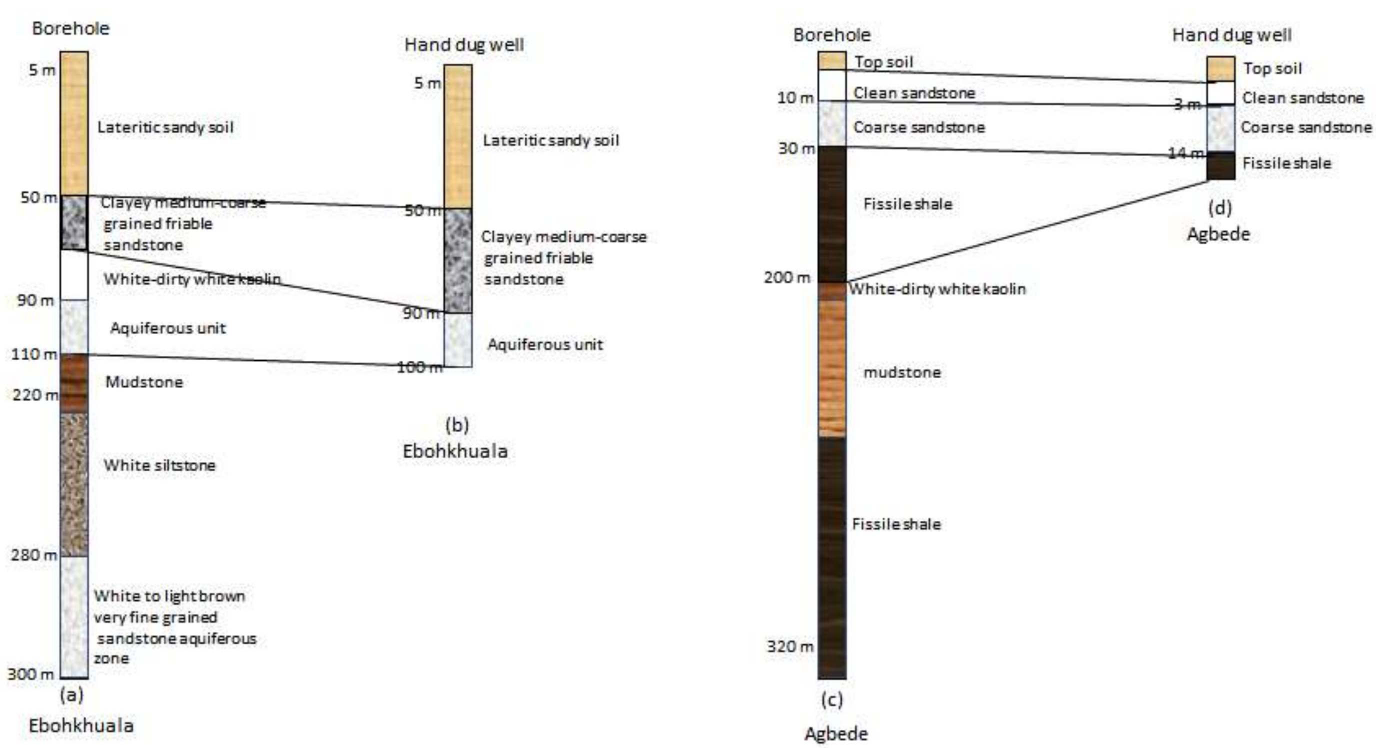

Figure 8. Correlation of hand dug wells with borehole in Ebohkhuala and Agbede, Edo State.

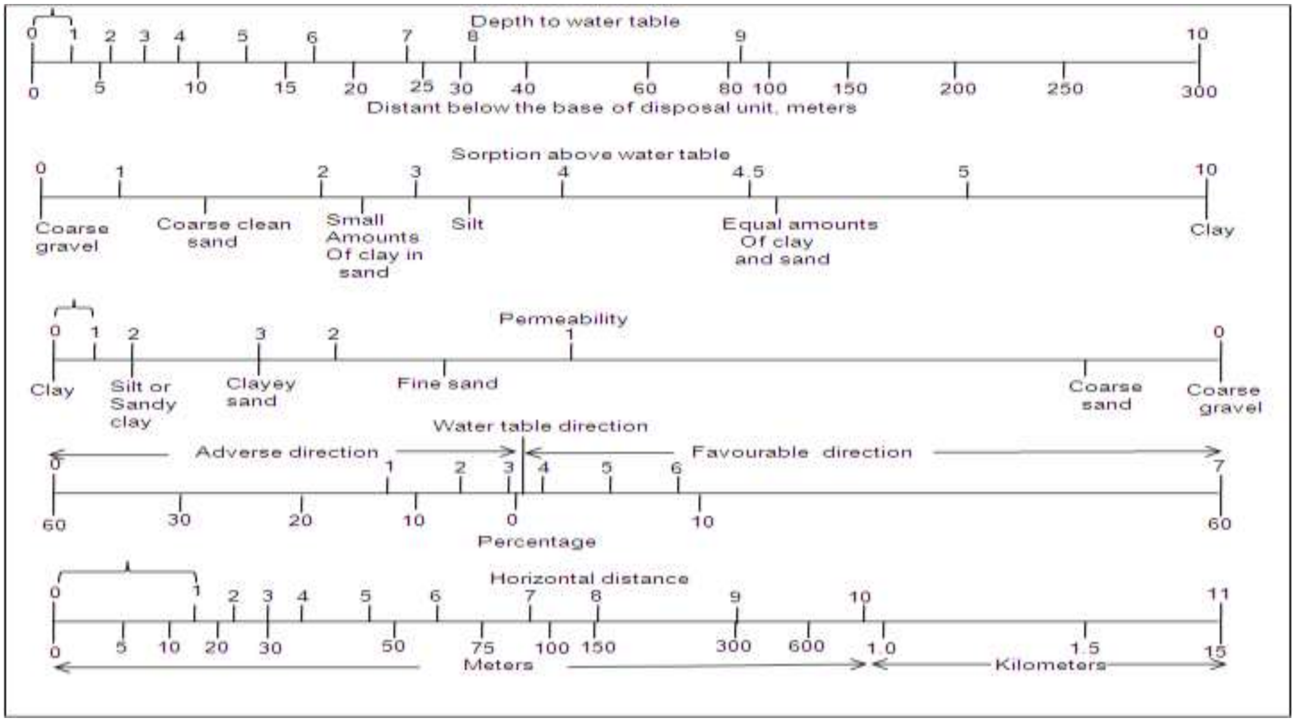

Figure 9. LeGrand pollution evaluation chart.

Table 1. Total point value for pollution evaluation in Ebhokhuala and environs, Ekpoma.

Parameter	Points for Ebohkhuala	Points for Agbede
Depth to water table	9	1
Sorption above water table	4.5	1
Permeability	3	1
Water table gradient	6	1
Horizontal distance to dump	10	3
Total	32.5	7

Table 2. LeGrand Interpretation table for total point in pollution evaluation.

S/N	Total points	Possibility of pollution
1	0-4	Imminent
2	4-8	Probable or possible
3	8-12	Possible but not likely
4	12-25	Very improbable
5	25-35	Impossible

Validation of the correlation chart with ERT and Hydrogeochemical Result of the study area

The results of LeGrand correlation result for Ebohkhuala and Agbede were validated by the ERT and the result of the hydrogeochemical groundwater of the area. The resistivity result for Ebohkhuala along the three traverses (Figures 10 to 12) showed that there was occurrence of contaminants as indicated by the resistivity signature that ranged from 35 to 89 Ωm (Figures 10 to 12). These low

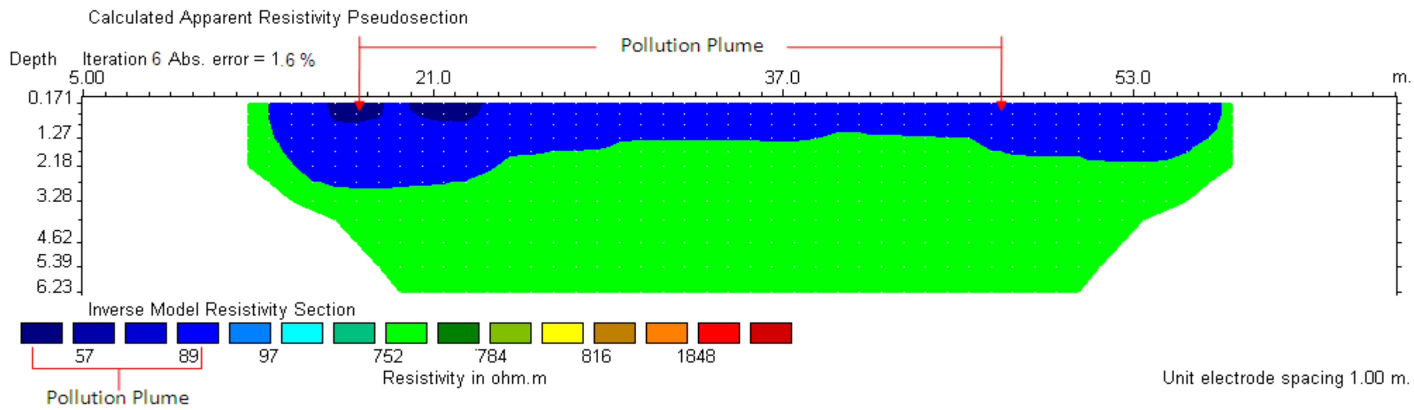

Figure 10. ERT result for traverse 1 acquired in Ebhokhaula 2m away from the dumpsite.

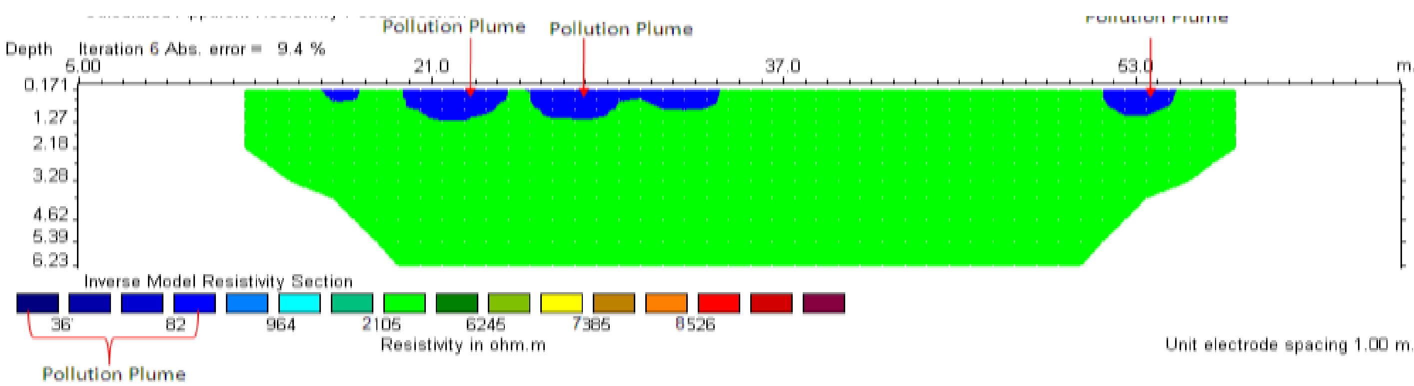

Figure 11. ERT result for traverse 2 acquired in Ebhokhaula 50m away from the dumpsite.

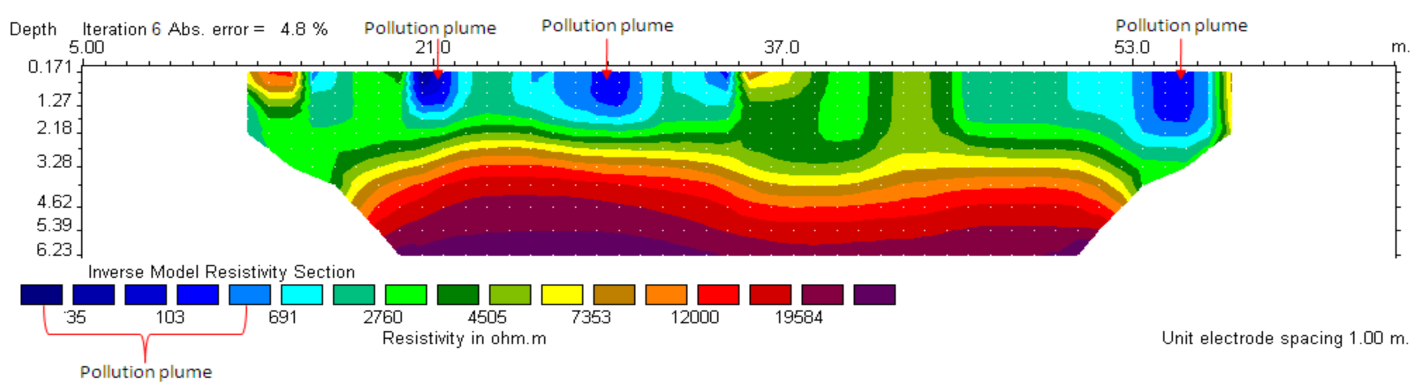

Figure 12. ERT result for traverse 3 acquired in Ebhokhaula 100m away from the dumpsite.

resistivity values indicated contaminants plume. However, the plume has not migrated into the water table and the distance to water table is very far about 90 m deep to the first aquifer and 270 m deep to the second aquifer. This validates the findings from the LeGrand correlation chart result for Ebohkhuala's groundwater.

Similarly, resistivity result in Agbede showed low resistivity values that ranged from 1.8 to 56 Ωm (Figures 13 to 15). These low resistivity values indicated contaminants infiltration into the subsurface from the dumpsite. The extent of the seepage or infiltration is very deep, up to 14 m into the subsurface as shown in Figure

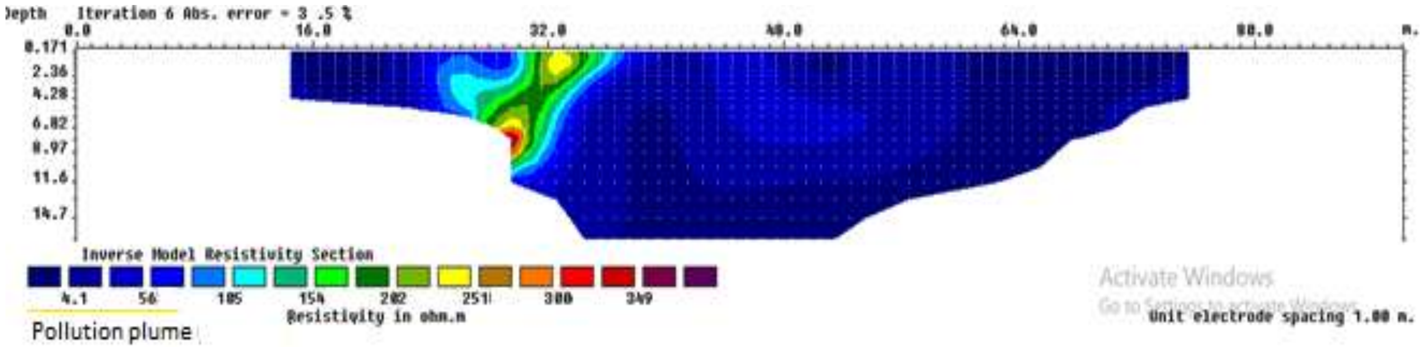

Figure 13. ERT result for traverse acquired in Agbede 2m away from the dumpsite.

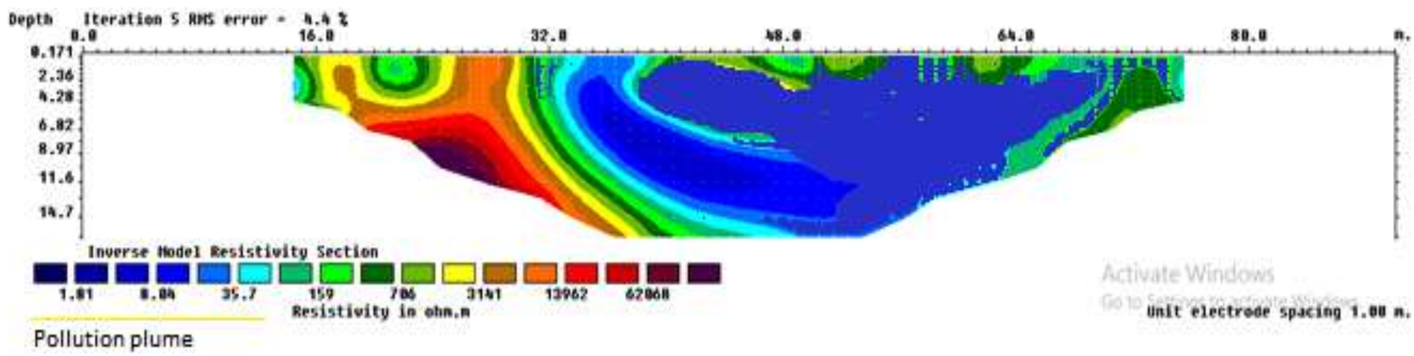

Figure 14. ERT result for traverse 2 acquired in Agbede 50m away from the dumpsite.

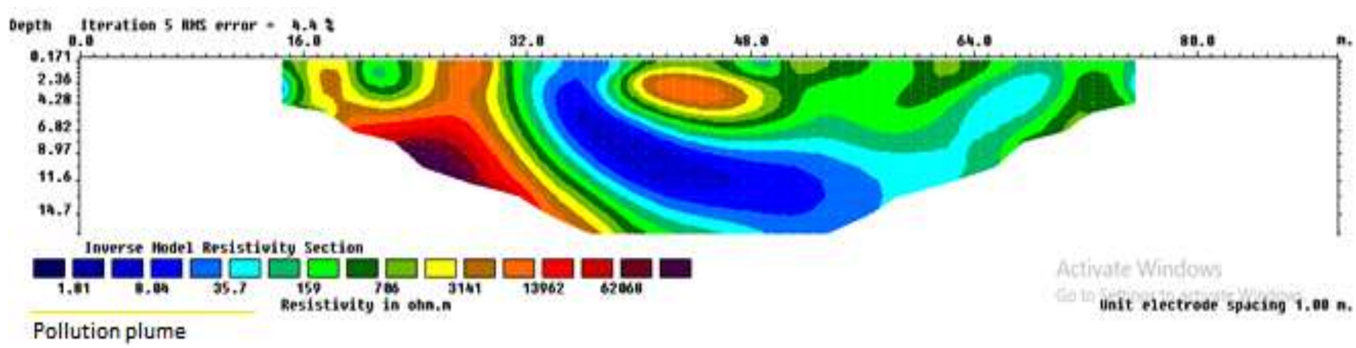

Figure 15. ERT result for traverse 3 acquired in Agbede 100m away from the dumpsite.

13. Since the borehole data of the area showed that water table in Agbede varies from 4 to 30 m, then the observation in the ERT suggests that the groundwater has been severely affected by the seepage of contaminants from the nearby dump site. The resistivity signature is cleared and the plume has migrated deep into the groundwater table as shown in Figures 13 to 15. This shows that the LeGrand correlation chart is efficient and accurate in predicting the potential of groundwater of an area to pollution or contaminants infiltration. In the two areas of study, the ERT result showed that there was lateral decrease in the load and migration of the contaminants, as one moves away from the dump sites. This shows that wells that are close to the dumpsite will experience the highest load of contaminants concentration in Agbede. In the case of Ebohkhuala, residential houses are common with underground reservoirs because of water challenges in Ekpoma. The reservoirs are dug about 3 m to 4 m into the ground either to collect rainwater or store water in it. However,

Table 3. Hydrogeochemical result of water samples from Ebohkhuala and Agbede.

Parameter	Ebhoakhuala well 1	Ebhoakhuala well 2	Agbede well 3	Agbede well 4
pH	7.1	6.9	6.7	6.9
EC (us/cm)	320	280	560	340
TDS (mg/l)	203	208	390	401
SO_4^{2-} (mg/l)	0.01	0.12	0.43	0.40
NO_3^- (mg/l)	0.34	0.74	0.21	0.23
HCO_3^- (mg/l)	10.3	13.5	32.00	30.00
Ca^{2+} (mg/l)	23.00	21.00	8.2	9.1
Cr^{2+} (mg/l)	-	-	0.00	0.00
Pb^{2+} (mg/l)	0.00	0.00	0.06	0.09
Ni^{2+} (mg/l)	0.00	0.00	0.00	0.00
Mn^{2+} (mg/l)	3.01	2.01	0.01	0.30
Fe^{2+} (mg/l)	0.20	0.52	0.001	0.00
Cu^{2+} (mg/l)	0.00	0.00	0.00	0.00
Zn^{2+} (mg/l)	0.001	0.00	0.03	0.001
E. coli	-	-	$6.4x10^5$	$4.3x10^2$
Total coliform	-	-	$8.1x10^5$	$4.3x10^2$

these reservoirs get filled, thus allows communication of the reservoir with the external environment that is already contaminated by infiltration from nearby dumpsite. This could give room for such reservoirs to get contaminated because the depth of plume occurrence in Ebohkhuala is within the range of the reservoirs depths.

Similarly, the hydrogeochemical results of Ebohkhuala and Agbede showed that Ebohkhuala does not have any *Escherichia coli* and coliform (Table 3). This implies that the groundwater in Ebohkhuala does not have contaminants infiltration, that is, there are no bacteria as bacteria can only be sourced from leachate seeping from nearby dumpsite. However, the two wells in Agbede have *E. coli* concentration of 6.4×10^5 and 4.3×10^2 and the concentration of coliform was 8.1×10^5 and 4.3×10^2. It shows that Agbede groundwater has been severely affected with bacteria that seeped from the leachate that infiltrates from the nearby dumpsite into the aquiferous unit that underlies Agbede. The hydrogeochemical results of the wells in the study area have validated the result of the LeGrand chart correlation. Hence, the chart is accurate in predicting contaminants migration into the groundwater table of an area and it can also be used to evaluate pollution level or status of an area with high level of accuracy.

Conclusion

The study has shown that LeGrand correlation chart is very efficient and accurate in the study and prediction of the potential of groundwater tendency to pollution in a given area. This is because the parameters that are used in LeGrand correlation to evaluate pollution potential of an area are directly from the geology and hydrogeological setting of an area and these are the basic parameters that are vital for the prediction of pollution occurrence. Hence we recommend the usage of this correlation for future evaluation and prediction of groundwater pollution of an area with high level of accuracy.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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