# The Place of Groundwater Velocity in Estimation of Safe Distances Between Boreholes and Objectionable Vectors: The Case of Uzuakoli-Umuahia and Environs, Abia State Nigeria

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**Abstract:** Groundwater plays a critical role in supplying clean water for domestic, agricultural, and industrial uses. However, its quality is highly susceptible to contamination from nearby objectionable vectors, such as septic tanks, landfills, and industrial waste sites. A fundamental factor influencing the risk and extent of contamination is the velocity of groundwater. Groundwater velocity is influenced by aquifer properties such as permeability, porosity, hydraulic gradient, and the nature of subsurface materials. Understanding this velocity is essential for assessing contamination risks and for estimating safe distances between boreholes and potential sources of pollution. The determination of safe distances requires a clear grasp of contaminant travel times, which are directly affected by groundwater flow velocity. Faster groundwater velocities reduce the time available for natural attenuation processes (like dilution, filtration, and chemical breakdown) and increase the risk of rapid contaminant transport to boreholes. Conversely, slower velocities may allow for sufficient natural purification before reaching a borehole, provided the distance is adequate. This paper highlights the critical place of groundwater velocity in risk assessments and regulatory frameworks for borehole siting .It emphasizes the need for site-specific velocity determination through field measurements or modeling and proposes methodologies for calculating minimum separation distances to safeguard groundwater supplies. A deeper understanding of groundwater dynamics not only protects public health but also enhances sustainable management of groundwater resources in the face of increasing anthropogenic pressures. The average seepage velocity in the study area is 0.4562 m/days while the highest and the lowest are respectively 0.9599 and 0.15483. This implies that areas bothering Isingwu-Ibeku and Ibeku –Fmc Umuahia axis which are above the average and are therefore pruned to faster contamination than the ones around Nkpa1-Nkpa2 and Ibeku-Amachara axis. To safeguard boreholes in these areas therefore more reassuring work using charcoal, sand and gravel has to be done by building strong concrete or impassable walls against the objectionable vectors which will aid in the attenuation of the water.

**Keywords:** Groundwater, Landfills, Contaminants, Objectionable Vectors, Pollution

## I. Introduction

Groundwater is a vital resource, supplying nearly half of the world's drinking water and supporting agriculture and industry (Freeze, Allan D., and Cherry, John A., 1979). Despite its critical importance, groundwater is highly vulnerable to contamination from objectionable vectors such as septic systems, landfills, and industrial waste sites. The movement of contaminants through groundwater is governed largely by the groundwater velocity -a function of aquifer properties, hydraulic gradients, and soil structure (Domenico and Schwartz, 1990).Groundwater velocity determines the time available for natural attenuation processes, such as filtration, adsorption, and microbial degradation, before pollutants reach a borehole. Faster velocities increase the risk of contamination, making it crucial to establish adequate safe distances between boreholes and potential pollution sources (Fetter, 2001).

Hydrogeological site characterization, including direct measurement or estimation of groundwater velocity, thus forms the basis for public health protection and regulatory planning.

This study explores the central role of groundwater velocity in contamination risk assessment and provides guidance on determining scientifically sound safe distances between boreholes and objectionable vectors, using methodologies grounded in established hydrogeological principles.

The movement and quality of groundwater have been subjects of extensive study due to the resource's critical importance for human consumption, agriculture, and industry. Understanding groundwater velocity is essential for predicting contaminant transport and for designing protective measures for water supply sources, particularly boreholes. Early foundational work by Freeze and Cherry (1979) described the role of hydraulic conductivity, porosity, and hydraulic gradient in determining groundwater flow velocities. They emphasized that in granular aquifers, velocities could range from a few centimeters to several meters per day, while in fractured rock systems, velocities could be significantly higher. Domenico and Schwartz (1990) further

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developed mathematical models of groundwater flow and solute transport, highlighting how variations in aquifer materials and the presence of preferential pathways (e.g., fractures) could accelerate contamination spread. Their work introduced the concept of "effective velocity" or "seepage velocity," which adjusts the average groundwater velocity for the actual flow paths through pore spaces, providing a more realistic understanding of contaminant travel times.

The relationship between groundwater velocity and contaminant migration has been clearly demonstrated in field studies. For instance, Mackay, Cherry, and Gillham (1986) conducted tracer tests that revealed significant variability in contaminant arrival times at monitoring wells based on local hydrogeologic heterogeneity. Their findings underscored the need for site-specific assessments rather than reliance on generalized safe distance guidelines.The determination of safe distances between boreholes and objectionable vectors has evolved alongside better understanding of groundwater behavior. According to Fetter (2001), safe separation distances must account not only for velocity but also for the contaminant type, the natural attenuation capacity of the subsurface, and the expected lifespan of the borehole. Regulatory guidelines, such as those from the U.S. Environmental Protection Agency (EPA, 1987), advocate for a risk-based approach, recommending minimum distances that are increased in areas of high permeability or high contaminant mobility. Recent studies have incorporated advanced numerical modeling to simulate contaminant transport under varying conditions. Zheng and Bennett (2002) emphasized the importance of combining field data with transport modeling to better predict contaminant fate and to refine safe distance requirements. Their work demonstrated that even relatively low groundwater velocities could result in rapid contamination over long periods if persistent sources of pollution exist. Sedimentary basins are known to have most prolific aquifers and their aquifer materials are often fairly homogeneous. The surface observations of the localities show disparity in rocks that makeup the subsurface of these areas. From south to north, top soil changes

from coarse sands to gritty sandstone intercalating with clay and sometimes only clay. By this harnessing groundwater may not be uniform in every place within the study area. The study area comprises of three geologic formations which can be investigated with geophysical methods to understand the lithologies of the different parts. However, of major concern for this study is to delineate the aquifer zones in Umuahia and the neighbouring towns. There has been some case of boreholes failing to yield enough water in certain areas within the sedimentary basin. This is however more prevalent in crystalline basements (Ajayi &Abegurin,1994).The technique of using electrical resistivity to interpret rock units is of immense help in the search for groundwater, Nwugha et al.,(2020). It will explore parameters such as aquifer resistivity, thickness as well as depths to water table. The thickness and depth of each unit has not been properly determined and this has caused a great financial loss and mismanagement in terms of groundwater development in this area. This may be due to lack of knowledge of the subsurface geology of the area. Also incessant abortive wells and numerous cases of re-drilling of boreholes before a successful one is achieved have necessitated the zeal to seek for a good understanding of the subsurface geology and the structural disposition of the subsurface layers. Vertical Electrical Sounding (VES) is a very good tool and aid accurate mapping of the subsurface geologic layers and the delineation of aquiferous zones in tectonically stable sedimentary basins ( Eke, Cookey & Ejiogu 2018).

**Location and Geology of the Study Area**

The study area is located in Southeastern part of Nigeria within latitudes 5° 25' N to 5° 41'N and longitudes 7° 25' E to 7°43'E. The major towns found in this area include: Umuda, Nkpa, Lohum, Afugiri, Ubani, Isingwu, Umuahia, lbeku and Ubakala., (figure 1).The area is drained by some perennial rivers such as lnyang River, Otenyi River, Eme River, Imo River, etc. The drainage pattern is dendritic. There are three Formations in the study area namely: Benin Formation in the southwestern part, Benin Formation which is Pliocene in age and consists of alternating layers of sands, sandstones and loams with clays. As the sandy component in most of the areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage co-efficient become high. The Ogwashi Formation of the Pleistocene age is in the central region and Ameki Formation in the northern area. Ogwashi Formation consists of clay that is gritty, pebbly sandstone units and lignite seams. The Ameki Formation is of Eocene age, consisting of series of highly fossiliferous grayish- green sandy clay with calcareous concretions and white clay sandstones. Sandstones are associated with primordial radionuclides (Nwaka, et al., 2018). The thickness may attain as much as 1400m in some places (Lambert-Akhionbare, Ogbe & Oteze, 1977). The beds dip gently between 5° to 7°S. Near Bende, the sandstones are almost horizontal. In general, Ameki strata show steeper dip than the overlaying strata, which is indicative of unconformable relationship (Wilson, 1925). Ameki Formation in South Nigeria

Eocene is correlative with middle Eocene (Lutetian) of the Senegal Basin (Monciardin, 1966) and later subdivisions of the Togo-Dahomey sequences (Skanshy, 1962). It shares the common occurrence of phosphate with both Basins and the diagnostic Eocene pelagic foraminifera, Truncorotaloidsrohric Bronnimann and Bermedez with the Senegal Basins

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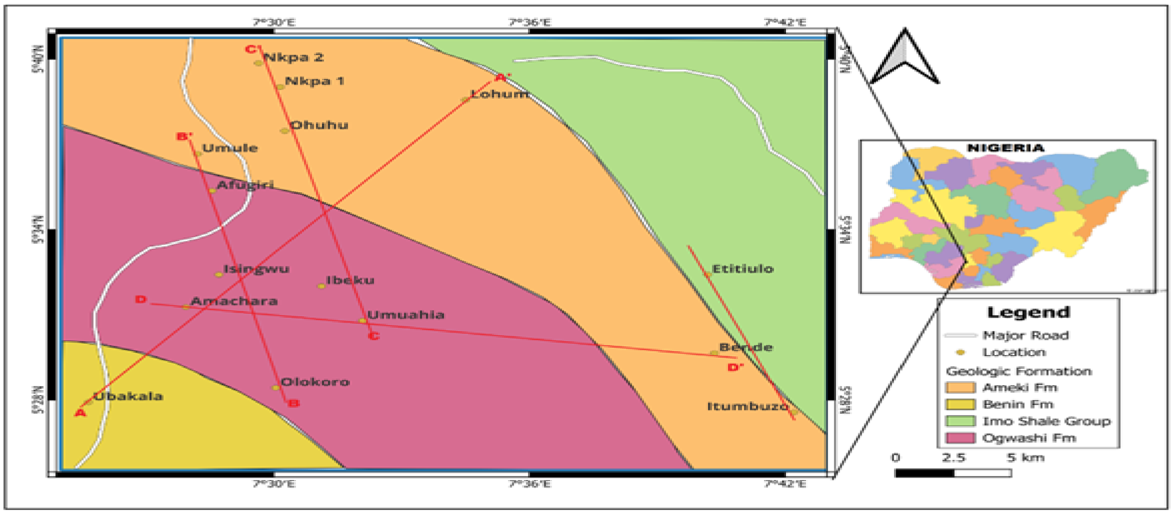


Figure 1: Map of Nigeria showing study Location

## II. Materials and Methods

The field equipment used in collecting data included: Germin GPS 78 CSX for obtaining the coordinates and elevation of various locations, a Terrameter 1000 SAS for resistivity survey. The data obtained in depth sounding was plotted as a graph of apparent resistivity against electrode separation (half the current electrode separation). This provided an idea of the depth of interfaces .Depth estimation was maded using an approximation of the depth of interface as equal to two – third (2/3) of the electrode separation at which the point of inflection occurs. The coordinates of various locations were superimposed on the geologic map (Fig 2). Each of the apparent resistivity sounding data was plotted on log-log graph, filtered and IP2WIN computer software used to iteratively model the curves to get geoelectric layers of the probable lithologies. Cross sections were drawn to establish four profiles of VES locations namely; A–A′, B–B′, C–C′ and D–D. A comprehensive approach of combining field measurements, laboratory analysis, and modeling techniques to assess groundwater velocity and estimate appropriate safe distances between boreholes and objectionable vectors were used as suggested by Fetters (2001). Accordingly the success of reservoir characterization lies in the integration of geologic, geophysical, and petrophysical data to build a coherent model of the subsurface. Fetters further emphasizes that understanding a reservoir accurately requires combining multiple type of data, geophysical ( like electrical resistivity data), petrophysical ( properties from well logs such as porosity) and depositional environments. This integration creates a realistic and comprehensive model of the reservoir, which is essential for effective resource estimation and development planning. Based on depositional environments sites where resistivity survey were conducted using the Schlumberger array were selected and considering the presence of active boreholes and nearby potential contaminant sources such as septic systems and waste disposal sites. The figures 2a, 2b,2c and 2d were obtained from which borehole data for this study were selected. Criteria for selection included aquifer type, soil porosity, and known groundwater use patterns, following recommendations from Todd et.al (2005). Darcy's Law and Effective Velocities explain the requisites parameters derivable. These equations are as shown:

$q = -k\ (hd/hl)$ and $V_e = -K \times (dh/dl)$ or $\{-K \times i\}/\{n_e\}$

Where:

$q$ =- Darcy velocity (m/s)

$V_e$ = groundwater seepage or effective velocity ( m/s )

$K$ = hydraulic conductivity ( m/s )

$i = dh/dl$ = hydraulic gradient ( dimensionless )

$n_e$ = effective porosity ( 0-1 )

The hydraulic gradient was estimated using the following equation:

$dh/dl = (h_2 - h_1)/L$

$h_1$ and $h_2$ = hydraulic heads at two points ( m )

$L$ = distance between the two points (m).

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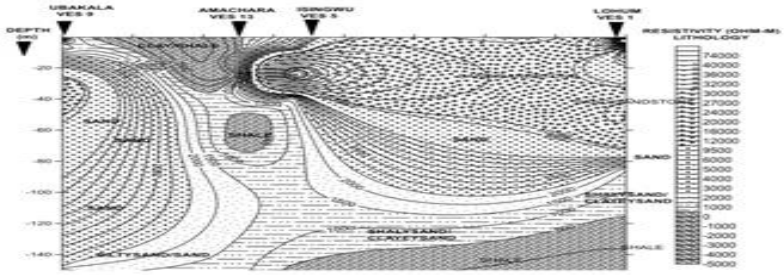


Fig 2b: Borehole points at Olokoro and Afugiri

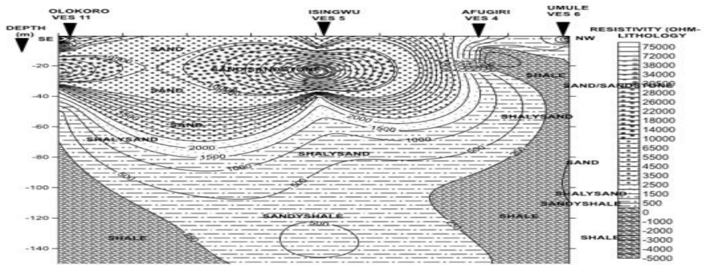


Fig 2a: Borehole points within Umuahia

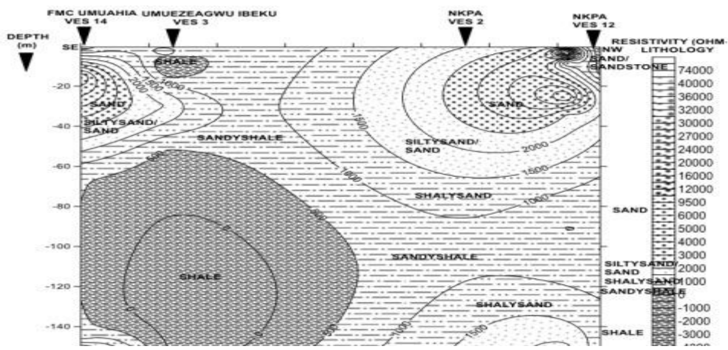


Fig 2b:Borehole points at Olokoro and Afugiri

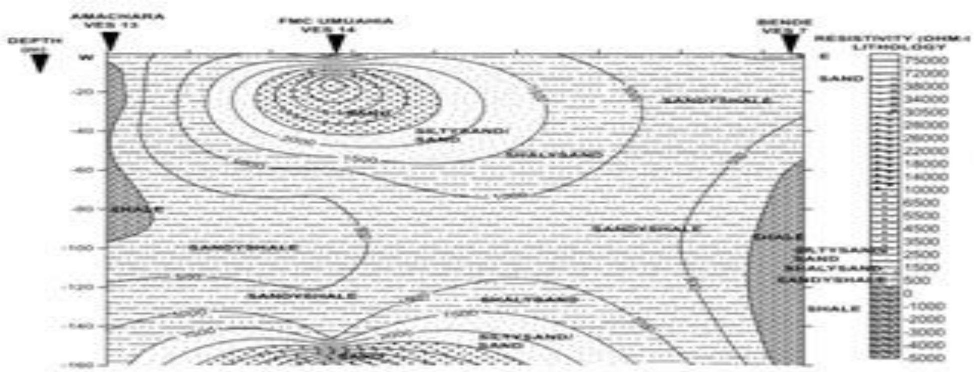


Fig 2d: Borehole points at Amachara and Bende

**III. Results**

Aquifer parameters; depth, thickness and porosity were measured to compute Darcy's velocity and Groundwater effective Velocity as suggested by Fetter (2001). These are shown in Tables 1 and 2.. Determination of safe distances were calculated to estimate time required for contaminants to travel from vectors to boreholes by combining measured velocities with known distances. Safety factors were applied based on contaminant type, using methodologies described by Foster and Chilton (2003).Empirical models from the U.S. Environmental Protection Agency (EPA, 1987) and WHO Guidelines (WHO, 2017) were consulted to define minimum travel times and distances necessary to allow for natural attenuation,( figure 5a – 5i).

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Table 1: Aquifer Parameters From Boreholes

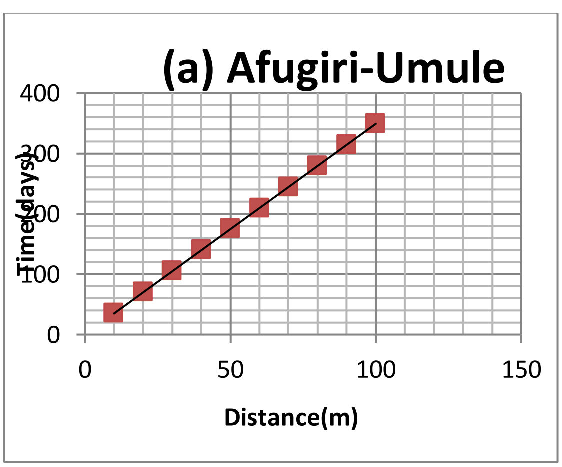
| S/N | Borehole Location | Aquifer Depth(m) | Aquifer Thickness(m) | Aquifer Porosity(%) |
|---|---|---|---|---|
| 1 | **Afugiri** | **27.1** | **9.3** | **35** |
| 2 | **Umule** | **19.2** | **9.2** | **35** |
| 3 | **Ibeku** | **43.8** | **14.3** | **32** |
| 4 | **.F.MC Umuahia** | **146** | **94** | **32** |
| 5 | **Isingwu** | **141** | **102.2** | **35** |
| 6 | **Amachara** | **92** | **23.2** | **35** |
| 7 | **Ubakala** | **148** | **42** | **35** |
| 8 | **Nkpa1** | **117** | **26.4** | **32** |
| 9 | **Nkpa2** | **138.5** | **23.5** | **32** |
| 10 | **Etitiulo** | **129** | **32** | **32** |
| 11 | **Bende** | **48** | **44.5** | **25** |
| 12 | **Itumbauzo** | **107** | **76.6** | **25** |
| 13 | **Lohum** | **85.7** | **17.6** | **30** |
| 14 | **Olokoro** | **69.5** | **19.6** | **32** |

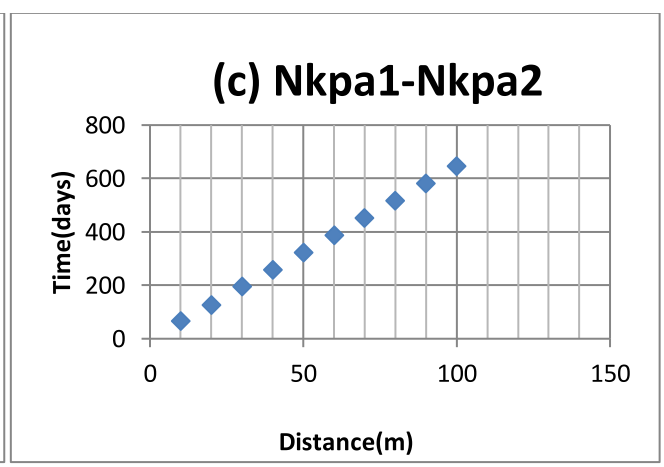
Table 2: Selected Borehole Distances and Aquifer seepage Velocities

| S/N | Selected Points | Distances(m) | Effective Porosity (0.1-1) | Seepage Velocity(m/day) |
|---|---|---|---|---|
| 1 | **Afugiri-Umule** | **2500** | **0.35** | **0.28636** |
| 2 | **Ibeku-FMC Umuahia** | **2600** | **0.32** | **0.94349** |
| 3 | **Nkpa1-Nkpa2** | **4000** | **0.32** | **0.15483** |
| 4 | **Ibeku-Amachara** | **7000** | **0.33** | **0.16157** |
| 5 | **Bende-Itumbuzo** | **5000** | **0.25** | **0.36953** |
| 6 | **Isingwu-Ibeku** | **4000** | **0.33** | **0.95990** |
| 7 | **Isingwu-Amachara** | **2500** | **0.35** | **0.48384** |
| 8 | **Ubakala-Olokoro** | **7500** | **0.33** | **0.27406** |
| 9 | **Bende-Etitiulo** | **5100** | **0.29** | **0.47225** |

Table:3 Seepage Velocity Within Areas of Highest and Lowest Velocities

| **Average Seepage Velocity(m/days)** | **Areas with High Velocity (m/days)** | **Areas with Low Velocity(m/days)** |
|---|---|---|
| **0.4562** | **Isingwu-Ibeku** ( **0.9599** ) | **Nkpa1-Nkpa2** ( **0.15483** ) |
| | **Ibeku-Fmc Umuahia** ( 0.9483 ) | **Ibeku-Amachara** ( 0.16157 ) |



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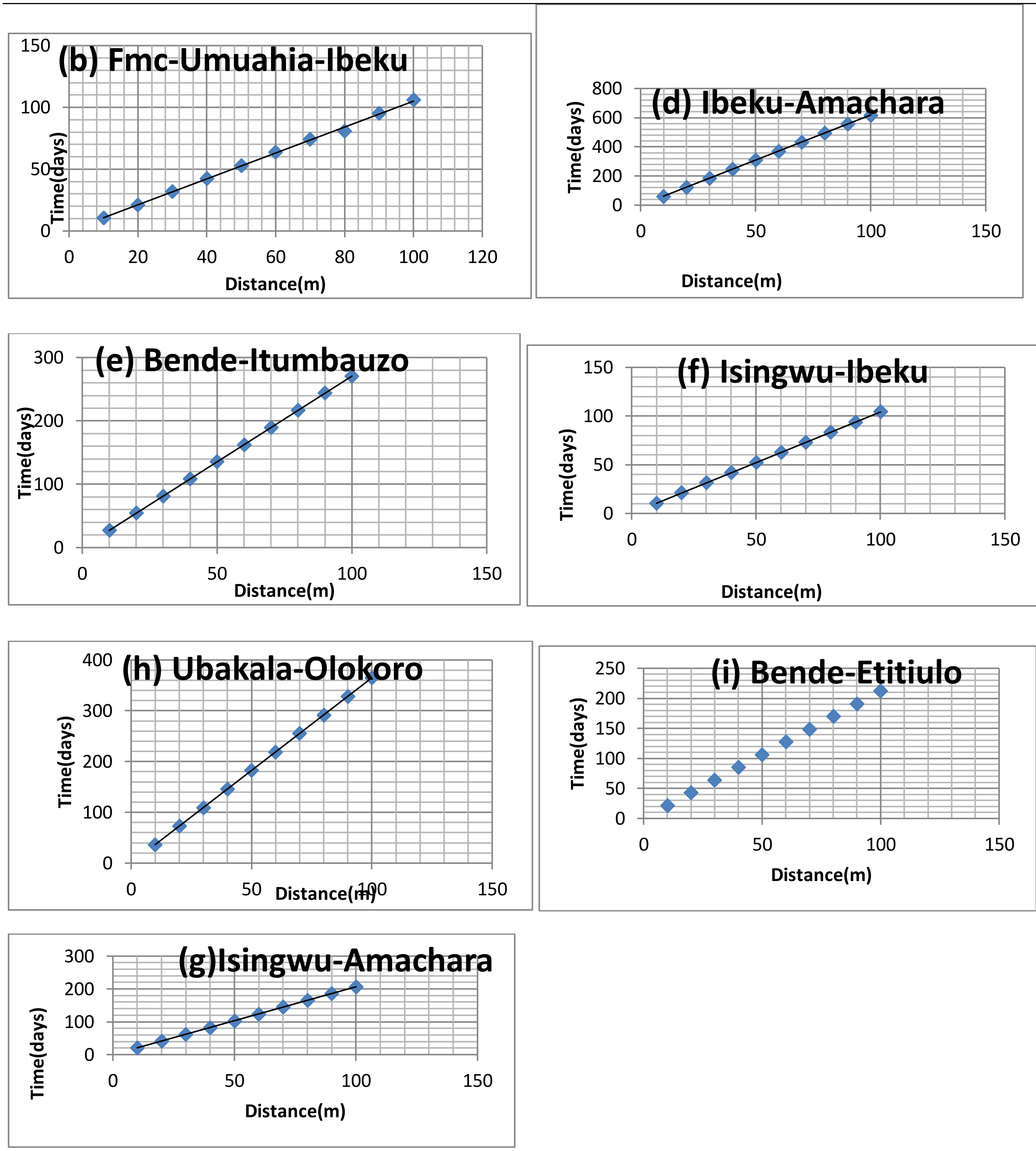


Fig 5: Graphs of Distance (m) versus Time (days) of Selected Areas ( a- i )

## IV. Discussion

The results of this study reaffirm the critical influence of groundwater velocity on the potential for contaminant migration toward boreholes. This is consistent with prior researches (Freeze and Cherry, 1979; Domenico and Schwartz, 1990). It was observed that faster groundwater velocities drastically reduce the natural attenuation time available for contaminants, thereby increasing contamination risk. In areas where coarse-grained sands are present, contaminants can travel considerable distances within relatively short periods, corroborating findings by Mackay et.al (1986). This can be easily observed from figure 5 ( a - i ). The application of Darcy's Law and the use of seepage or velocity provided consistent estimates of groundwater velocity, validating

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the importance of direct measurements over reliance on regional averages. Furthermore, safe distance calculations indicated that regulatory guidelines often underestimate the required separation distances, especially in highly permeable zones. While agencies such as the EPA (1987) recommend generic buffer distances, the site-specific analysis here supports more conservative estimates, particularly for boreholes used for drinking water supply. Neglecting either aspect could result in unsafe borehole placements, ultimately threatening public health.

## V. Conclusion

This study establishes that groundwater velocity is a pivotal factor in assessing contamination risks and estimating safe distances between boreholes and objectionable vectors. Site-specific measurements of hydraulic gradient, and effective porosity are indispensable for accurately estimating groundwater velocities and, by extension, contaminant travel times. Generic safe distance guidelines, while useful, should not replace detailed hydrogeological investigations. Contamination risks vary greatly depending on local conditions, and a "one-size-fits-all" approach may leave boreholes vulnerable to pollution. By combining field data collection with robust modeling techniques, a more accurate and defensible estimation of safe distances can be achieved. Ultimately, protecting groundwater quality requires not only technical precision but also cautious regulatory frameworks that prioritize human health over convenience. In this study location, the average seepage velocity is 0.4562 m/days while the highest and the lowest are respectively 0.9599 and 0.15483. This implies that areas around Isingwu-Ibeku and Ibeku –Fmc Umuahia axis which are above the average are pruned to faster contamination than the ones around Nkpa1-Nkpa2 and Ibeku-Amachara axis. To safeguard boreholes in these areas therefore more reassuring work has to be done to safeguard boreholes around them by building defensive and protective shields using charcoal, fine sand and gravel as shown in figure 6.

## VI. Recommendations

1. For Site-Specific assessments, hydrogeological surveys should be preceded by comprehensive investigations that include measurements of hydraulic gradient, its conductivity, effective porosity, and groundwater gradients to determine groundwater velocities and tailor safe distances accordingly.

2. Tracer Tests for High-Risk Areas in zones with highly permeable or fractured formation, should be made mandatory to predict real contaminant migration pathways.

3. Regulatory agencies should revise minimum safe distance requirements upward, particularly in regions with rapid groundwater flow or vulnerable aquifers. This is necessary and essential where corpses are buried in residential compounds.

4. Safe distance calculations should integrate groundwater flow models with contaminant transport simulations for more accurate risk assessment.

5. Regular sampling and monitoring of borehole water should be enforced, especially where objectionable vectors are located within a 500-meter radius.

6. Communities relying on groundwater should be educated on the importance of safe siting practices to reduce the risk of anthropogenic contamination because nearer the boreholes are to objectionable sources the more they are at risks to contamination.

6. Protective soak-away design format using charcoal, gravel and sand should be applied. This could be done with crushed or powdered charcoal, clean river sand and gravel to construct. Charcoal will help to remove toxins, control adsorption of organic contaminants, prevent pathogens, repel odor; sand will provide fine filteration and trap sediments while gravel will promote drainage and prevent clogging. The layering will enhance percolation by filtering out suspended particles and slow down water movement, (figure 6 below).

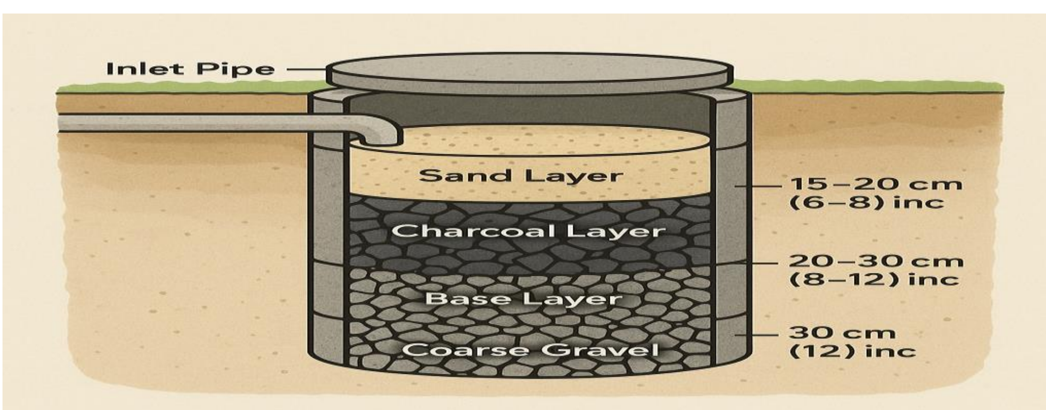


Figure 6: Soak-away Design for Borehole Water Protection

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