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Vertical Velocity of Pollutants through Porous Rocks of Anambra State: Implications for Water Resources Planning and Management

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Abstract
Indiscriminate siting of human activities has become a common practice in Anambra State, resulting to generation of mobile pollutants. To this effect, an infiltrometer was used to investigate the velocities of pollutants (four fluids) through five sedimentary formations of varying lithological characteristics, with a view to proffering efficient strategy for management of groundwater resources in the area. A purposive/judgmental sampling technique was used to select the formations used. The study tested the following hypotheses:(i) the velocity of pollutants through rocks is not related to the lithological characteristics of the underlying rocks and (ii) pollution level (densities of pollutants) is not related to the vertical infiltration (velocity) of pollutants. The following findings were recorded: (i) the velocity of pollutants through rocks is closely related to the lithological characteristics of rocks, including porosity and hydraulic conductivity, (ii) pollution level (densities of pollutants) is weakly related to vertical infiltration of pollutants. Consequently, the study recommended that the lithological characteristics of underlying formations should be known before selecting such sites for human activities that generate pollutants so as to safeguard the groundwater resources of the area. This is to say that shale terrains or any other formations that have, at most, porosity and hydraulic conductivity values of 18% and 2.3×10^{-8} cm/sec. respectively, should be used for human activities that generate mobile pollutants. It also recommended that site selection for various wide scales human activities that generate mobile pollutants should be based on the knowledge of underlying geology of the place in question, and not merely on the availability of such space and close proximity to users. Further research areas were also recommended.
Keyword: Pollutants, porous rocks, groundwater, lithological characteristics and management

Introduction

Siting of human activities indiscriminately has become a common practice in both developing and industrialized countries of the world. Many urban and rural areas of many countries have been adversely affected by the resultant pollutants and contaminants, resulting in losses in human, material and financial resources. In many countries, huge amounts of money are spent annually in researches to combat and control widespread of pollutants and contaminants. Volumes of these pollutants are continuously produced yearly through many human activities, like industrial activities, agricultural practices, waste disposal systems, etc. Consequently, various levels of wastes in different states, including solid, liquid and gaseous, are released into the environment at discrete intervals or on continuous basis. These pollutants and contaminants, which may have short or long half-lives in the environment, have continued to damage the environment of the industrialized countries, having defied many painstaking control programs *(Egboka et al, 1989 and Fano et al, 1987).*

In addition, geologic and hydrologic cycles have several components and characteristics that enhance or aggravate the incidence of pollutants and contaminants origin, transport, and spread through hydrodynamic dispersion (diffusion, advection and dispersion) into the hydrogeologic environments that embrace the atmosphere, pedosphere, lithosphere, hydrosphere and biosphere.

Consequently, these resultant pollutants/contaminants, in one way or the other, via the hydrologic cycle, reach the groundwater system to pollute/contaminate them. This is to say that these pollutants/contaminants move, via porous rocks, through the circulation of water within the hydrologic cycle. Pollutants on the ground surface are transferred through the soil zone into the aquifer horizons where they degrade potable water sources.

Anambra State is underlain by sedimentary rocks of varying types, and of different lithological characteristics. Sequel to these soft rock types, and relative even geomorphology, various locations in the state are indiscriminately used for various human activities. Moreover, the underlying formations are good aquifers (Jone and Hockey, 1964, Onyeagocha, 1980). This is why groundwater is the major, if not the only source of water in the area. Consequently, most of these formations are tapped at different scales and purposes. For instance, majority of the people in Onitsha exploit Ogwashi-Asaba Formation while most of the inhabitants of Awka, Ekwulobia and Nanka exploit the Nanka Sands (Onyeagocha, 1980).

Sequel to the above, there is need for a management strategy to protect these water supply sources since groundwater has become the main, if not the only reliable source of water for various uses in the area, especially in the urban-areas. Part of this strategy is to establish the velocity at which pollutants/contaminants move through these porous rocks. When this is done, geographical locations whose underlying formations do not favour the movement of mobile pollutants can be recommended for those activities that generate these mobile pollutants. In doing this, the groundwater resources can be protected.

Study Problem

Consequent upon the wrong assumption that groundwater is always free from pollution, its use has tremendously risen across the globe for various purposes: domestic, industrial, agricultural, etc. But contrary to this assumption, studies by different people in both developing and developed countries of the world show that pollutants from various sources get to the groundwater, with time, and pollute it. For example, works by Elrik and French (1966), Thoma and Phillips (1979), Wild (1972), Egboka et al., (1989), Trenthan and Orajaka (1986), Orajaka (1986), and Shell Petroleum Development Company (SPDC) (2003, 2005a and 2005b) have proved this. Ajiwe et al (2006) explained that industrial effluents released into the environment get to the groundwater with time, and pollute it; hence they recommended that the velocity of these pollutants be established.

Unfortunately, most of the time, in most places, especially in developing countries, emphasis is usually placed only on steady water supply and quantity. Minimal priority is given to water quality and treatment. This could be the main cause of out breaks of diseases, especially waterborne ones in many places.

A casual look at most urban centres in Nigeria, and indeed in the area, reveals unplanned and unorganized uses of various locations for various purposes like solid waste dumping, effluents disposal, siting of burial grounds for dead bodies, siting of wide scale toilet facilities, disposal of chemical wastes from human activities, and wrong and frequent application of artificial fertilizers. These are done without putting the lithological characteristics of the underlying formations of such sites into consideration.

There is no doubt that these activities take place either in recharge waters or in groundwater recharge areas. Considering the concept of hydro-geopollution cycle, these resultant pollutants are circulated via the hydrologic cycle. Hence, groundwater is in an ever-present risk in these porous rocks as confirmed by Ajiwe et al (2006) and Onwuka et al (2007) in Onitsha.

It is to this effect that this work investigated the rate at which pollutants move through porous rocks of different lithological characteristics with a view to establishing a reliable strategy for groundwater resources management in the area.

Aim and Objectives of the Paper

The aim of this paper is to investigate the velocity of leachates/effluents (pollutants) through sedimentary rocks of Anambra State with a view to establishing a reliable strategy for groundwater resources management in the area.

The following objectives will be pursued to achieve the aim:

- to establish formations where mobile-pollutants generating activities are carried out,
- to establish the porosity and hydraulic conductivity values of the formations, and
- to determine velocities of pollutants through the formations.

Area of Study

This study is carried out in Anambra State. The state is located between latitudes 05^o 40'N and 07^0 10N' and longitudes 06^o 35'E and 07^0 20'E (Figure 1). Anambra State is made up of 21 local government areas. The state is located in South-Eastern Nigeria.

Two climatic seasons exist in the study area, namely rainy season (March- October) and dry season (November- March). The dry season is characterized by heavy down pours accompanied by thunder storms, heavy flooding, soil leaching, extensive sheet outwash, ground water infiltration and percolation (Egboka and Okpoko, 1984). The annual rainfall of the area is about 2000mm.

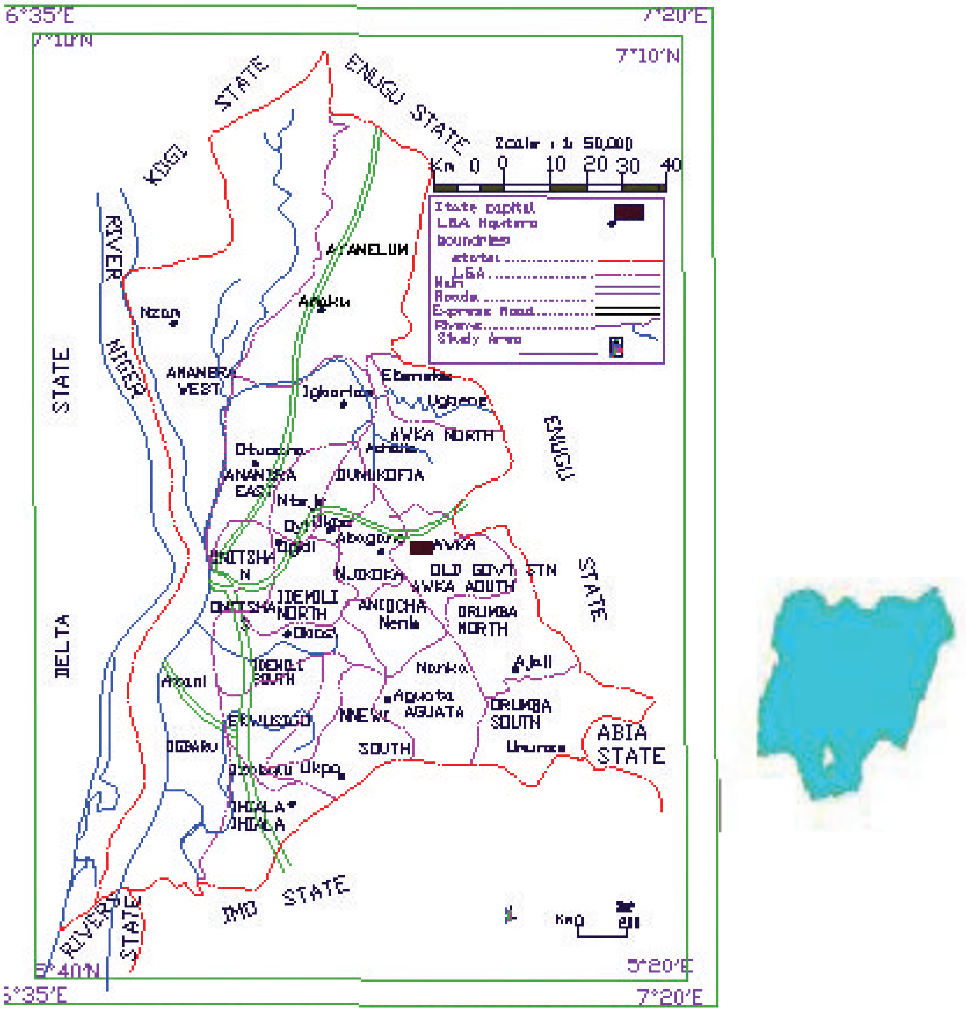

Fig. 1: Map of Area of Study (Anambra State)

The study area lies within the rain-forest belt of Nigeria. In the south, the area is bounded by mangrove swamp forest, and in the north, by savannah grassland.

Anambra State is underlain by sedimentary formations of varying types and ages. Consequently, most of the formations, being mainly sandstone, are good aquifers of high economic viability. Typical examples, according to Jones and Hockey (1964) and Onyeagocha (1980) are Nanka Sands, Ogwashi Asaba Formation, and Ameki Formation. The geologic map of Anambra State is shown in Figure 2 below. It also contains the formations used for the study. The natural flow patterns of the rivers in the area and their tributaries are dendritic drainage pattern (Igbokwe et al, 2008).

Urbanization processes involving road construction, building developments are on the increase in the area. This is due to the economic activities that go on in many parts of the area. Igbokwe et al (2008) discovered that due to the level of urbanization processes in the area, coupled with indiscriminate sand-mining, the area is prone to immense gully development.

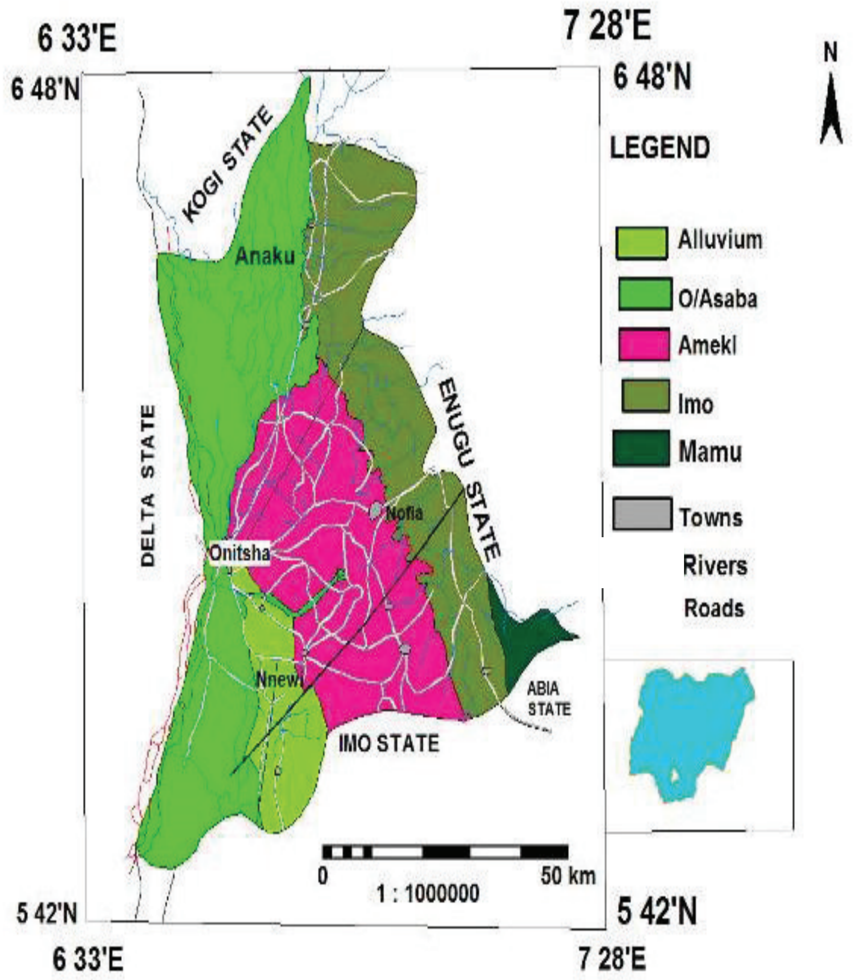

Fig. 2: Geogical Map of Anambra State (Source: Nigerian Survey Agency, 2006)

As a result of all of the above, there is continuous and increased generation of mobile pollutants. These pollutants are either indiscriminately released into the water bodies, or carelessly dumped on the earth surface. Now owing to the high porosity and permeability of the underlying formations, these mobile pollutants, via the hydrologic cycle, penetrate to the groundwater resources and render them deleterious for various direct and indirect human uses.

Conceptual Framework of the Paper

This work is built on the concept of the hydro-geopolution cycle. This stems from the popular hydrologic cycle as propounded by Darcy (1856).The hydrologic cycle describes the fluxes of water between the various reservoirs of the hydrosphere. The hydrologic cycle is composed of pathways, the various processes by which water is cycled around in the outer part of the earth, and reservoir or "store tank", where water may be held up for varying lengths of time. Again, the hydrologic cycle maintains a mass balance, which means that the total amount of water in the system is fixed, and the cycle is in a state of dynamic equilibrium.

According to Nnodu and Ilo (2000), the atmosphere is a gaseous envelope surrounding the earth. Precipitation, through condensation of water vapour molecules, which form clouds, falls down to the earth as rain, snow, hail, mist, or fog. Atmospheric pollutants and contaminants may be washed out of the atmosphere as fallouts. Rain carries pollutants into surface waters for possible evaporation back into the atmosphere or storage in rivers, streams, lakes, seas and oceans. Some of the fallouts may infiltrate into the soil zone, or be evapo-transpired into the atmosphere or percolate into the groundwater zone. Here, the moisture joins a complex hydrodynamic flow system to be transported to the oceans or other surface waters where evaporation may return the water to the atmosphere. In these processes, pollutants and contaminants introduced are cyclically dispersed from one point of the hydrologic cycle to another. Egboka et al (1989) explained this pollutant/contaminant cyclic movement in what they called the hydro-geopollution cycle. This is diagrammatically shown in Fig.1.3.

The implication of this is that pollutants migrate from one part of the hydrologic cycle to another. Consequently, this results in a resource-water quality relationship in the processes.

Pollutants and contaminants may be generated through natural or anthropogenic processes and circulated in the environment- atmosphere, pedoshpere, lithosphere, biosphere and hydrosphere (Ajiwe et al, 2006). This happens through the activities of water, air, chemical, physical and microbiological processes. There is no doubt that these complex and cyclic processes may be continuous with respect to distance and time and may be localized or regionalized in areal spread. This pollution at a point source or distributed source may spread and threaten nearby and distant places unless its spread is checked and controlled (Nnodu and Ilo, 2000).

From the fore going, therefore, it is quite clear that the proper understanding of the migration of pollutants/contaminants will stem from the sound understanding of the hydro-geopollution cycle, part of which is the lithosphere. To this effect, part of the management and control of these pollutants/contaminants, as advocated by Nnodu and Ilo (2000) and Ajiwe et al (2006), will be monitoring the speed at which they move via this part of the hhdrologic cycle, that is the lithosphere, hence this work.

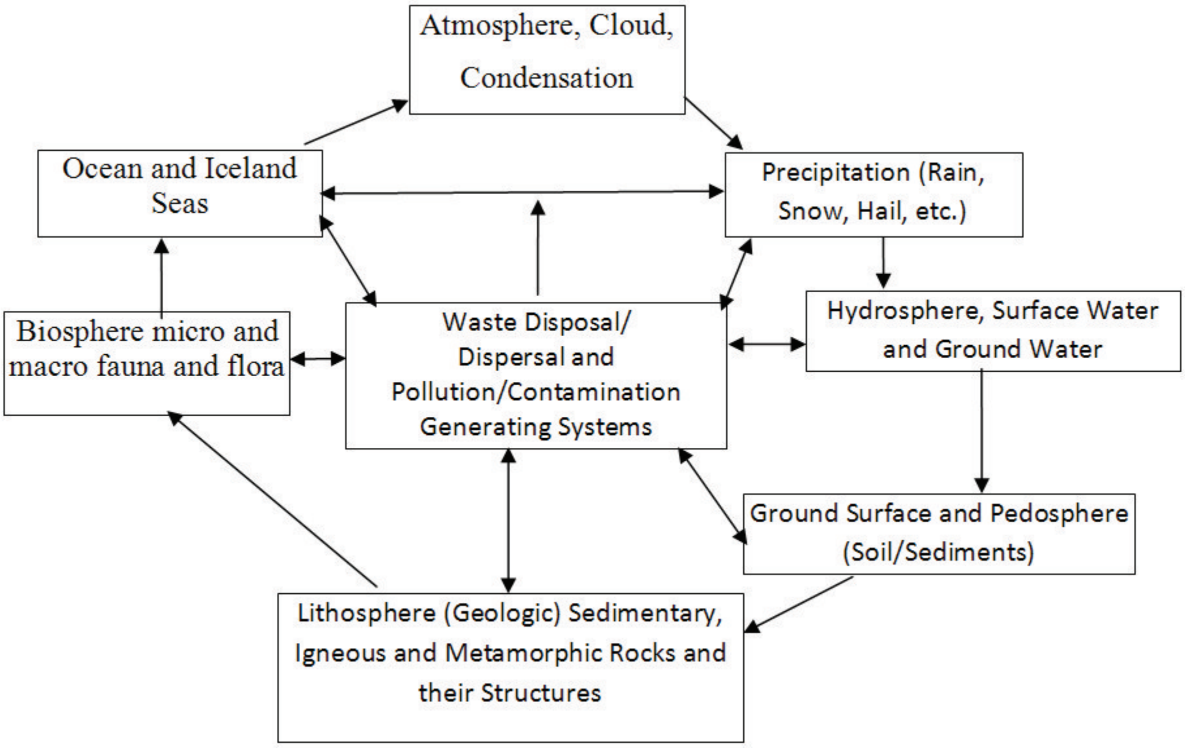

Fig. 3: The Hydrogeopollution Cycle, (After Egboka et. al (1989)

Methodology of the Study

The experimental design was adopted in this study. Due to the nature of the study, a judgmental/ purposive sampling technique was chosen in selecting the formations with which the laboratory analyses were run. This is because according to Babie (1973: 106) purposive sampling is the most suitable in a study of this type.

The design used in the work is laboratory analysis. The rock samples from the formations used and their locations are shown in Table 1 below:

Table 1: Rock/Fluid Sampling And Their Locations

Formation /Fluid Samples	**Location**
Formation	
Imo Shale	Quarry Site at Agu Awka, along Old Road,
Ogwashi Asaba Formation	Quarry Site at Onitsha/Owerri Road, Opposite Metallurgical Training Institute, Obosi.
Ajali Sandstone	Erosion Site at Ninth Mile Corner, Enugu State
Nanka Sands	Nanka Erosion Site, Nanka.
Boundary of Formation-	Equal mixture of the other formations
Fluid Samples	
Leachates	Solid-waste Dump Site behind GTC, Amawbia
Pharmaceutical Effluents	Godswill Pharmaceutical Company Ltd, Awka
Breweries Effluents	Breweries Industries at Ninth Mile Corner, Enugu State
Textile Effluents	General Cotton Mill Ltd, Onitsha

Source: Author's work (2009)

With the rock samples so collected, percolation/flow rate and grain size analyses were performed for all the formations differently. Subsequently, the data so generated were used to test the two hypotheses below:

1. The velocity of pollutants through porous rock is not related to the lithological characteristics of the underlying rocks, and
2. Pollution level (density of pollutants) is not related to the vertical infiltration (velocity) of pollutants

Findings and Discussion

Table 4.1: Result of the Laboratory Analysis of Imo Shale

Fluid Type	Formation Properties			Untreated Fluid			Treated Fluid		
	Coefficient of Curvature Cc	Porosity (%)	Hydraulic Conductivity (Cmk/Sec)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm3)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm3)
	0.6380	18	$2.3 * 10^{-8}$						
Pharmaceutical				0.0000001	0.9772	0.8749	0.0000002	0.8773	0.8736
Breweries				0.0000001	0.9902	0.8750	0.0000002	0.8773	0.8599
Textile				0.0000001	0.9868	0.8306	0.0000002	0.8773	0.8599
Leachete				0.0000002	0.7112	0.8583	0.0000003	0.5384	0.8331

Source: Author's Field Data (2009);Civil Engineering Lab. UNIZIK

Table 4.3: Result of the Laboratory Analysis of Ajali Sanstone

Fluid Type	**Formation Properties**			**Untreated Fluid**			**Treated Fluid**		
	Coefficient of Curvature Cc	Porosity (%)	Hydraulic Conductivity (Cmk/Sec)						
	0.6806	25	0.0051	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/cm^3)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/cm^3)
Pharmaceutical									
Breweries				0.037247	0.8373	0.8750	0.050972	0.6118	0.8599
Textile				0.032518	0.9590	0.8306	0.047056	0.6628	0.8145
Leachete				0.033554	0.8451	0.8583	0.034533	0.9031	0.8331

Source: Author's Field Data (2009);Civil Engineering Lab. UNIZIK

Table 2: Result of the Laboratory Analysis of Ogwashi-Asaba Formation

Fluid Type	Formation Properties			Untreated Fluid			Treated Fluid		
	Coefficient of Curvature Cc	Porosity (%)	Hydraulic Conductivity (Cmk/Sec)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm^3)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm^3)
	1.2902	25	0.0054						
Pharmaceutical				0.038449	0.9542	0.8749	0.041476	0.8846	0.8736
Breweries				0.041648	0.8846	0.8750	0.044769	0.8195	0.8599
Textile				0.041476	0.8846	0.8306	0.04667	0.7861	0.8145
Leachete				0.033358	0.8892	0.8583	0.041257	0.8893	0.8331
Source: Author's Field Data (2009);Civil Engineering Lab. UNIZIK									

From the analysis done, the data were generated are presented in the tables below:

Table 4.5: Result of the Laboratory Analysis Nanka Sands

Fluid Type	Formation Properties			Untreated Fluid			Treated Fluid		
	Coefficient of Curvature Cc	Porosity (%)	Hydraulic Conductivity (Cmk/Sec)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ m^3)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm^3)
	1.630	24	0.0032						
Pharmaceutical				0.022163	0.8829	0.8749	0.025145	0.7782	0.8736
Breweries				0.021935	0.8921	0.8750	0.025907	0.7553	0.8509
Textile				0.022708	0.8617	0.8306	0.026846	0.7289	0.8145
Leachete				0.021669	0.9031	0.8583	0.020873	0.7418	0.8331
Source: Author's Field Data (2009);Civil Engineering Lab. UNIZIK									

Table 4.4: Result of the Laboratory Analysis of Boundary of Formations

Fluid Type	Formation Properties			Untreated Fluid			Treated Fluid		
	Coefficient of Curvature Cc	Porosity (%)	Hydraulic Conductivity (Cmk/Sec)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm^3)	Velocity (cm/sec)	Hydcmraulic Gradient (cm)	Fluid Density (g/ cm^3)
	0.1733	28	0.0049						
Pharmaceutical				0.032418	0.9243	0.8749	570.91	0.035032	0.8753
Breweries				0.032779	0.9590	0.8750	570.91	0.035032	0.8599
Textile				0.051584	0.9294	0.8306	620.37	0.032239	0.8145
Leachete				0.049769	0.6021	0.8583	387.72	0.051584	0.8331
Source: Author's Field Data (2009);Civil Engineering Lab. UNIZIK									

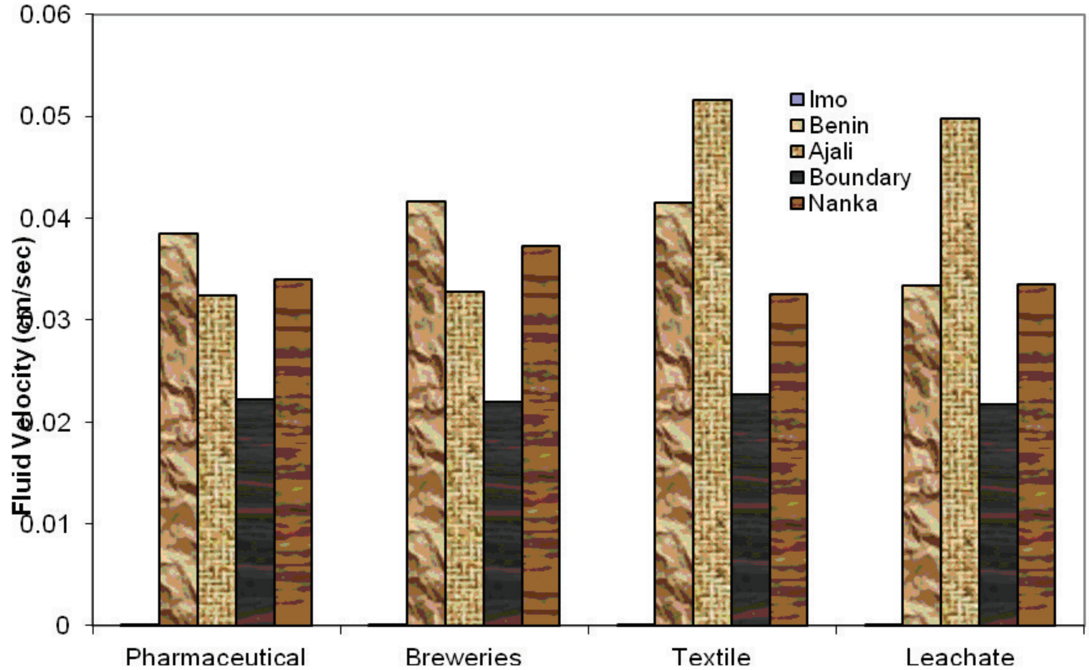

Fig. 4.1: Comparative Velocities of Untreated Fluids through Various Format ions Arthurs's Work (2009)

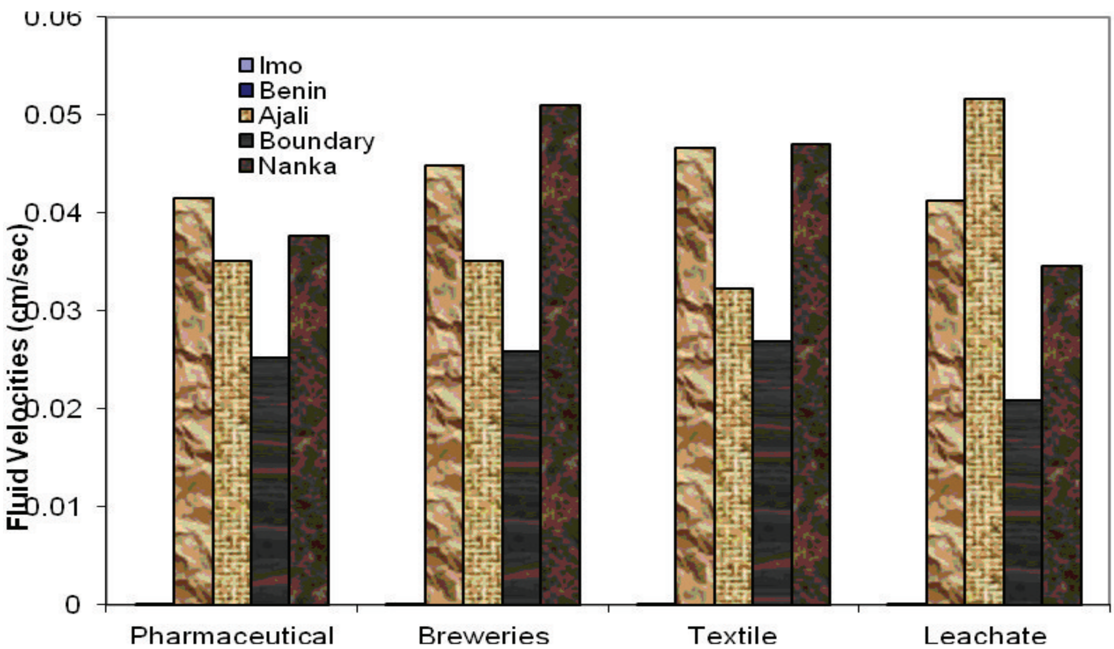

Fig.4.2: Comparative Velocities of the Treated Fluids through Various Formations Arthurs's Work (2009)

The velocities of these fluids (untreated and treated) through the five formations are shown in Figures 1 and 2. It can be seen that the velocity values of Imo Shale for both treated and untreated fluids were so low that the computer did not pick them. This implies that there is little or no passage of the pollutants through the shale formation. This further confirms that shale terrains and their likes are the only terrains good for siting human activities that generate mobile pollutants.

An important general information and inference could be drawn here that if pollutants must be prevented from migrating to pollute the groundwater resources of Anambra State greatly depended upon by the inhabitants of the area, *then the knowledge of pollutants' vertical velocity through the underlying rocks of the area becomes inevitably important. This finding also applies to any other sedimentary terrain used for wide-scale human activities anywhere.*

Looking at Tables 1-5, it can be seen that the readings of Table 1(Imo Shale), are very different from those of the other formations. For instance, it has the least values of the coefficient of curvature, i.e. 0.6380, porosity, i.e. 18% and hydraulic conductivity, i.e. 2.3 x 10^{-10}m/sec. In terms of the velocity values, it has the lowest. This means that all the fluids took very long time to pass through it unlike in all the other formations. This is seconded by the boundary of the formations (Table 4).

For the Imo Shale, the very long time (i.e. very low velocities) taken for the fluids to flow through it is explained by the formation properties. The coefficient of curvature calculated, the porosity, and the hydraulic conductivity determined, all shows that the formation is of very fine texture; and the grains are so closely packed together that there is little or no space for fluid movement. This is to say that shale formations allow little or no permeability. This is because they have little or no pore spaces, and hence very low hydraulic conductivity values. This explains why it took very long time for all the fluids to flow through it. This shows that this formation (Imo Shale) and any other one with similar lithological properties are good for siting any human activities that generate mobile pollutants, like industries, burial grounds, waste-dumping sites, etc, since they pass little or no pollutants that migrate to pollute groundwater systems.

Again, Table 4, which is the Boundary of Formations shows velocity values slightly higher than those of any of the remaining formations – Ajali Sandstone, Ogwshi-Asaba Formation, and Nanka Sands. Again, its porosity, as well as hydraulic conductivity, is also slightly lower than it is in all others. This lowered permeability is simply because of the introduction of the shale in its mixture. The high value of the coefficient of curvature could be traced to the proportional mixing of the different rock types. An inference could be drawn here, *that any site with similar lithological properties (ie much shale content other than sandstone) is preferable for mobile pollutants' – generating activities.*

For the remaining formations–Ogwashi Asaba Formation, Ajali Sandstone and Nanka Sands, their porosity values as well as their hydraulic conductivities are close to one another. This, therefore, explains why the velocities of the fluids through them show close similarities. The slight variations in the values could be attributed to the slight variation in grain sizes, which are revealed by their coefficients of curvature.

Moreover, the velocity values of these three formations: the Ogwashi Asaba Formation, Ajali Sandstone and Nanka Sands, which are all sandstone formations, are all very high compared to those of the Imo Shale and Boundary of Formations. This quickly establishes the fact that since the flow time of dissolved pollutants through sandstone formations (terrains) are low (that is high velocity), and since they are, by nature, aquiferous formations containing the groundwater resources we depend on, they are not good for siting of any mobile – pollutants – generating activities, agreeing with the findings of Onwuka (2009).

Testing of Hypotheses

In order for the inferences not to be drawn from mere observations made on the data, the data were subjected to statistical analyses, where the hypotheses postulated were tested.

Hypothesis One

Ho: The velocity of pollutants through rocks is not related to the lithological characteristics of the rock.

This involves relating the lithological characteristics and the treated and untreated fluids. The lithological characteristics to be tested using the velocities of both untreated and treated fluids are coefficient of curvature, porosity, and hydraulic conductivity of the formations. To this effect, the test was separate for all of them. The Karl Pearson Product Moment correlation was used.

For the coefficient of curvature, the result of the correlation for the untreated fluids was -0.101 each, showing weak relationship between them and the velocities of the untreated fluids.

Similarly, the correlation value between the coefficients of curvature of the formations and velocities of the treated fluids was -0.008 each. This also shows very weak correlation, leading to the rejection of the null hypothesis.

Hence, we conclude that the velocity of pollutants, irrespective of the pollutant level (density of the pollutant) through a geologic formation is weakly related to the coefficient of curvature of the underlying rock, implying that the rate of movement of pollutants (regardless of the density) through a rock or soil is weakly related to the grading of its constituent grains.

Again, the analyses showed that the correlations between porosities of the formations and the velocities of both untreated and treated fluids are 0.921 and 0.856 respectively, showing that there is a very strong correlation between them. This led to the rejection of the null hypothesis, and acceptance of the alternative, that the velocity of pollutants through rock is strongly related to the porosity of the rock/soil.

This finding clearly clarifies the type of formation that is suitable for siting human activities that generate pollutants. The implication is that since infiltration rate of pollutants through a geologic formation is related to the porosity of the underlying rock, it means that in the planning and management of the physical environment for siting of human activities that generate pollutants, in order to protect the groundwater resources on which people greatly depend upon in South-Eastern Nigeria, particularly Anambra State, formations with high porosity values, like sandstone formations, are not good for siting such human activities. This is to say that shale terrains and their likes which have low porosity values are the only terrains suitable for siting such human activities.

In addition, the correlations between the hydraulic conductivities of the formations and their velocities were 0.942 and 0.959 (untreated & treated) respectively. This, again, shows that there is a strong relationship between velocities of the fluids and the hydraulic conductivities of the formations, just as in the case of the porosity. Hence the null hypothesis is rejected and the alternative hypothesis is accepted that the velocity of pollutants through any geologic formation is strongly related to the hydraulic conductivity of that formation. This implies that sandstone terrains, whose hydraulic conductivity values are high, unlike shale terrains with low values, are not good for siting human activities that generate mobile pollutants.

Suffice it to say at this stage that this finding that the velocity of pollutants through rock or soil of any place is a function of the porosity and the hydraulic conductivity of that rock or soil greatly enriches the arsenal kit of environmental managers and even physical planners. This is because it fully gives the ***criteria that should guide physical planners in the selection and siting of human activities generating pollutants?*** Hence we can emphatically say that the criteria for selecting any terrain for human activities generating pollutants are ***the porosity and the hydraulic conductivity values*** of the underlying rock of that terrain. Put in other words, in planning of physical environments for various human activities generating pollutants, physical planners and environmental managers and all concerned with water resources should be guided by the porosity and hydraulic conductivity values of such physical environments. This is because these are the two things upon which the velocity of any pollutants passing through them depends.

Hypothesis Two:
Ho: Pollution level (density of pollutants) is not related to the vertical infiltration (velocity) of pollutants
In testing hypothesis two, the densities of pollutants and their velocities were used.

The result of the analysis gave the correlation values of the untreated fluids as – 0.023 each. Similarly, that of the treated fluids is -0.241 each. This shows that there is a very weak correlation between the pollution level of pollutants (density of pollutants) and the infiltration rate (velocity) of pollutants through soil, leading to the acceptance of the null hypothesis, and the rejection of the alternative. Hence we infer that regardless of the pollution level of whatever pollutant (density), so long as that pollutant is mobile (ie soluble in water), and so long as the porosity and hydraulic conductivity values of the rock definitely pass through the rock (soil) to pollute the groundwater, although the rate of movement may differ as discovered from the result of hypothesis one.

Conclusions and Recommendations
From the analyses done, the following conclusions can be drawn:

i. Formations do not allow the flow of mobile pollutants at equal rates.
ii. The nature of geologic formations affects the rate at which pollutants (fluids) pass through them.
iii. The velocities of pollutants (fluids) through geologic formations are not affected by the nature of the fluids.
iv. The mean velocities of the pollutants (fluids) through the Imo Shale differ from every other formations.
v. Only Imo Shale has the highest flow times (little or no flow-very low velocity).
vi. The porosity and hydraulic conductivity values of Imo Shale are 18% and $2.3*1^{0-8}$ cm/sec respectively.
vii. The nature of the underlying geology of a place should be the criteria for selecting such a place for human activities like industrialization and waste dumping, burying of dead bodies (use of a place as burial ground), wide scale hospital activities, indiscriminate use of fertilizer, etc.
viii. The correlation between the velocity of both treated and untreated fluids and coefficient of curvature is very weak.
ix. The velocity of pollutant through the geologic formation is strongly related to the porosity of the formation**.**
x. The velocity of pollutant through the geologic formation is strongly related to the hydraulic conductivity of the formation.
xi. There is no correlation between the pollution level of pollutants and infiltration rate (velocity) of pollutant through soil.

Recommendations

Based on the findings made, the study the following:

a. The availability of an open place or close proximity of such a place to users should not be the criteria for selecting such a site for every human activity, particularly those activities which generates mobile pollutants.

b The underlying geology of a terrain should be known before selecting such a terrain for mobile-pollutants' generating activities. Any formation whose porosity and hydraulic conductivity values are greater than 18% and $2.3*10^{-8}$ cm/sec. respectively should not be selected for such activities since such a formation is likely to allow the passage of pollutants through it. However, those whose values are less than these are acceptable for such activities.

c Shale terrains and their likes should be used for siting of human activities that generate mobile pollutants. Awka area, for instance, is safe for such activities.

d Sites where such activities are already going on should be geologically investigated to confirm their suitability lest the resultant pollutants eventually pass through them to pollute the underlying groundwater of such places.

e Such geologic investigations (as advocated in (d) above) should cover both lateral and vertical facies, since facies changes occur both laterally and vertically across formations.

f Unguided and indiscriminate uses of fertilizers, particularly around recharge area of aquifers for urban water supply schemes, like those of Orumba North Local Government Area should be avoided/checked immediately because of alakalinisation, salinisation and soil hardness.

g The government should come up with laws capable of prohibiting individuals from indiscriminate siting of industries in areas whose geologic formations are of high porosities and hydraulic conductivity values in human settlement areas, especially in our urban centres.

h The environmental impact assessment (EIAs) of projects capable of generating mobile pollutants should include, among other things, the potentials of underlying geology of such sites for pollutants passage before approval is granted.

I Erosion sites which are known to abound mainly in sandstone terrains should not be used for waste dumping sites as it is the case in many parts of the study area. This is to avoid faster infiltration of the resultant pollutants to pollute the groundwater resources.

j Government should quickly sponsor the comprehensive geologic mapping of the entire Anambra State and indeed, the whole of South-Eastern Nigeria (since the entre area is underlain by sedimentary rocks) so as to establish geologic formations which are good for sitting human activities that generate mobile pollutants. This is to say that the geologic map of the area is of great importance in urban environmental planning and management of the area.

k Further research should be carried out on the following areas:
- The effect of chemistry of pollutants on infiltration rate of pollutants.
- The effect of chemistry of formations on infiltration rate of pollutants.
- Pollutants velocity via porous consolidated rocks.

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