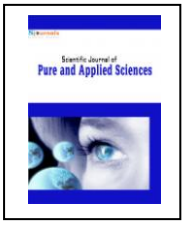
Sjournals
Scientific Journals
Scientific Journal of Pure and Applied Sciences (2013) 2(3) 140-150
ISSN 2322-2956

Contents lists available at Sjournals
Scientific Journal of
Pure and Applied Sciences
Journal homepage: www.Sjournals.com



Original article

Predictive model to monitor the transport of *E. coli* in homogeneous aquifers in port harcourt Niger delta of Nigeria

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ARTICLE INFO

Article history:
Received 07 February 2012
Accepted 27 February 2013
Available online 30 March 2013

Keywords:
Predictive model
Transport and homogeneous aquifers

ABSTRACT

Predictive model to monitor the transportation of E. coli in homogenous aquifer has been evaluated. The model where generated from a mathematical expression derived from E. coli experiment. Least square method where apply to resolve the equations, theoretical value where generated from the mathematical equation, this values were compared with other experimental values from o different locations, both parameters expressed a valuable fit. The expression from both parameters shows that the concentration develop a rapid increase at three meters, were we have lateritic soil, while the lowest concentration where deposited at thirty meters where we have homogenous fine and coarse sand, this expression displayed a physical process of concentration influenced by variation of distance, which is from high to low concentration. This study is imperative because the model has absolutely defined the behavior of E. coli with respect to change in concentration and depths, formation characteristic like deltaic nature of the soil including high rate of porosity has been confirmed to influence the E. coli transport to ground water aquifers. The study expressed high concentration of E. coli at thirty meters and it deposited 0.51mg/l, comparing to world health organization of zero deposit of E. coli concentration on water implies that ground water at those depths are not good for human consumption, therefore it is recommended that where there is regeneration of contaminant, water treatment plant should be applied in ground water design at shallow aquifers.

1. Introduction

Groundwater is considered to be of excellent quality because of the soil barrier providing effective isolation of this high quality source water from surface pollutants. This is true for most groundwater resources although we know that many aquifers all over the world are polluted and/or is being polluted (Engelbrecht, 1993). Habitats containing only a single kind of microorganism are found only in the laboratory. Natural habitats contain many kinds of organisms which interact in complex ways. The great reservoir of bacteria in nature is the soil, which contains both the largest population and the greatest variety of species. Most bacteria that are found in surface waters are derived from the soil. However, the quality of subsurface waters may be impacted both by naturally occurring processes as well as by actions directly attributable to human activities. The number and variety of the microorganisms in natural waters vary greatly in different places and under different conditions. Bacteria are washed into the water from the air, the soil and from almost every conceivable object. Significant numbers of bacteria can be removing through media even when the percentage retained is very high. The faeces of animals contain vast numbers of bacteria and many enter natural water systems. The sizes of openings in subsurface material can be assumed to be variable and are generally not measured, but porosity and permeability measurements on aquifer sediments indicate that adequate spaces for bacteria exist in many sediment types, even in some rather dense porous rocks (McNabb and Dunlap, 1975).

The interstices of the shallow aquifer sediments can easily accommodate bacteria and probably protozoa and fungi as well. Larger organisms will be excluded from most subsurface formations, except for gravelly and cavernous aquifers (Ghiores and Wilson, 1988) Microbiological pollution derived mostly from human and animal activities such as unsewered settlements; on-site sanitation; cemeteries; waste disposal; waste disposal; feedlots; etc. Microorganisms certainly will be the dominant forms of life and, in most cases; they will be the only forms of life present in aquifers. However, with very few exceptions the only waterborne microbial pathogens of man are essentially human bacteria, viruses and protozoa, and in considering the safety of drinking water from the point of view of infectious diseases one can almost completely ignore any source of infectious agents except human excreta. In relation to microbial pollution of groundwater it is therefore only necessary to ensure that at the point of extraction no contamination with human excreta occurs (Engelbrecht and Tredoux 2000).

Coliform bacteria are the bacteria most commonly associated with well water. The United States environmental protection agency (EPA) standard for drinking water is a total coliform count of zero. Coliform bacteria are a large group of various rod-shaped species and strains of bacteria. The group includes bacteria that occur naturally in the intestines of warm-blooded animals (fecal coliform) and no fecal coliform. Non-fecal coliform bacteria are very common and are found virtually everywhere on soil particles, insects, plants, animals, walls and furniture in homes and on your skin and clothes. Fecal coliform can include disease causing (pathogen species) and non-disease causing species. Over 200 types of non-disease causing bacteria have been found in human digestive tracts. Most arrive on the food and drink we consume. Many yogurt cultures include coliform bacteria. *Lactobacillus* acidophilus is the most common bacteria strain used in commercial yogurts and some studies show it creates an acidic environment that inhibits harmful bacteria in the digestive tract. *Escherichia* coli (E. coli), often listed in water quality analyses, is one species of fecal coliform bacteria. A single E. coli is 2 microns long and about 0.5 microns in diameter. There are hundreds strains of E. coli bacteria that differ only in the type of toxin or enzyme that they produce. Despite the fact that they originate in the digestive system of a warm-blooded creature, most E. coli strains are not harmful to humans. E. coli can be easily cultured in a laboratory and therefore, they are a good indicator species for bacterial contamination in water tests. Its presence in a water sample indicates that sewage material may be present and that if sewage is present, more harmful disease-causing organisms may also be present, for example *Vibrio* cholerae that causes cholera (American Ground Water Trust 2002). esearchers today have discovered that *E. coli* may not always be an effective indicator of water quality. While it is true that *E. coli* is found in the intestines of warm blooded animals, scientists have recently revealed that E. coli can also persist and perhaps thrive in many other natural environments! (Whitman and Nevers, 2003, Whitman, et al 2004).

Take soil for example. Research conducted at the USGS Lake Michigan Ecological Research Station (USGS LMERS) has shown that temperate forest soils in the Indiana Dunes harbor *E. coli* throughout the entire year (winter included)! The sediments and soil in the watershed of Dunes Creek (a Lake Michigan tributary) contain *E. coli*, and the persistently high *E. coli* counts in Dunes Creek itself may be due to rainfall and stream flow eroding the sediment-borne bacteria into the water. In these cases there was no significant human fecal input, yet the *E. coli* was there. (Byappanahalli, et al., 2003) What about sand? *E. coli* is found in beach sand as well! Bacteria harbored in sand may even persist longer than in water because the bacteria adhere to sediment particles, unlike bacteria that are free in the water (Whitman and Nevers, 2003).

Research has shown that *E. coli* counts were higher in the near shore sand and submerged sand than in the beach water. Additionally, the *E. coli* counts were typically several orders of magnitude higher in the sand than in the water. The geometric mean of *E. coli* counted in the foreshore sand in a study on 63rd street beach in Chicago was 4,000 CFU's/ 100 ml of water, as compared to only 43 CFU's /100 ml water in the water. (Whitman and Nevers, 2003) How ironic that by closing the swimming waters that may have 240 colonies/100 ml of water, we may actually be increasing the contact people have with even higher concentrations of *E. coli* (sometimes as high as 11,000 CFU/100 ml of water) in shallow water and sand (Whitman and Nevers, 2003). Water samples for bacteria testing are collected and cultured, and then must incubate for 18 hours before the colony growth is visible. Therefore, after a water sample is collected, results are not available until the next day." By that time, the bacteria levels in our beach waters may have changed significantly. In fact, most studies show little or no correlation between indicator levels from the sampling day to the next day when the results are actually used by the beach managers to make decisions about beach closings (Rabinovici, et al., 2004). Urinary tract infections (UTI) are the most common nosocomial infections which accounts for 40% of hospital acquired infections (Gales et al., 2000; Talebi and Golestanpour, 2009). *Escherichia coli* are the most frequently found bacteria in both community and hospital acquired UTIs (Daza et al., 2001; Farrell et al., 2003). In recent years antimicrobial resistance has emerged explosively in many diverse bacterial types largely as a consequence of unrestrained antimicrobial use in medicine (Johson et al., 1999). This affects the management of UTI by increasing prevalence of multidrug resistant strains of *E. coli* (Rafay and Nsanze, 2003). Therefore developing methods for accurate identification of multidrug resistant strains of *E .coli* is mandatory (Giamarellou and Poulakou, 2009; Katz et al., 2004). In recent years several methods have been diffusion agar is a traditional and routine method of antimicrobial sensitivity testing. E-test provides a rapid and convenient means for determining minimal inhibitory concentration (MIC) for a variety of antimicrobial agents. Studies have shown that E-test shows good agreement with reference "agar dilution" susceptibility testing methods (Rosser et al., 1999). MIC determining methods like E-test, although provide quantitative measurement of antimicrobial sensitivity (Erfani et al., 2008) because of their cost and limited availability in developing countries, their application is not as frequent as disk diffusion method (Khan and Zaman, 2006; Rahbar et al., 2006). Although, previous reports have compared E-test with disk diffusion in determining antimicrobial susceptibility, differences in their capabilities for selection of multidrug resistant strains of *E. coli* in UTI has not been fully encountered. In this study we have compared E-test and disk diffusion results in finding out multidrug resistant strains of *E. coli* in urinary tract infections (Erfani et al 2011).

2. Material and method

Column experiments were also performed using soil samples from several borehole locations, the soil samples were collected at intervals of three metres each (3m). An E.coli solute was introduced at the top of the column and effluents from the lower end of the column were collected and analyzed for E.coli, and the effluent at the down of the column were collected at different days for analysis,

2.1. Theoretical background

Theoretical background for 3rd degree polynomial curve fitting

General: $y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \ldots\ldots\ldots + a_n x^n$

If the above polynomial fits the pair of data (x, y) it means that every pair of data will satisfy the equation (polynomial).

Thus; $$y_1 = a_0 + a_1 x_1 + a_2 x_1^2 + a_3 x_1^3 + \ldots\ldots\ldots + a_n x_1^n \qquad \ldots\ldots\ldots\ldots (1)$$

$$y_2 = a_0 + a_1x_2 + a_2x_2^2 + a_3x_2^2 + \ldots\ldots\ldots + a_nx_2^n \ldots \quad \ldots\ldots\ldots (2)$$

$$y_3 = a_0 + a_1x_3 + a_2x_3^2 + a_3x_2^2 + \ldots\ldots\ldots + a_nx_2^n \quad \ldots\ldots\ldots (3)$$

$$y_4 = a_0 + a_1x_4 + a_2x_n^2 + a_3x_n^2 + \ldots\ldots\ldots + a_nx_4^n \quad \ldots\ldots\ldots (4)$$

Summing all the equations will yield (1 n)

$$\sum_{i=1}^{i=n} y_i = \sum a_0 + \sum_{i=1}^{i=n} a_1 x_i + \sum_{i=1}^{i=n} a_2x_i^2 + \sum_{i=1}^{i=n} a_3x_i^3 + \sum_{i=1}^{i=n} a_4x_i^4 + \ldots\ldots + \sum_{i=1}^{i=n} a_nx_i^n$$

$$\sum_{i=1}^{i=n} y_i = na_0 + a_1\sum_{i=1}^{n} x_i + a_2\sum_{i=1}^{n} x_i^2 + a_3\sum_{i=1}^{n} x_i^3 + \ldots\ldots + \sum_{i=1}^{n} x_i^n \quad \ldots\ldots\ldots (5)$$

To form the equations to solve for the constants $a_0, a_1, a_2, a_3, \ldots\ldots a_n$.

We multiply equations (3.84) by $x_{i,}\, x_i^2, x_i^3 \ldots\ldots\ldots x_i^n$.

$$\sum_{i=1}^{1} y_i = na_0 + a_1\sum x_i + a_2\sum x_i^2 + a_3\sum x_i^3 + \ldots\ldots + a_n\sum x_i^n \quad \ldots\ldots\ldots (6)$$

Multiply equation (6) by x_i

$$x_i\sum y_i = na_0\, x_i + a_1\, x_i\sum x_i + a_2\, x_i\sum x_i^2 + a_3\, x_i\sum x_1^3 + \ldots\ldots\ldots + a_n\, x_i\sum x_i^n$$

$$\sum y_i\, x_i = a_0\sum x_i + a_1\sum x_i^2 + a_2\sum x_i^3 + a_3\sum x_i^4 + \ldots\ldots\ldots + a_n\sum x_i^{n+1} \quad \ldots\ldots\ldots (7)$$

Multiply equation (6) by x_i^2

$$x_i^2\sum y_i = na_0\, x_i^2 + a_1\, x_i^2\sum x_i + a_2\, x_i^2\sum x_i^2 + a_3\, x_i^2\sum x_i^3 + \ldots\ldots\ldots + a_n\, x_i^2\sum x_i^n \quad \ldots (8)$$

$$\sum y_i\, x_i^2 = a_0\sum x_i^2 + a_1\sum x_i^3 + a_2\sum x_i^4 + a_3\sum x_i^5 + \ldots\ldots\ldots + a_n\sum x_i^{n+2} \quad \ldots\ldots\ldots (9)$$

Multiply equation (3.85) by x_i^3

$$x_i^3\sum y_i = na_0\, x_i^3 + a_1\, x_i^3\sum x_i + a_2\, x_i^3\sum x_i^2 + a_3\, x_i^3\sum x_i^3 + \ldots\ldots\ldots + a_n\, x_i^3\sum x_i^n$$

$$\sum y_i\, x_i^3 = a_0\sum x_i^3 + a_1\sum x_i^4 + a_2\sum x_i^5 + a_3\sum x_i^6 + \ldots\ldots\ldots + a_n\sum x_i^{n+3} \quad \ldots\ldots\ldots (10)$$

Multiply equation (6) by x_i^n

$$x_i^n\sum y_i = a_0 n\, x_i^n + a_1\, x_i^n\sum x_i + a_2\, x_i^n\sum x_i^2 + a_3\, x_i^n\sum x_i^3 + \ldots\ldots\ldots + a_n\, x_i^n\sum x_i^n$$

$$= a_0\sum x_i^n + a_1\sum x_i^{n+1} + a_2\sum x_i^{n+2} + a_3\sum x_i^{n+3} + \ldots\ldots\ldots + a_n\sum x_i^{n+n} \quad \ldots\ldots\ldots \text{n}$$

Putting equation (6) to n into matrix form

$$\begin{bmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 & \ldots\ldots & \sum x_i^n \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \ldots\ldots & \sum x_i^{n+1} \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \ldots\ldots & \sum x_i^{n+2} \\ \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 & \ldots\ldots & \sum x_i^{n+3} \\ \ldots & \ldots & \ldots & \ldots & & \ldots \\ \sum x_i^n & \sum x_i^{n+1} & \sum x_i^{n+2} & \sum x_i^{n+3} & \ldots\ldots & \sum x_i^{n+n} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ \ldots\ldots \\ a_n \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \\ \sum y_i x_i^3 \\ \ldots \\ \sum y_i x_i^n \end{bmatrix}$$

Solving the matrix equation yields values for constants $a_0, a_1, a_2, a_3, ...a_n$ as the case may be depending on the power of the polynomial.

From the above matrix; for our particular case; i.e. polynomial of the third order:

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \quad (11)$$

The equivalent matrix equation will be; (*n = 3*).

$$\begin{bmatrix} n & \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 \\ \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \sum x_i^6 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \\ \sum y_i x_i^3 \end{bmatrix}$$

3. Results and discussion

Predictive model to monitor the transport of e.coli in homogeneous aquifers are presented in figures and tables bellow.

Table 1
Comparison of calculated and measured value for E.coli Transport at various Distances.

Distance	Calculated Results E. coli	Measured E. coli Result
3	1.59	1.59
6	1.54	1.52
9	1.48	1.48
12	1.39	1.5
15	1.29	1.2
18	1.17	1.24
21	1	0.8
24	0.88	0.88
27	0.7	0.7
30	0.51	0.45

Table 2
Comparison of calculated and measured value for E.coli Transport at various Distances.

Distance	Calculated Results E. coli	Measured E. coli Result
3	1.59	1.51
6	1.54	1.6
9	1.48	1.4
12	1.39	1.35
15	1.29	1.25
18	1.17	1.22
21	1	0.9
24	0.88	0.77
27	0.7	0.64
30	0.51	0.44

Table 3
Comparison of calculated and measured value for E. coli Transport at various Distances.

Distance	Calculated Results E. coli	Measured E. coli Result
3	1.59	1.61
6	1.54	1.49
9	1.48	1.52
12	1.39	1.41
15	1.29	1.22
18	1.17	1.15
21	1	0.8
24	0.88	0.75
27	0.7	0.64
30	0.51	0.34

Table 4
comparison of calculated and measured value for E.coli Transport at various Distances.

Distance	Calculated Results E.coli	Measured E.coli Result
3	1.59	1.59
6	1.54	1.56
9	1.48	1.5
12	1.39	1.31
15	1.29	1.24
18	1.17	1.19
21	1	0.7
24	0.88	0.66
27	0.7	0.6
30	0.51	0.41

Table 5
Comparison of calculated and measured value for E. coli Transport at various Distances.

Distance	Calculated Results E. coli	Measured E. coli Result
3	1.59	1.62
6	1.54	1.59
9	1.48	1.53
12	1.39	1.36
15	1.29	1.27
18	1.17	1.19
21	1	0.9
24	0.88	0.95
27	0.7	0.8
30	0.51	0.38

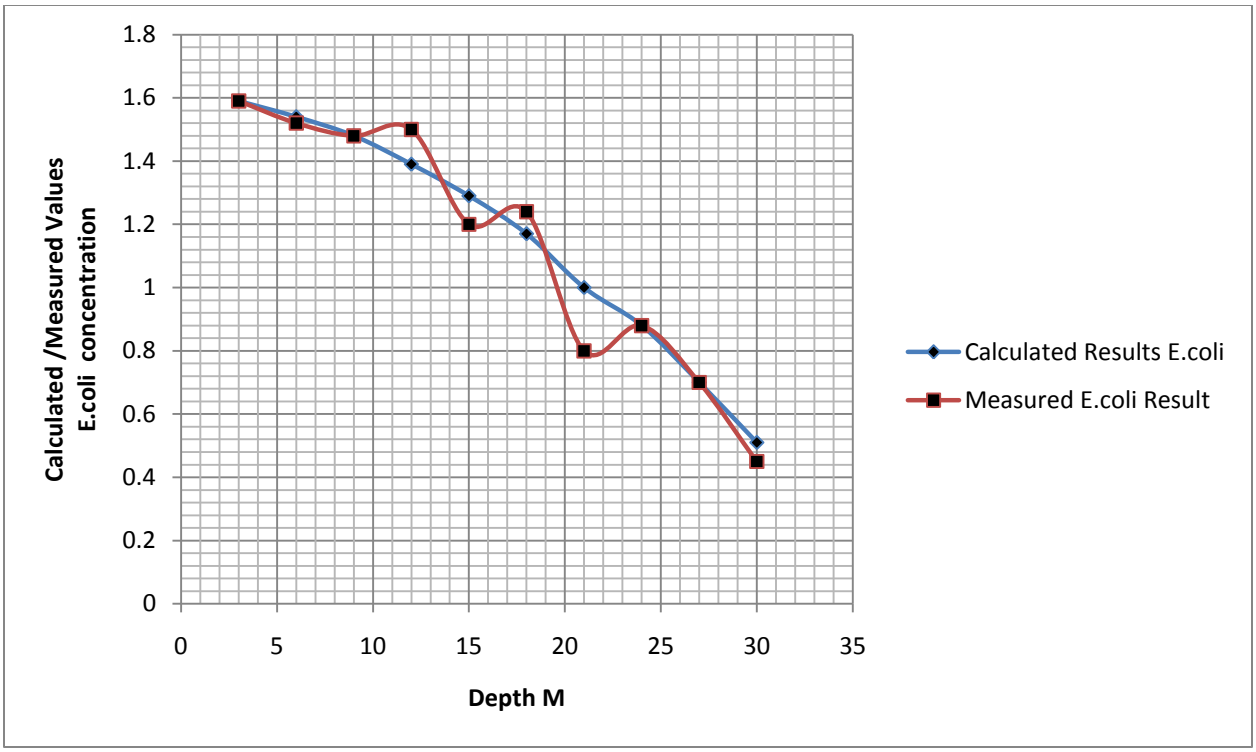

Fig.1. Comparison of calculated and measured value for E. coli transport at various distances.

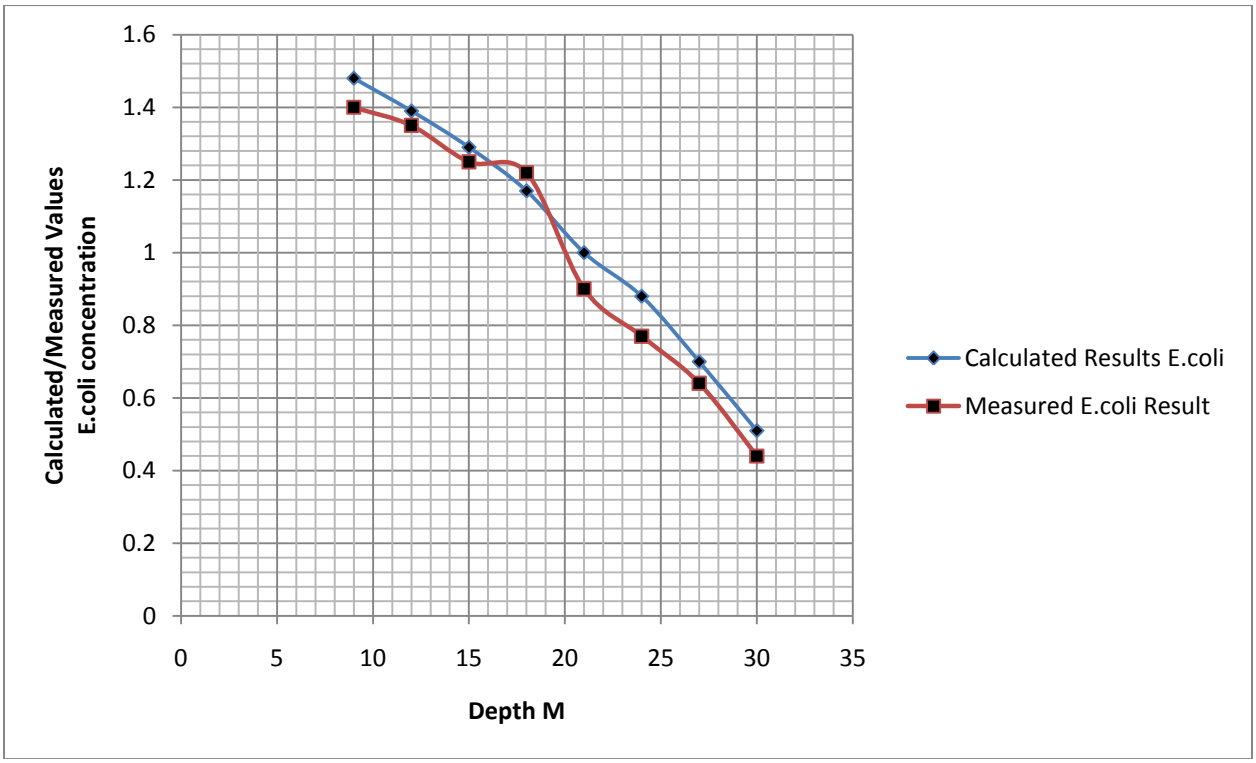

Fig. 2. Comparison of calculated and measured value for E. coli Transport at various Distances.

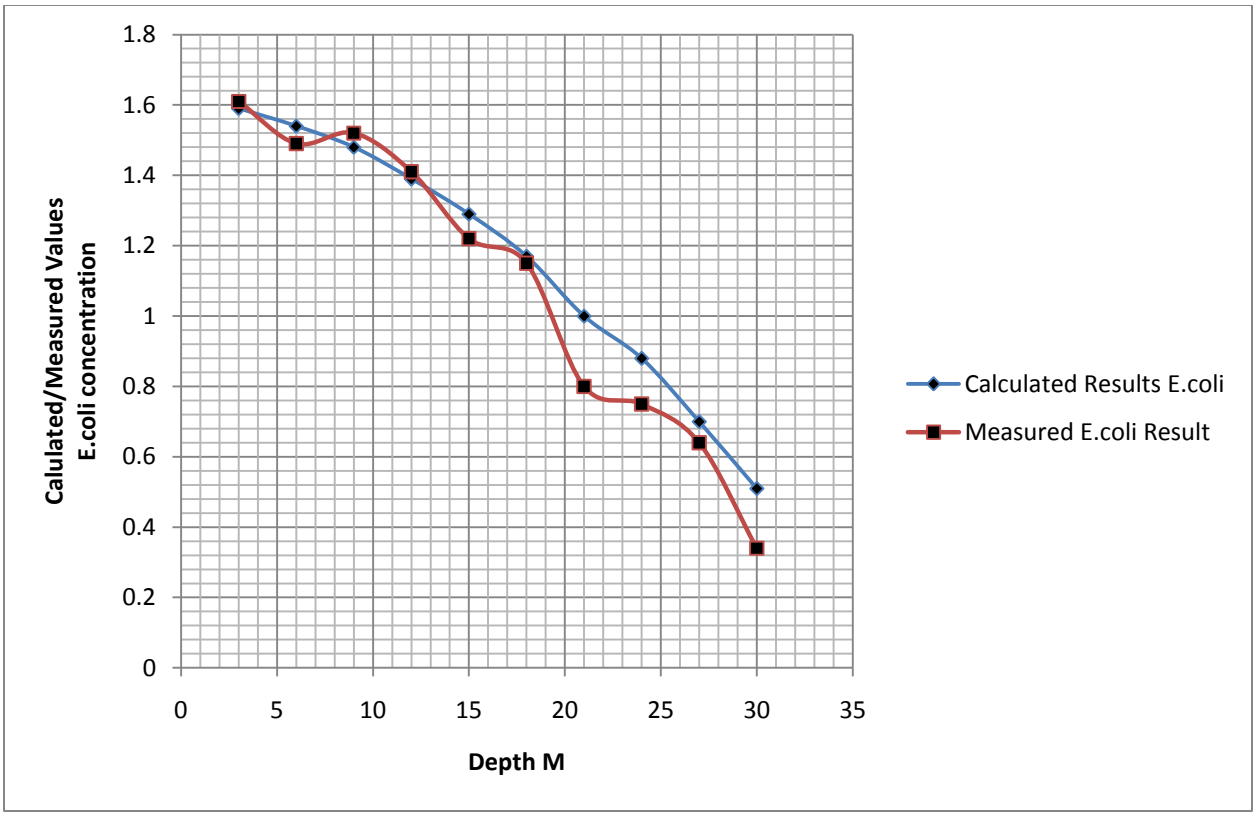

Fig. 3. Comparison of calculated and measured value for E. coli transport at various distances.

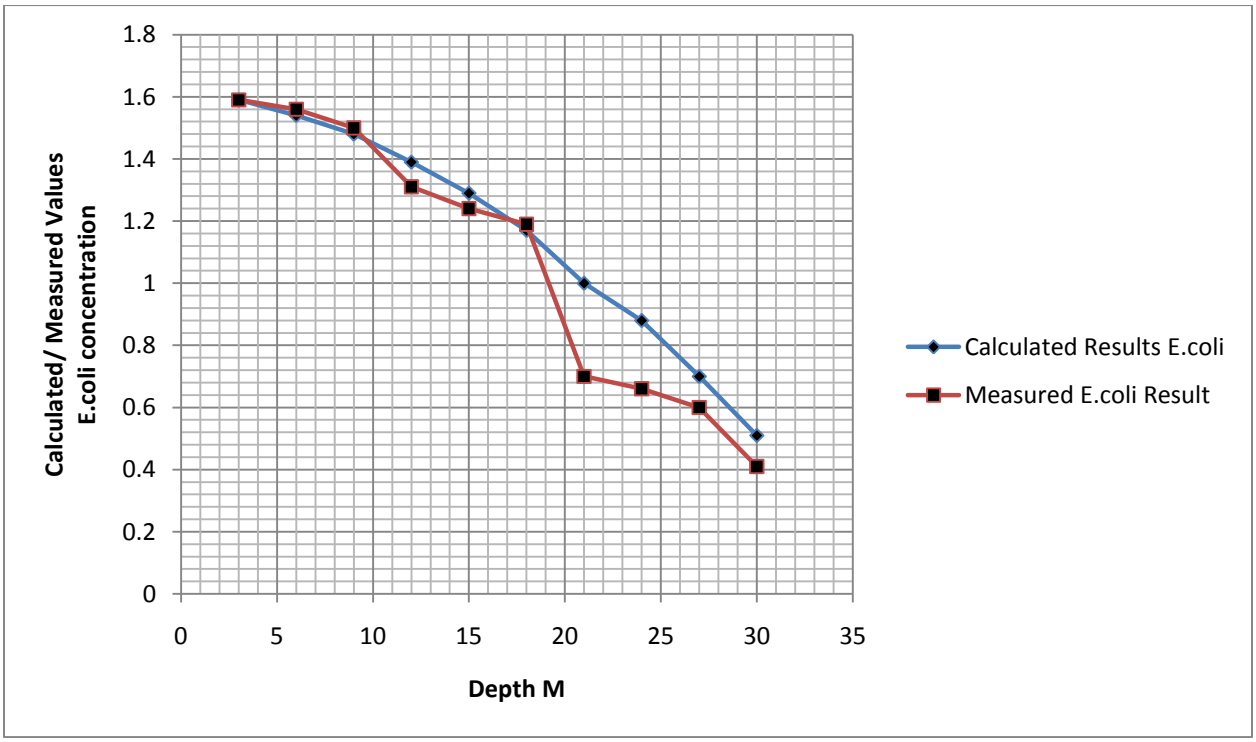

Fig. 4. Comparison of calculated and measured value for E. coli transport at various distances.

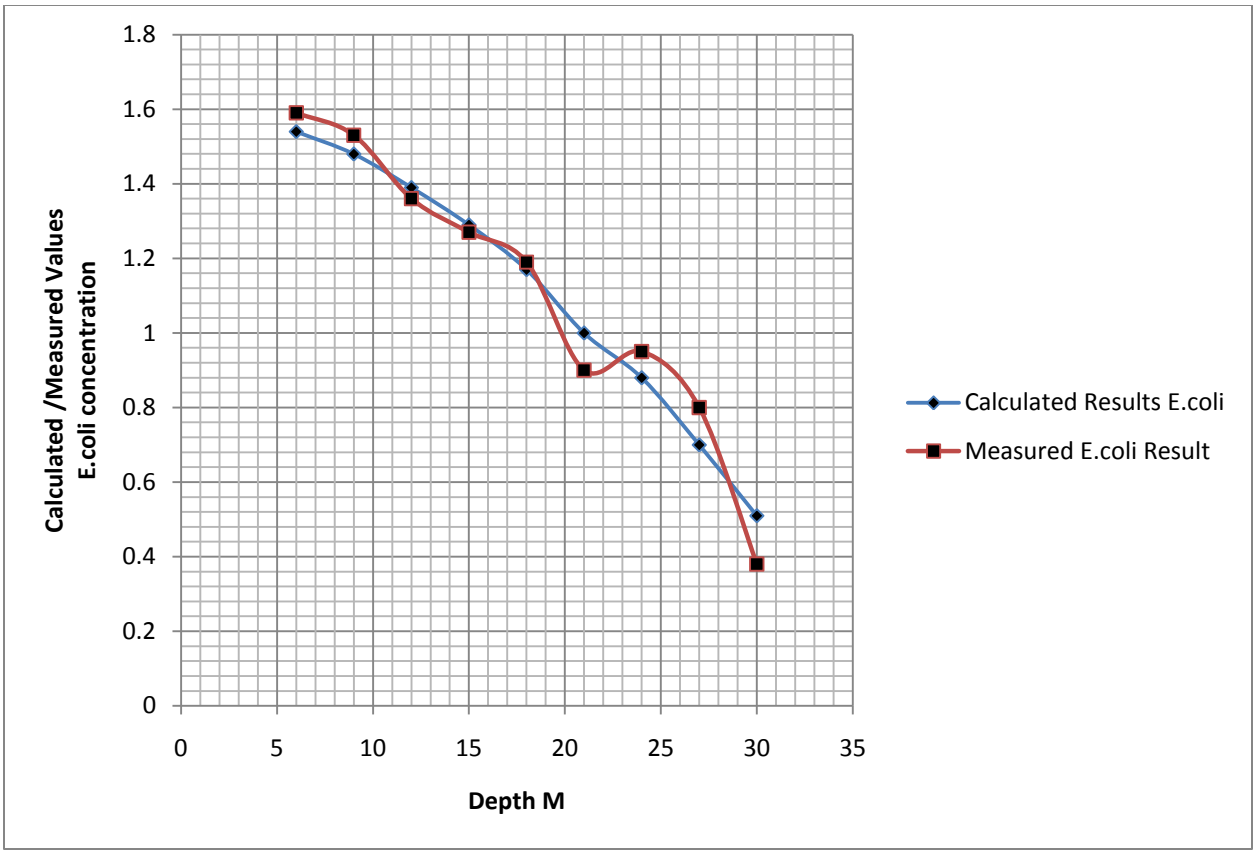

Fig. 5. Comparison of calculated and measured value for E. coli transport at various distances.

Figure one shows that the calculated values developed a rapid increase at three meters and gradually decrease to where the lowest concentration where observed at thirty meters, while the measured values experienced rapid increase, constantly decrease between three to six meters where observed, and finally it fluctuate down to the lowest rate of concentration, recorded at thirty meters. Figure two calculated values experienced gradual decrease from the optimum values at six meters down to the lowest level of concentration at thirty meters, similar condition where observed in the measured values, rapid increase where experienced at six to nine meters, fluctuation where observed between fifteen to twenty-four meters and finally decrease to the lowest rate of concentration at thirty meters. Figure three developed a rapid increase at three meters and gradually decrease in a linear condition down to the lowest at thirty meters, while the measured values express a rapid increase at the same three meters, but observed fluctuation to the lowest concentration at thirty meters Figure four developed rapid concentration at three meters and gradually decrease with variation in concentration and distance down to the lowest rate at thirty meters, while the calculated values express rapid increase with linear concentration between three to six meters. Vacillation where observed between twelve to thirty meters, where the lowest degree of concentration where recorded. Figure five developed a rapid increase at the same three meters, it experience similar condition with figure four, where by gradual decrease where observed from the optimum value at three meters down to the lowest value at thirty meters, while the calculated values in the same vein expressed its rate of concentration with a rapid increase as observed at three meters, fluctuation where experienced between eighteen and thirty meters, where the lowest concentration where recorded. The figures of calculate values expressed the highest concentration at three meters and the lowest at thirty meters, while the measured values maintain similar condition, but with fluctuation at different distance. This condition can be attributed to the influence of geomorphology and geochemistry which has pressured the concentration to rapidly decrease from high concentration at three meters to the lowest at thirty meters. More so, the study area geologic history played a major role, where by the stratification based on structural deposition of the formation are influenced by the deltaic nature in the study area, this may have pressured the condition of the microbial

transport, as expressed in the figures. Variation in distance including the velocity of flow in some condition may also pressure the behavior of the microbes as expressed in the figures.

4. Conclusion

Microbial transport in un-confined beds are influenced by the structural deposition of the soil, these conditions developed several variations, even if the soil deposit homogenous formation,. The concentration of E. coli from the predictive values and the experimental results shows that the concentration expressed a physical process know as from high to low concentration as presented in the figures. The study locations are predominant by Alluvia deposition and these influence the homogenous nature of the soil, it also pressure the microbial transport in the study area, substrates utilization played a major role on microbial growth and pressured its transport behavior in homogenous formation. These conditions is confirmed through the predominant Alluvia deposition of the formation, as it has played a major role on the variations of E.coli formation at different strata, metallic elements are one of the inhibition of microbial population on transport processes. Regenerations of this contaminant from man made activities play a major role from high increase of concentration transporting E.coli to ground water aquifers. Permeability levels of the formation are also an influence to fast migration of E.coli to ground water aquifer. The study is imperative because the develop model has expressed the rate of concentration of E.coli at different formation and depths, it is a benchmark for practicing professionals to understand the behavior of microbial specie E. Coli at different formation to ground water aquifer. The model will monitor the concentration of this microbial specie at different formation, during the design of ground water system in the study area. Regeneration of E. Coli concentration has been confirmed as high rate of concentration between three to fifty meters, has been expressed from the figures, this implies that shallow wells between three to fifty meters will definitely contain high concentration of this microbes, therefore it is recommended that shallow wells that contain such kind of microbial concentration should not be use for human consumption.

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