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Variation of Attenuation of Bacteria Migration with Volume Flux Rate and Porosity in Porous Media

J. A. Adegoke [α], A. A. Ogunjobi [σ] & T.A. Lateef [ρ]

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I. Introduction

Availability of quality water for domestic, industrial and agricultural use has a great challenge to the water resources researcher. Technologically, more effort have arose to avert the increasing contamination of shallow aquifer by chemical waste, septic wastes and microbial pathogen which has led to considerable interest in the study of transport of bacteria in porous media. Also, onsite systems for waste water treatment are increasingly used in small towns, suburban and rural areas in many countries. In U.S, decentralized systems serve approximately 25% of the population (USEPA, 1997). Percolation through a natural or engineered porous media is the most frequently used treatment systems. Migration can lead to microbial contamination of groundwater resulting in outbreaks of waterborne disease (Craun et al.,1985, Yates et al.,1988 and Corapcioglu et al.,1984).

In the U.S,contaminated of groundwater causes almost half of the outbreaks of waterborne disease each year (Craun et al.,1985), and septic tank effluents is the most frequently reported source of groundwater contamination (USEPA 1977). In developing country Such as Nigeria where there is little availability of water regardless of its quality, there is need for a plan into onsite systems for wastewater treatment and the protection of the groundwater where boreholes and wells, streams serve as the main sources of water for drinking and domestic use (Ibe et al., 2005).

To locate, design and operate an onsite system, and to limit/avoid migration of pathogenic bacteria through the system, knowledge of the mechanisms and factors that influence their movement is required (Tor kristian et al.,2004). More so, considerable interest in the factors controlling the transport and the fate of microorganism in porous media a result of concern about the contamination of surface water and groundwater with pathogenic microorganisms.Whenever any groundwater supply well is constructed, a viable groundwater measure must be put in place to prevent contamination by pollutant; one approach is to control/removal of contaminants using a natural media of an appropriate porosities (Leonards, 1962 and Silliman et al., 1998).

Soil serve as a natural filter and its ability to do so depends on its physical properties such as permeability and porosity (Henry, 2003).Natural filter have been used as landfill liners to reduce the movement of contaminant fluid from solid waste landfill and waste water disposal into subsurface (Benson et al.,1990 , Benson et al., 1995, Benson et al., 1994, Boadu,2000, foreman et al., 1986, Henry, 2003 and Rowel et al., 1995).Soil when used as a filter serve as hydrogeological barrier. Hydrogeological barrier is defined as the physical, biological and chemical factors singly or in combination that protect a well from pathogenic organism. The removal of microorganisms during infiltration in porous media normally attribute to combination of straining, adsorption and inactivation. The efficiency of these processes is related to several factors (Antonina et al., 2009). Straining is influenced by the physical characteristics of the filter medium, hydraulic loading and clogging (Antonina et al., 2009). Adsorption is controlled mainly by the grain surface characteristics of the porous medium, water flow velocity, waste water ionic strength, pH, moisture content and cell surface characteristics (Auset et al., 2005).

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The efficiency of most of these processes is therefore related to physical flow conditions, and studies on the removal of microorganisms should consider all the parameters that affect hydraulics during infiltration in porous media (i.e hydraulic parameter of the filter material and filter depth).

Intermittent transport is slow, discontinuous migration of bacteria through an aquifer. The contribution of discontinuous transport to the movement of bacteria through aquifer has not been studied (Harvey, 1989). Discontinuous transport may be an important in the movement of bacteria through the subsurface over geological time and may be important as a mechanism by which large areas of contaminated aquifers are eventually seeded with waste-adapted bacteria. Many studies on the transport of bacteria in porous media focused on geological factors in addition to the biological and chemical factors contributing to the retention and removal of pathogenic organism but neglect the effects of hydrological characteristics of the media i.e physical flow condition.

The purpose of this work is to examine the effects of volume flux (refer as hydraulic loading) and the porosity on the attenuation of bacteria migration in saturated porous media using an intermittent mechanism.

II. Materials and Method

In this work, two independent experiments were carried out, one to determine the flow parameters of the sand media i.e the volume flow rate, seepage velocity refer to as average pore water velocity as given by

$$V = \frac{q}{A\phi} \text{ (Jacob and Armold, 1990)}$$

Where v is the seepage velocity (ms^{-1}), q is volume flux (ms^{-1}) and ϕ is porosity.

While the second set is to determine the attenuation of bacteria migration using the media with pre-determined physical flow characteristics.

Sample preparation: Sand was collected from the river bed in Osun River along Iwo-Gbongan road, Osun state. The sand were thoroughly washed with water and later with deionised water, boiled with 1M hydrochloric acid for two hours and latter treated with 1M of NaOH to remove metallic oxide coating on the sand and equilibrate the pH respectively. The treated samples of the sand were washed again with deionised water, sundried and stoney pebbles were removed. Samples were sieved with different mesh sizes to get different grain sizes. The mesh sizes used were 150μm, 212μm, 300μm, 425μm and 600μm. Each particle sizes of different grain size were packed into clear jars and sterilized with dry heat oven at 160° for 48 hours.

a) Determination of physical flow parameter

The porosity of each of sample was determined by volumetric approach using basic parameter.

$$\text{Porosity} = \frac{pore\ volume}{bulk\ volume}$$

$$= \frac{Bulk\ volume - Grain\ volume}{Bulk\ volume}$$

In this experiment, bulk and grain volumes were determined volumetrically by measured 3ml of dried sand into 10ml measuring cylinder, the sand were thoroughly compacted before value of volume was recorded. A similar cylinder was half filled with water and volume was noted. The sand were then poured into the water and the final volume of the mixture (water and sand) was recorded (Adegoke, 2005).

Porosity was calculated as following

Volume of sand (bulk volume) = x (ml)

Volume of water = y (ml)

Volume of mixture of water and sand = z (ml)

$$\text{Total porosity } `\phi' = \frac{(x+y)-z}{x}$$

Volume flux rate q for each sample at different hydraulic gradients were determined using a transparent glass cylinder (pyrex tube) of length 1m and 2.79cm in diameter. The cross-sectional area is 6.12×10^{-4} m^2. To ascertain uniform compaction throughout the sample, the screened end was blocked so as to prevent the water from draining down t ensure complete saturation when transferring the sample into the column. A continuous steady supply of water was fed through the sand samples of length 'l' and at height 'h', a hole was drilled, this enabled the constant height to be maintained; as excess water got drained through an overflow arrangement. The volume of the discharge 'Q' through the sample for a period of 60sec after steady state has been attained at constant head was measured by measuring cylinder. The length of the sand used were 10cm, 20cm, 30cm, 40cm and 50cm to get varied hydraulic gradient and in resonant with the design of the flow through experiment (filtration of bacteria). The results of this experiment were used to plot the graph of volume flux against hydraulic gradient and the slope of the graph gives hydraulic conductivity. The permeability was then computed using equation

$$K = \frac{\rho g}{g} k$$

From which k is written as $`k = \frac{K\mu}{\rho g}$

Where, K = hydraulic conductivity (ms^{-1})

K = Permeability (m^2)

μ = Viscosity of fluid (Nsm^{-2}) and

μ/ρ = Kinematics viscosity (water) = 1×10^{-6} m^2s^{-1}

b) Filtration experiments

The experiment was carried out in Environmental laboratory, Department of microbiology, university of Ibadan. The prepared microorganism –

bacteria used- Escherichia coli were collected from the same laboratory. Exactly 1ml of the suspension was serial diluted and plated to determine the colony forming unit per milliliter (CFU/ml).

Glass column (1m long, 2.79cm diameter) Pyrex used to determine the physical flow parameter were washed and disinfected with 97% ethanol and sterilized in hot air oven at 120° for 2 hrs. The column cylinder was covered with muslin cloth at outlet to prevent water passage. The saturated sand was then poured into the column up to height 'h' equal 10cm corresponding to hydraulic gradient of 1.600 under gravitational pull. The column was repeatedly tapped during packing to prevent any entrapment of air bubble with the pore space (Carl et al, 2006). The cover was removed and water was allowed to pool down, until the dripping water from the column has a frequency of one drop per 10 seconds. Then, 2ml of bacterial suspension of known concentration was dropped onto the sand bed in the column with aids of 5ml sterile syringe and this was followed by intermittent supply of bacteria- free water (distilled). The effluents of the column were collected and analyzed for the bacteria load. This was done five times for different rainfall simulation. The effluents were subjected to microbial analysis using pour plate technique for bacteria count. These were normalized to the respective influent concentration.

III. Results and Discussion

Table 1 showed the results of porosity for five samples which range between 0.28 and 0.42 with hydraulic conductivity ranging from 0.230 x 10-3 m/s to2.721 x 10-3 m/s. The values of these porosities give the Reynolds number that range between 0.123 and 11.76 for the lower and upper bound of the flow rate at 0.82 x 10-4 m/s and 195.93 x 10-4 m/s respectively for all the samples considered. Table 2 and 3 showed the value of volume of discharge and volume flux rate 'q' for sample A to E and at the following hydraulic gradient (1.600, 2.000, 2.667, 4.000 and 8.000) which are equivalent to the five depths of the samples considered in filteration experiment. Table 4 showed the computed average value of normalized concentration (C/Co) for five drains at different porosities. The reason for normalization is to limit the error that may arise as a rsult of unequal influents concentration.

Table 1 : Values of porosity for the five samples using volumetric approach.

Samples	A	B	C	D	E
Porosity(ϕ)	0.28	0.36	0.37	0.40	0.42

Table 2 : Experimental determined values of volume of discharge 'Q' for samples at various hydraulic gradient (h+ L/L) for 60 sec, where L = length of the sand media in the column, h = height over which the head is loss.

Hydraulic Conductivity (i)	Discharge Vol. (A) x 10^{-6} (m^3)	Discharge Vol. (B) x 10^{-6} (m^3)	Discharge Vol. (C) x 10^{-6} (m^3)	Discharge Vol. (D) x 10^{-6} (m^3)	Discharge Vol. (E) x 10^{-6} (m^3)
1.600	3.0 ± 0.01	11.5 ± 0.10	31.5 ± 0.11	48.0 ± 0.03	76.0 ± 0.02
2.000	5.0 ± 0.01	13.5 ± 0.02	42.0 ± 0.12	58.0 ± 0.03	128.0 ± 0.06
2.667	8.5 ± 0.02	23.0 ± 0.15	63.0 ± 0.14	84.0 ± 0.05	170.0 ± 0.10
4.000	20.0 ± 0.02	25.0 ± 0.10	108.0 ± 0.03	178.0 ± 0.07	289.0 ± 0.11
8.000	56.0 ± 0.15	104.0 ± 0.02	286.0 ± 0.06	410.0 ± 0.14	719.0 ± 0.15

Table 3 : Experimental determined values of volume flux rate 'q' for samples at various hydraulic gradient (h +L/L).

Hydraulic gradient (i)	Volume flux'q' (A) x 10^{-4}(m/s)	Volume flux'q' (B) x 10^{-4}(m/s)	Volume flux'q' (C) x 10^{-4}(m/s)	Volume flux'q' (D) x 10^{-4}(m/s)	Volume flux'q' (E) x 10^{-4}(m/s)
1.600	0.82 ± 0.01	3.13 ± 0.10	8.58 ± 0.11	13.08 ± 0.03	20.71 ± 0.02
2.000	1.36 ± 0.01	3.68 ± 0.02	11.45 ± 0.12	15.81 ± 0.03	34.88 ± 0.06
2.667	2.32 ± 0.02	6.27 ± 0.15	17.17 ± 0.14	22.89 ± 0.05	46.33 ± 0.10
4.000	5.45 ± 0.02	6.81 ± 0.10	29.43 ± 0.03	48.51 ± 0.07	78.16 ± 0.11
8.000	15.20± 0.15	28.34± 0.02	77.94 ± 0.06	111.70± 0.14	195.93± 0.15

Table 4 : Computed average value of normalized concentration (C/Co) for five drains at different porosity for the five depths considered.

Porosity (ϕ)	10.00cm	20.00cm	30.00cm	40.00cm	50.00cm
0.28	0.1228	0.1186	0.0885	0.0744	0.0514
0.36	0.2904	0.1846	0.1789	0.1577	0.0846
0.37	0.1734	0.1699	0.1445	0.1538	0.0694
0.40	0.2986	0.2296	0.1986	0.0902	0.0845
0.42	0.3514	0.2972	0.1910	0.1164	0.0949

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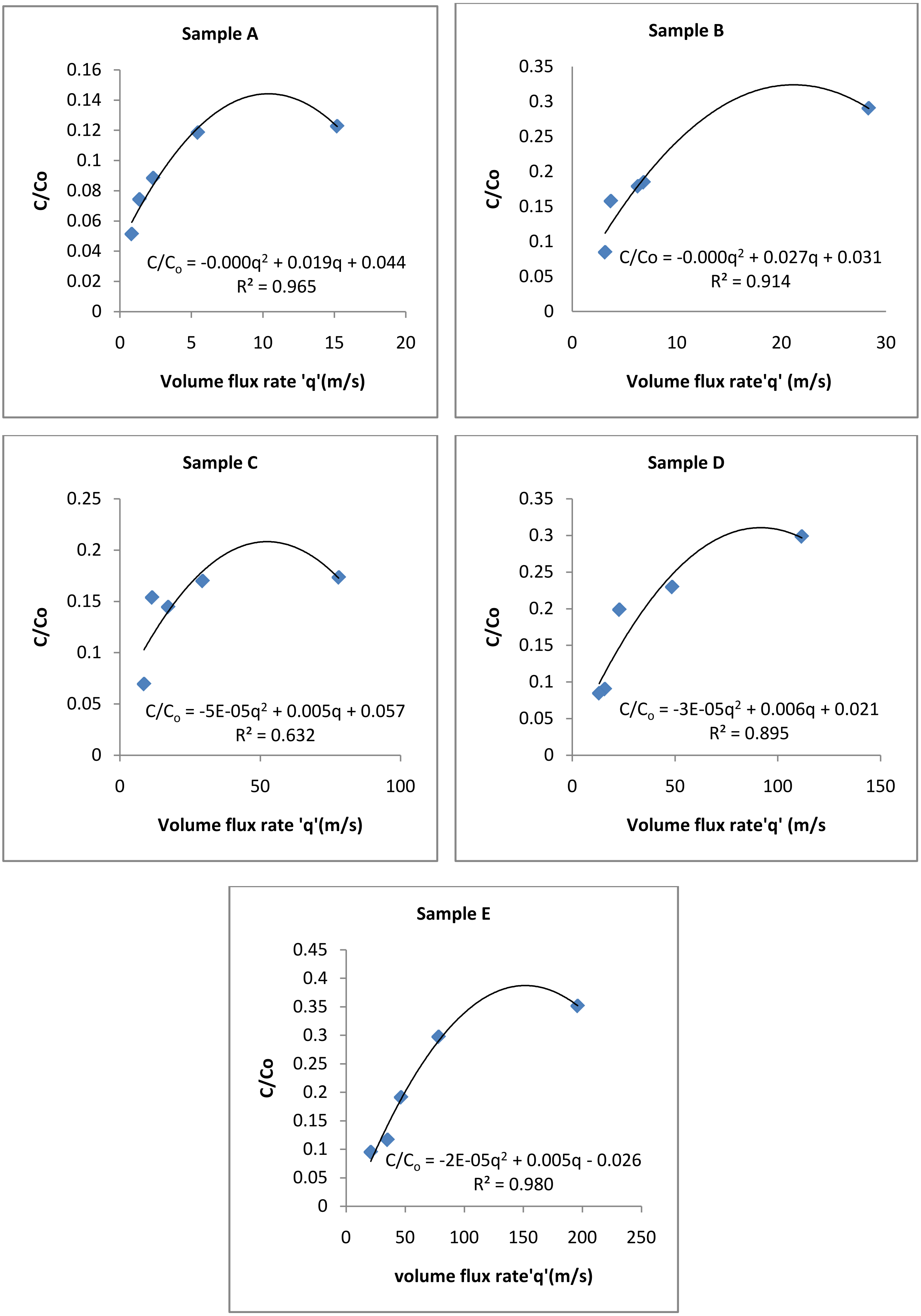

Figure 1 : Plot of normalized concentration versus volume flux in ms^{-1} .

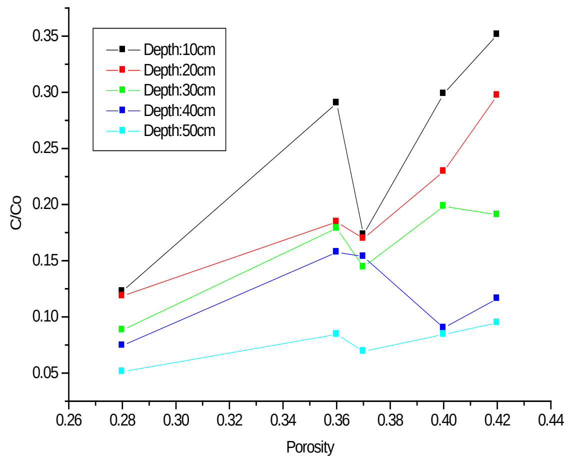

Figure 2 : Plot of average normalized concentration for five drains at different porosity for the five depths.
five

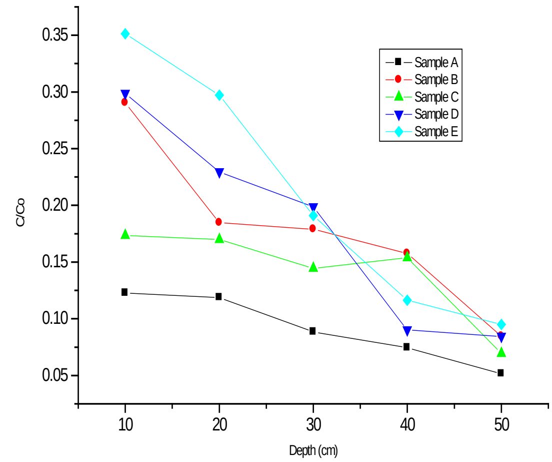

Figure 3 : Plot of average normalized concentration for five drains at different depths for the porosities

One of the relevance of this this research work is to have a deep insight into the mechanisms and the factors that influence the microbial migration as may be applicable to onsite waste water treatment system (OWTS) of which the soil characteristics the main controlling properties. Volume flux rate as well as porosity which were considered in this work convergently determine the effects of all other hydrological physical factors that may inluence the influx of pathogenic bacteria in subsurface. The variation of volume flux rate with bacteria load is shown in figure 1(a) to (b). Ploynomial curve give the best fit for the relationship. It shows for all samples that recovery of bacteria load is not linearly prroportional to volume flux rate as reported in other works. Theoretically, high flow rate increases the average water suction in an unsaturated filter medium.This result in greater transport through larger pores, which decreases the effect of bacteria straining byporous material (Thomas et al. 1979 and Bouma et al. 1974).

Blombat et al. 1994 and Ausland et al. 2002 observed a higher removal of fecal coliform bacteria in filtration systems using uniform pressure distribution compared to gravity dosing. Our result is in partial agreement with these but it was observed for all samples (different porosities) that as the volume flux refered to hydraulic loading increases, the recovery of bacteria increase to a point where it begins to decreases as volume flux rate increases as this increment of flux will continuously reducing the pores size within the mediaas time increases. Smith et al.1985 reported that the retention of bacteria in soil was inversely related to the rate at which water was applied to a filter. This is not in resonant with the work of thomas et al. 1994 and Bouma et al., 1974. The limitation in their work is as a result of experimental design which did not considered the trends of application but mere of low and high flow rate.Consideration of this trends enable us to unveil the actual relationship between the recovery of the bacteria and the flow rate. Adsorption and desorption of bacteria within the column contribute to the outcome of our findings. Husman and verstraete, 1993 observed that transport of bacteria in filters was much greater when water was applied at rate of 4.7 m/s than 0.8 m/s. High flow rate increases the water movement through macropores (Bouma and Thomas) but reduces the displacement (Thomas). This reduces the contact time between the bacteria cell and the grain surface, and greater distance which decreases the rate of adsorption (Yates et al. 1988, Lance et al.1984, sharma et al. 1992).

Figure 2 showed the plot of average normalized concentration of bacteia elutes for five drains at different porosities for depths considered. This outcome revealed that attenuation of migration of bacteria depend on porosity for all depths but it is critically shown that the higher the depth the higher the degree of attenuation which is due to reduction in the pore sizes vis- a- vis porosity. It was observed for allthe depths that there is geometric increase in attenuation between media porosity between 0.36 and 0.37, this may be as a result of insignificant different between the two point. As porosity increases the permeability increases which leads to larger magnitude of effluent recovered, thus lower the attenuation. Random motility will be reduced more profoundly in the smaller pores as shown in figure 3. The attenuaton capacity of media with lowest porosity is greater than others in all the depths considered. This findings will not only be useful to the design of good filter as use in slow and rapid sand filter but also in all area of environmental issues that involves the protection of groundwater from contaminants.

IV. Conclusion

The research work examines the variation of attenuation of migration of bacteria with volume flux and porosity on sand media under saturated condition. In order to better understand and protect the quality of groundwater, an understanding of the processes controlling contaminants (virus, bacteria and protozoa) form an important class of pollutants that pose a significant threat to public health due to their occurrence in drinking water. It was observed in this research work that the use of sand media on attenuation of bacteria migration is highly significant and when designing a filter media for water treatment, all other factors controlling the attenuation must consider the porosity and volume flux as a prime factors that determine the influence of both biological and chemical factors on microorganisms transportation, hence their reduction in water treatment facilities.

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