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Modelling Raw Water Treatment Using Slow Sand Filtration Method (A Case Study of Odor River in Amaokpala Orumba North Local Government Area, Anambra State)

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Abstract
The use of slow sand filtration proves to be an efficient approach for eliminating pathogenic microorganisms in rural communities. This study aims to create a model for a slow sand filter system designed to remove microorganisms. Various tests were conducted on both the untreated water sourced from the Odor River in Amaokpala, Orumba North L.G.A of Anambra State, and the filtered water from the system. The results revealed that the purification of water involves a combination of processes such as sedimentation, straining, and bacteriological actions. Comprehensive assessments, including physical, chemical, and microbial tests, were performed on water samples. A mathematical model was developed, indicating that all variables followed a normal distribution and were suitable for regression analysis.Data analysis was carried out using regression analysis, initially focusing on effluent, influent, discharge, media depth, and detention time. Subsequently, the model's validation was conducted on the other portion of the dataset. The Mann Whitney test was also performed to determine the significance of the predicted calibration versus the predicted validation. The results in table 4.4 demonstrated that the model adequately estimates the dependent variable, with an R-square value of 77.2%.Furthermore, the results presented in table 4.9 displayed a test value of 81.0 and a p-value of 0.1893, which was not statistically significant, as the p-value of 0.1893 exceeded the significance level of 0.05, assuming a 95% confidence level for the dependent variable in comparing the calibrated model to the validation model. In conclusion, slow sand filters are characterized by their simplicity in construction and operation. They prove to be effective in removing bacteria, organic matter, reducing turbidity, and are suitable for domestic water purification purposes.
Keyword: Modeling, water treatment, slow sand filtration, filter media, Odor River.

1.0 Introduction

There are wants that are essential for man to have in order to survive on earth, and there are needs that are secondary. According to the WHO and UNICEF (2010), many people still lack a safe and long-term access to both sanitation and drinking water. With the expansion in world population, there is a direct correlation between the demand for water and that number. A decrease in the amount of freshwater accessible for consumption is also a result of water quality degradation (Peters and Meybeck, 2000). According to the United Nations (2016), 663 million people drank unimproved water sources or surface water in 2015. According to WHO and the UN, the slow sand filter is the best method for treating surface water (WHO, 2009). And Oxfam, a global organization that works with poor nations to end poverty, supports the use of the slow sand filter as a surface water treatment method in rural regions because of its effectiveness, simplicity, and low cost (Oxfam, 2015). Slow sand filter is the most suitable approach for surface water treatment and is best ideal for small-scale applications (EPA, 1990).
In the meantime, the United Nations established a number of goals for the Agenda 2030 for Sustainable Development, one of which is to ensure that everyone has equitable access to clean, inexpensive drinking water (Assembly, 2015). The implementation of an appropriate water treatment technology to enhance the water quality in these areas is required to meet the aim. According to the United Nations General Assembly

(2010), having access to clean drinking water is a fundamental human right and reduces illness and mortality in developing nations (Van Leeuwen, 2013). This drives the hunt for energy-efficient water treatment technology that meet strict drinking water standards, combined with the depletion of fossil resources and the difficult economic conditions the globe is currently experiencing. Adopting a water treatment plan that complies with these requirements is therefore imperative.

Supply of water with quality befitting to human health is paramount to the wellbeing of mankind and by extension, the development of a country. This is so because the development of any country is largely dependent on the public health of its citizenry! An optimal public health results to a corresponding economic growth (Devadas, 1984). Sanitation and good hygiene of the populace is solely dependent on safe water, thus, provision of water is paramount to protecting our life and consequently, our work force. (Devasdas, 1984).

Quality of water is the most important part of environmental engineering. The main objective is to provide consumers with safe and potable water, and there are both international and national criteria for the quality of water that can be given for human use. Water should be noticeably nice; it shouldn't be corrosive or scale-forming, and it shouldn't include any minerals that could have negative physiological effects. Thresholds should be set on the minimal recognized standard of water to achieve this course (WHO, 2006).

Water is available in the following states namely: liquid, solid and gas. The nature of collection purification, transmission and distribution works is determined by its source. Water is obtained from three main sources namely: surface water, ground water and rainwater (Jorniz and Mettzer, 2003).

Surface water is one of the sources of water and it is liable to contamination from both human and animal sources. As regards to the liability of surface water to contamination, it has been labeled unsafe and hazardous for human consumption with an exception: if the water is subjected to sanitary protection and purification. Surface water is known to contain suspended and dissolve impurities and gathers up characteristics of the surface over which is passes (USEPA, 1997)

1.1 Problem Statement

In Orumba North, Oko precisely, the cost of getting even borehole water is very high and this is due to the fact that its soil has greater percentage of shale, with its water table far below the ground surface, i.e. about 100m (330ft) below the ground surface.

Fig. 2: Teenagers obtaining contaminated water to consume

The available surface water is exposed to different forms of pollution which renders it unsafe. Majority of the citizens have resorted to consuming water from unsafe sources. Unsafe water brings with it defects those ripples from children to adults. Infants have a higher mortality rate when unsafe water is consumed and for those that makes it into adulthood, they are infringed with poor health, loss of productivity and eventually, a shortened life span. Most communities are ridden with life threatening and highly communicable diseases like diarrhoea asmebiasis, typhoid and round worm and this is owing to polluted aqua system and poor hygiene.

1.2 Intent of the Research

The intent of this thesis is to model slow sand filter and how it’s used to achieve optimal removal of micro-organism without the use of chemicals.

2.0 Materials and Methods

The 25mm diameter galvanized pipe, the pipe fittings the drum and the watertight bucket were washed thoroughly. The different sand sizes and gravels were washed and air dried. The pipe was measured, cut and perforated and a dead end was provided using a cap at one end of the perforated pipe. The 20 liters bucket was perforated using the tubular iron pipe. The perforation was few millimeters from the bottom of the bucket.

An adapter was fixed to the perforation on the bucket from outside and the designed pipe was fixed to the bucket at the same spot from inside. Again, the pipe was measured, cut, perforated and joined together using T-connectors, elbows and cap to form the inlet drainage system .The drum cover was also perforated at a point using the (iron pipe) as the inlet drainage system which was connected to the 20 liters bucket through the perforation on the drum cover. The connection was enhanced by the use of a pipe and elbow to form the shape .The drum was perforated few millimetres from the bottom using also the iron pipe.

An adapter was fixed to the pipe work from outside the drum, followed by the tap (outlet), as the under-drain system which was fixed to the same spot from inside to obtain the connected under drain. After obtaining the shape, the gravel was laid to a depth of 25cm (0.25m) in the drum, the next layer {activated charcoal) was laid to a depth 5cm (0.05m), followed by the coarse sand layer of 0.3m depth and the fine sand layer of 0.3m depth. Altogether, a total bed thickness (depth) of 90cm (0.9m) was obtained leaving a free board of 3cm (0.3m) in the drum.On the bucket was poured a layer of gravel to a thickness 10cm to help in collecting some of the impurities.

Plate 1,0: the finished slow sand filter

After all the processes, the set-up (filter box) as shown was realized

2.2 System Testing

Stream water from Odor River in Amaokpala was collected and tested for turbidity, pH, total dissolved solid, dissolved oxygen and the presence of microorganism as the parameters were clearly recorded before pouring into the system.This was done in other to check the difference in mineral contents between the raw and the filtered water.

2.3 Mathematical Modelling

$$\frac{C}{C_O} = f(Q, H, \theta) \text{ ....(3.6)}$$

$$\frac{C}{C_o} = aQ^b T^c \theta^d \text{ ....(3.7)}$$

$$\ell n \frac{C}{C_o} = \ell na + b\ell nQ + c\ell nH + d\ell n\theta \text{ ....(3.8)}$$

Where;

C = Effluent

C_O= Influent
Q =Discharge
H = Depth of filter media
θ = Detention time
a, b, c, d are constant of dependent variables

3.0 Results

The experimental results were firstly presented, followed by the regression analysis and model validation. Table 1 and 2 presents the experimental results obtained from the influent and effluent water quality.

Table 1: Influent water quality (raw water)

Parameter	**Unit**	**Influent (Co)**	**Mean**
Ph	-	5.0-5.7	5.38
Turbidity	NTU	1.32-1.90	1.62
Temperature	˚C	23.4-28.5	25.12
TDS	Mg/l	24-26.7	25.3
DO	Mg/l	7.9-8.4	8.17
Alkalinity	Mg/l	80-86	82.2
2Total Hardness	Mg/l	51.2-53.6	52.02
Sulphate	Mg/l	5.5-6.5	5.87
Chloride	Mg/l	4-5.2	4.60
Ca Hardness	Mg/l	2.5-6.1	4.47
Mg Hardness	Mg/l	2.81-3.3	3.04
Iron	Mg/l	0.4-0.89	0.59
Nitrate	Mg/l	1.1-2.5	1.81
Conductivity	ɥs/cm	101.2-103.4	102.38
Total Coliform	MPN/100ml	4-6	5
E-Coli	MPN/100ml	10-16	13

The experimental results were firstly presented, followed by the regression analysis and model validation. Table 4.1 and 4.2 presents the experimental results obtained from the influent and effluent water quality.

Table 2; Effluent water quality (treated water)

Parameter	Unit	Effluent (C)	Mean	WHO Std (2004)	Deviation
Ph	-	6.8-7.10	6.97	6.5-9.5	0.47,2.53
Turbidity	NTU	0.01-0.037	0.22	5	4.78
Temperature	˚C	22’6-23.5	23.02	23.5	0.48
TDS	Mg/l	0.16-0.23	0.19	500	499.81
DO	Mg/l	5.9-6.4	6.18	>6	0.18
Alkalinity	Mg/l	84-87	85.58	100	14.42
Total Hardness	Mg/l	49.3-52.6	50.88	500	449.12
Sulphate	Mg/l	5-5.4	5.22	250	244.78
Chloride	Mg/l	3.5-4.1	3.74	250	246.26
Ca Hardness	Mg/l	0.5-2.0	1.2	100	98.8
Mg Hardness	Mg/l	2-2.3	2.18	150	147.82
Iron	Mg/l	0.02-0.1	0.07	0.3	0.23
Nitrate	Mg/l	0.1-0.2	0.16	1	0.84
Conductivity	ɥs/cm	104.2-106.1	105.08	120	14.92
Total Coliform	MPN/100ml	0	0	0	0
E-Coli	MPN/100ml	0	0	0	0

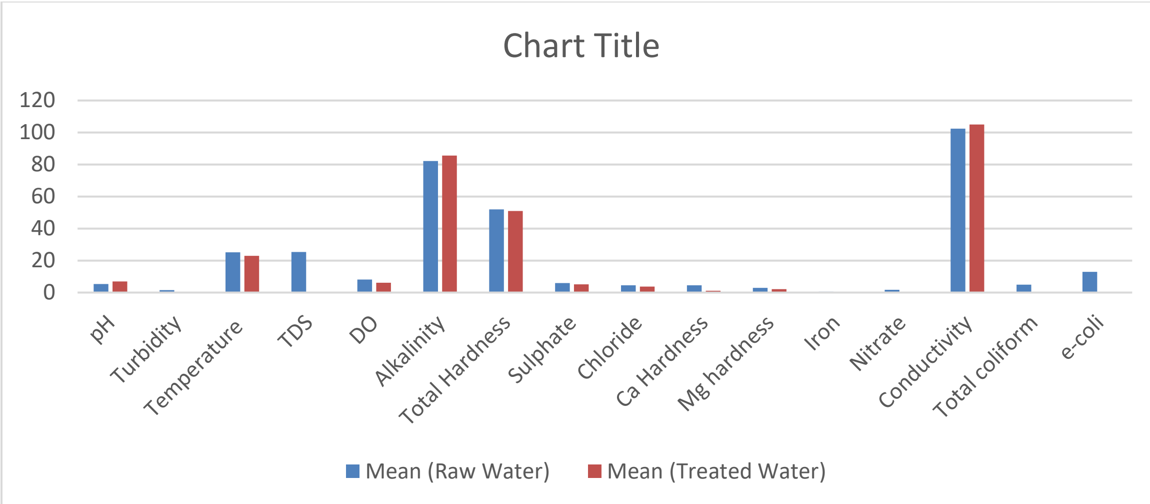

Figure 2: Bar chart showing treated water and raw water

From the analysis in table 2 above shows that parameters of the effluent shows that the filtered waters are within the permissible range of WHO standard.

Table 3: Effects of discharge, detention time and depth of media

Run order	*Diameter of filter column (d)mm*	*Area (A) =* $\prod d^2/4$ *(m²)*	*Flow rate(Q) m³/hr*	*Filtration Rate(m/hr)*	*Depth of media(h)m*	*Volume of media V=Axh*	*Detention time θ=V/Q*
1	400	0.126	0.030	0.2	0.3	0.0378	1.26
2	400	0.126	0.036	0.2	0.3	0.0378	1.05
3	400	0.126	0.042	0.2	0.3	0.0378	0.9
4	400	0.126	0.048	0.2	0.3	0.0378	0.79
5	400	0.126	0.066	0.3	0.6	0.0756	1.15
6	400	0.126	0.072	0.3	0.6	0.0756	1.05
7	400	0.126	0.084	0.3	0.6	0.0756	0.9
8	400	0.126	0.096	0.3	0.6	0.0756	0.79
9	400	0.126	0.12	0.4	0.9	0.1134	0.95
10	400	0.126	0.126	0.4	0.9	0.1134	0.9
11	400	0.126	0.138	0.4	0.9	0.1134	0.82
12	400	0.126	0.15	0.4	0.9	0.1134	0.76
13	400	0.126	0.162	0.6	1.05	0.1323	0.82
14	400	0.126	0.174	0.6	1.05	0.1323	0.76
15	400	0.126	0.18	0.6	1.05	0.1323	0.74
16	400	0.126	0.192	0.6	1.05	0.1323	0.68

4.0 Discussion

4.1 Statistical Analysis

The experimental results obtained were basically analysed using SPSS, and Regression analysis. Model calibration was done on half of all the possible data collected during the experiment to determine the statistical model, analysis of variance was done to check if it is statistically significant.

Result of the Calibrated Regression Model: LN(C/C0) versus LN(Q), LN(H), LN(Ɵ)

The regression equation for the calibrated model is given as

$$LN(C/C0) = -770 - 372.50 * LN(Q) + 375.20 * LN(H) - 368.50 * LN(\Theta)$$

Table 4: Individual coefficients of the Calibrated model

Predictor	Coefficient	Standard Error of Coefficient	T-statistic	P-value
Constant	-769.50	720.60	-1.07	0.346
LN(Q)	-372.50	348.30	-1.07	0.345
LN(H)	375.20	348.70	-1.08	0.343
LN(ϴ)	-368.50	349.30	-1.05	0.351

S = 1.50488   R-Sq = 77.2%   R-Sq(adj) = 65.0%

The result obtained in table 4 found that Q and ϴ has inverse relationship with the dependent variable with coefficients of -372.50 and -368.50 respectively for the calibrated model. This result implies that as Q increases by a unit, the dependent variable is expected to decrease by 372.50 coefficients while as ϴ increases by a unit, the dependent variable decreases by 368.50 coefficients. Also, it was found that H has positive relationship with the dependent variable which indicates that as H increases the dependent variable increases by 375.20 coefficients. Further result showed that the model is adequate in estimating the dependent variable since R-square value of 77.2% was obtained.

Table 5: Analysis of Variance of the Calibrated model

Source	Degree of Freedom	Sum of Squares	Mean Square	Root Mean Square	F-Statistic	P-value
Regression	3	12.086	4.029	2.01	1.78	0.290
Residual Error	12	9.059	2.265	1.50		
Total	**15**	**21.144**				

The result analysis of variance obtained in table 5 found F-statistic value of 1.78 and p-value of 0.290. This result indicates that the independent variables does not significantly impact on the model.

4.2 Model Validation

In this validation, half of the data was used to fit the calibrated regression model while the other half was used to validate the model. The Mann-Whitney test was used to test whether the prediction from the calibrated model and validation were statistically significant at a significant level of 0.05.

Result of the Regression Model for validation: LN(C/C0) versus LN(Q), LN(H), LN(ϴ)

The regression equation for the calibrated model is given as

LN(C/C0) = 108 + 52.4*LN(Q) - 58.1*LN(H) + 63.4*LN(ϴ)

Table 6: Individual coefficients of the Validation model

Predictor	Coefficient	Standard Error of Coefficient	T-statistic	P-value
Constant	108.50	188.60	0.58	0.596
LN(Q)	52.35	91.69	0.57	0.599
LN(H)	-58.09	94.19	-0.62	0.571
LN(ϴ)	63.39	86.14	0.74	0.503

S = 2.22757   R-Sq = 67.8%   R-Sq(adj) = 56.1%

The result obtained in table 6 found that Q and ϴ has positive relationship with the dependent variable with coefficients of 52.35 and 63.39 respectively for the validation model. This result implies that as Q increases by a unit, the dependent variable is expected to increase by 52.35 coefficients while as ϴ increases by a unit, the dependent variable increase by 63.39 coefficients. Also, it was found that H has inverse relationship with the dependent variable which indicates that as H increases the dependent variable decreases by 58.09 coefficients. Further result showed that the model is adequate in estimating the dependent variable since R-square value of 67.8% was obtained.

Table 7: Analysis of Variance of the Calibrated model

Source	Degree of Freedom	Sum of Squares	Mean Square	Root Mean Square	F-Statistic	P-value
Regression	3	27.15	9.05	3.01	1.82	0.23
Residual Error	4	19.84	4.92	2.22		
Total	**7**	**46.99**				

The result analysis of variance obtained in table 7 found F-statistic value of 1.82 and p-value of 0.23. This result indicates that the independent variable does not significantly impact on the model. The root means square error for the calibrated model is 2.01 while that of the validation model was 3.01. This result indicates that the calibrated model is more relatively efficient than the validation model for estimating the dependent variable since it has the less error value. The Mann-Whitney test was used to test whether the prediction from the calibrated model and validation were statistically significant at a significant level of 0.05.

Mann-Whitney Test to examine whether there exist significant difference between the Predicted Calibration and the Predicted Validation

Table 8: Descriptive Summary

	Number of Observation	Median
Predicted_Calibration	8	-1.216
Predicted_Validation	8	-2.178

Table 9: Mann-Whitney result

Point Estimate	W test Statistic	P- value	Remark
Predicted_Calibration-Predicted_Validation	81.0	0.1893	Not Significant

The result obtained in table 8 showed that the median score of the predicted calibration model was -1.216 while that of the validation was -2.178. Further result obtained in table 9 found a test value of 81.0 and a p-value of 0.1893 which is not significant since p-value of 0.1893 is greater than significant level of 0.05 assuming the 95% confidence level.

4.3 Scenario Analysis

The different variables of Ln(C/Co), Ln(H), Ln(Ө) and Ln(Q) were individually correlated with each other so as to envisage how a change in a single variable would affect the influent and effluent when other variables are held constant, a graphical analysis was carried out on the model. Scenarios analyses allow recalculation of model outcomes under alternative assumptions. The graphs of the paired variables are presented below.

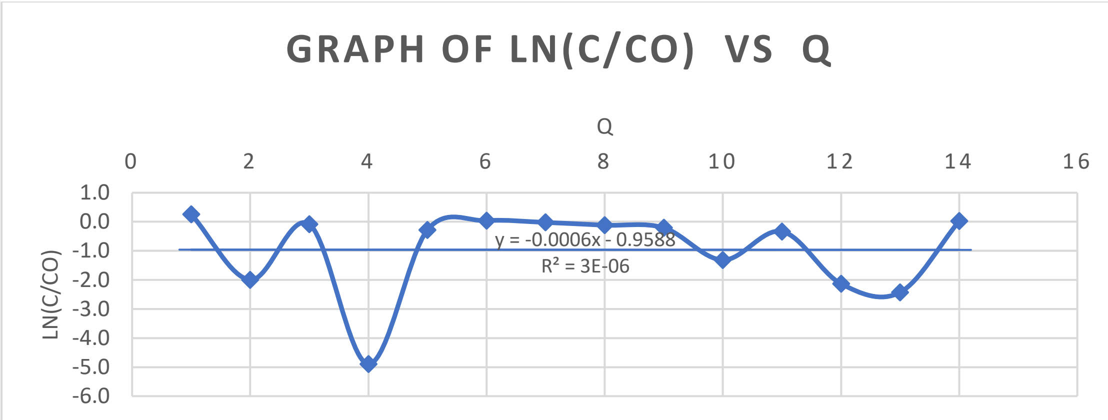

Figure 3: a graph showing paired variables of Ln(C/Co), vs Q

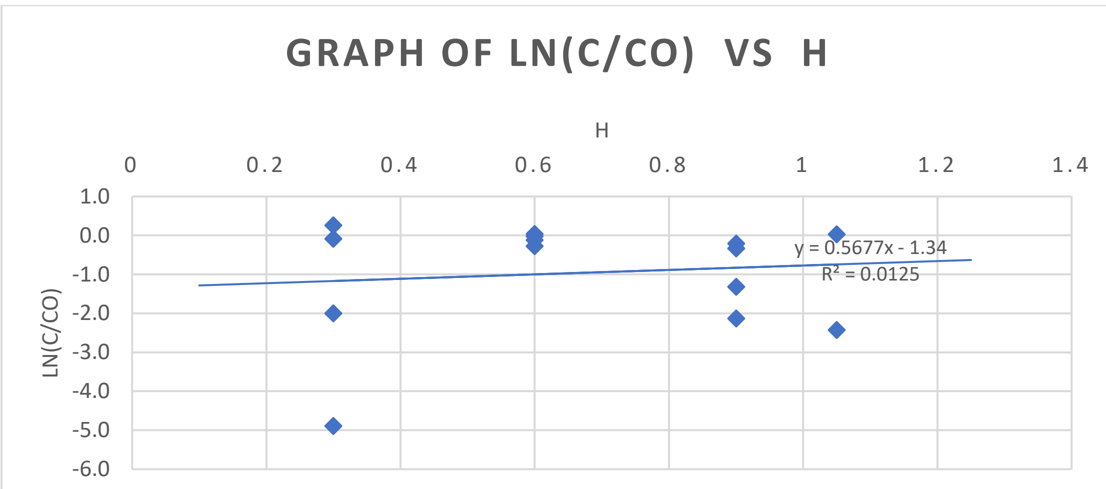

Figure 4: a graph showing paired variables of Ln(C/Co), vs H

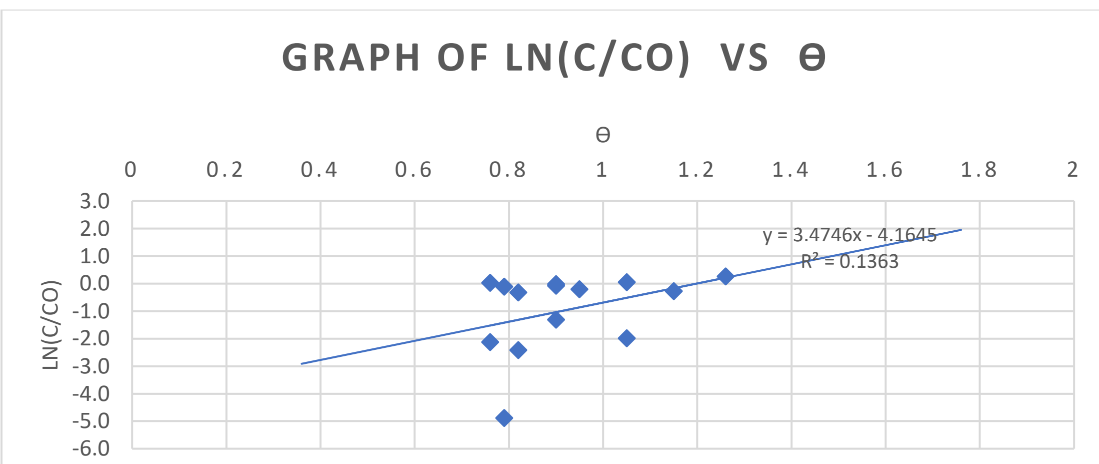

Figure 5: a graph showing paired variables of Ln(C/Co), vs Θ

The R-Squared value obtained from the graphs of Ln(C/Co) vs Ln(Q), Ln(C/Co) vs Ln(H) and Ln(C/Co) vs Ln(Θ) clearly shows that there is no correlation between the dependent variable. However, the model calibration clearly shows that when the independent variables are jointly correlated with the dependent variable, there is a strong corelation between them. However, there exist a strong corelation among the various independent variables. It is seen in the graphs below.

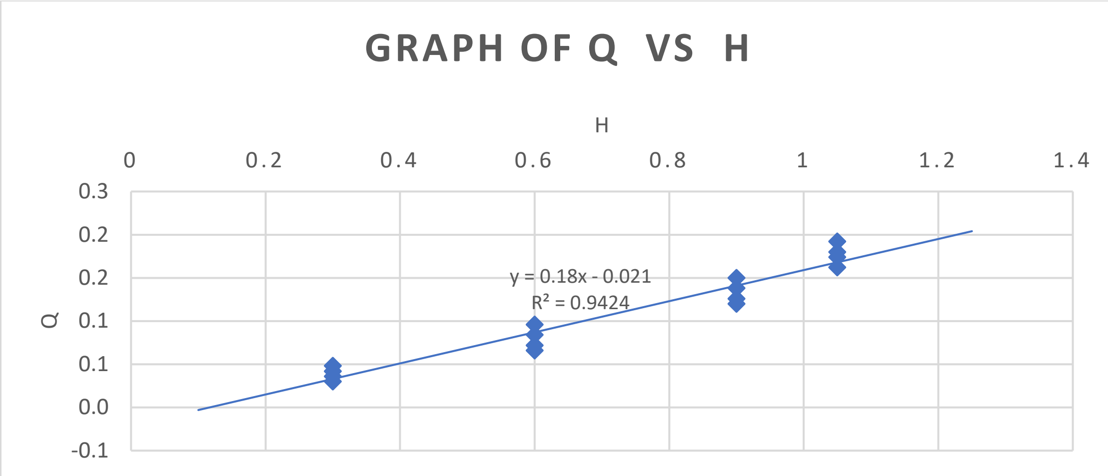

Figure 6: a graph showing strong correlation of the between Q vs H

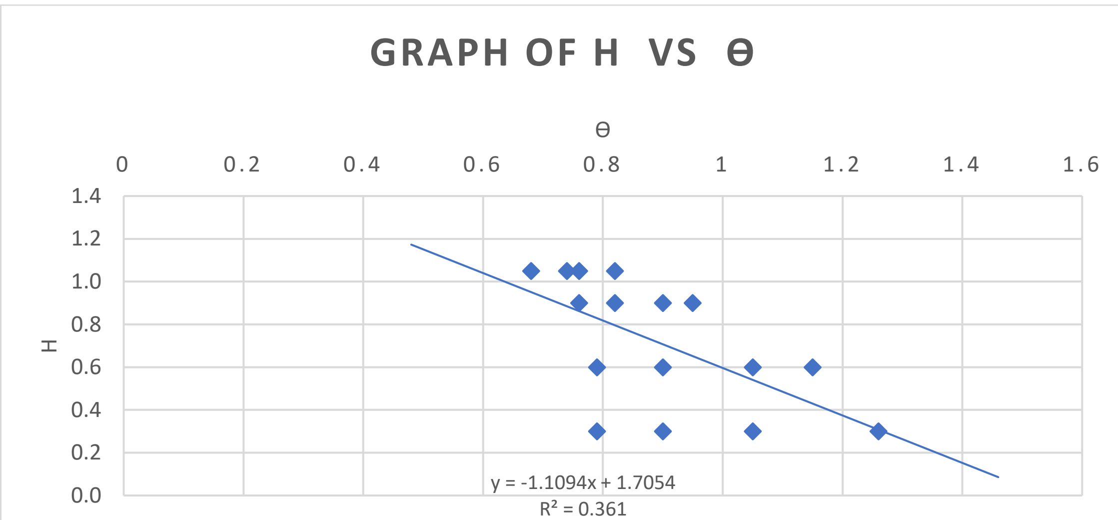

Figure 7; a graph showing strong correlation of the between H vs Ө

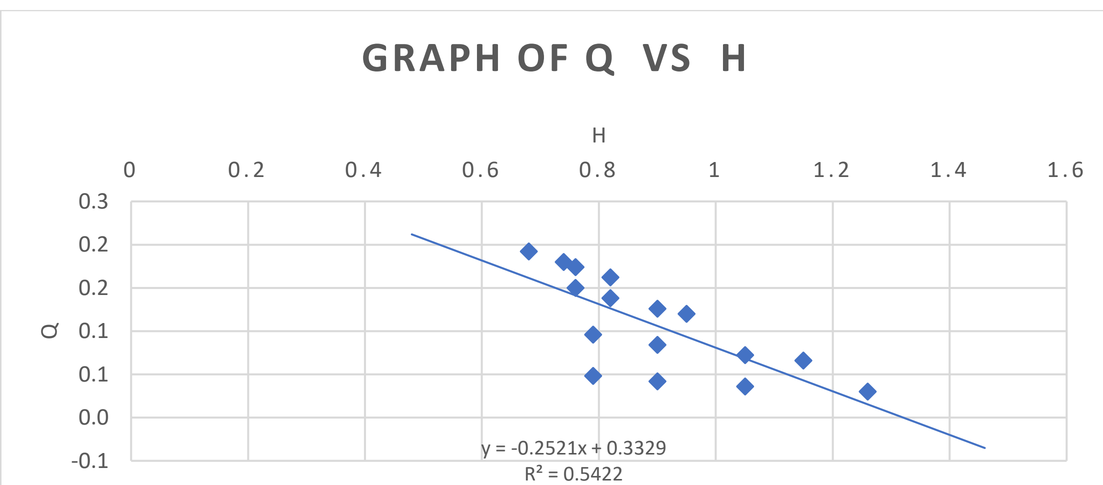

Figure 8: a graph showing strong correlation of the between Q vs H

5.0 Conclusions

The slow sand filter should be used for filtering because drinking surface water directly could have negative health effects. The thesis's findings demonstrate that a dependable method to enhance the microbiological purity of water is the slow sand filter. More microorganisms are removed when the grain size is lower. The adsorption processes that facilitate bacteria removal tended to get better due to the high number of bacteria in the influent. An ideal slow sand filter produces water of outstanding quality with a 90–99% reduction in bacterial cell count. A good method for removing turbidity is created by the system. To achieve its great effectiveness in removing turbidity, it combines filtration, sedimentation, straining, and bacteriological operations. A technically, socially, and economically viable choice for domestic water treatment is the slow sand filter.The developed model successfully estimates the dependent variable.

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