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Effects of Roof Materials and Roof Pitch on Some Selected Physiochemical Properties of Harvested Rainwater

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Abstract: Rainwater harvesting is a strategy that brings many benefits to plants, animals and human lives. The effects of roof materials and roof pitch on harvested rainwater were analyzed to evaluate the optimization and modeling on quality of harvested rainwater (HR) on physicochemical properties on four roofing sheet materials, such as Aluminium, Fibre, Asbestos and Biomass based materials on different angle of tilts 35°, 40° and 45°, respectively. Results obtained showed that the optimum condition was at 30° for fibre roof material which gave 4.39 litres of water, 26.48 mg/l Biochemical Oxygen Demand BOD, 38.87 ppm Total suspended solids (TSS) , 6.50 UpH pH, 40.32 mg/l Chemical Oxygen Demand (COD), 3.20 NTU turbidity, 692.13 mg/l Total dissolved solids (TDS), level at an overall desirability of 0.54. More concerted efforts should be geared towards public sensitisation for an increased public interest to harvest more rainwater for irrigation farming; domestic use and other farm operations especially in places with water scarcity areas where there is low annual rainfall. Fibre roof materials showed good harvested rainwater quality in line with acceptable standards.

Keywords: *Rainwater* harvesting, runoff coefficient, water quantity, water quality, roof materials

1 Introduction

Rainwater is the most pure water for life on earth. It helps to increase the ground water amount Ugwuorah *et al.*, (2018). Consequently, rainwater is also an essential component in every aspect of life and must be valued and safeguarded (Babalola, 2014). The National Capital Region (NCR) is a water-scarce region but can bridge this gap if sufficient rainwater is harvested and managed properly. There has been lack of emphasis of planning and development of ground water sources including recharge through (RWH) and other schemes to harness the potential of water necessary for sustainable development in Nigeria.

Despite its role as a crucial resource, the World Water Council (WWC) projected that the demand for water within the next fifty years will increase due to a prediction of 40–50% population growth coupled with industrialization and urbanization (United National Environmental Programme (UNEP, 2004). An estimated two billion people will lack access to safe drinking water by the middle of this century (Olaoye and Olaniyan 2012). Infact, the demand for clean water has doubled every twenty- one (21) years despite the depletion of water supply due to environmental issues such as water pollution (Tobin *et al.*, 2013). One of the approaches to tackle the problem of limited access to water is the identification and utilization of additional source of water to supplement existing or dominant sources, hence, there is need to investigate and explore the potentials of harvested rainwater as reported by Gikas and Tsihrintzis (2012).

The aim of this study is to investigate the impact roof materials and roof pitch on the quality of harvested rainwater. More so, the specific objectives are to: determine the effects of roof materials on the quality of harvested rainwater; determine the influence of roof pitch on the quality of harvested rainwater and asses the consistency of rain water quality in relation to the time since the onset of rain; develop a deterministic model to optimize water quality as a function of type of roof materials and pitch.

2 Materials and Methods

2.1 Rainwater Harvesting Method

Four (4) mini-structures were constructed with different roof materials (Aluminum, Fiber, Asbestos and Biomass based materials). The amount of rainwater harvested over the 4 different roof materials (*Aluminum roof; Fibre roof; Asbestos roof; and* Biomass based *roof material; subscripts are the angles of tilt 35º*, 40º and 45º). Each structure measures 1.0 m by 0.5 mm for each of the roof material; roof gutters were connected to the edge of each roof to harvest the rainwater coming from the roofing sheets, a plastic bucket (5.0 liter) capacity was used to collect rainwater from each roof separately. Gutter and flushing system were constructed from the top of the roof with the roofing materials to create easy passage. An extra bucket was placed on the open field to harvest rain water directly from the sky to serve as control. The volume of water harvested was measured and the samples were properly labeled, sealed and conveyed to the laboratory to determine the effect of roof materials on the quality of the harvested rainwater. Each roof material was constructed with an adjuster to set the roof surface to three major tilt angles (35^0, 40^0 and 45º, respectively) based on preliminary investigation and literatures review. They were carefully placed on the open field to avoid environmental obstructions and human’s interference.

2.2 Experimental design and Replicate details

The experimental set up is presented in Table 1, it was conducted in a completely randomized block design with three replicates.This implies that each roof material was tilted three times based on the selected angles of tilt at angle (35º, 40º and 45º, respectively).

Table 1: Experimental design showing four roofing materials and three tilt angle.

1_{35}	1_{40}	1_{45}
2_{35}	2_{40}	2_{45}
3_{35}	3_{40}	3_{45}
4_{35}	4_{40}	4_{45}

(1 – Aluminum roof; 2 – Fibre roof; 3 – Asbestos roof; and 4 – Biomass based *roof material; subscripts are the angles of tilt 35º*, 40º and 45º).

2.3 Determination of physico-chemical properties of the harvested rainwater

The physicochemical properties of the harvested rainwater determined include: Biochemical oxygen demand (BOD), Total suspended Solids (TSS), Chemical Oxygen Demand (COD), Turbidity, Total dissolved solids (TDS), and pH concentration

(a) Biochemical Oxygen Demand (BOD): this is a measure of the oxygen used by microorganisms to decompose the waste. If there is a large quality of organic waste in the water supply, there will also be a lot of bacteria present working to decompose the waste. It is determined by the measure of the oxygen consumed by bacteria from the decomposition of organic matter using biosensors indirectly measure BOD via a fast (usually < 30min) to be determined BOD substitute and corresponding calibration curve method (Devange *et al.,* 2013).

(b) Total Suspended Solid (TSS): this was determined by the quantity of water passing through a known volume of water sample through a glass Fiber filter apparatus and weighing the dry residue left. It will be obtained by a simple subtraction method. The total solid will be first determined and the total dissolved solid obtained will be subtracted from it.

$$TSS = TS - TDS \quad (1)$$

Gravimetric method was used for determination of Total solids 10ml of the samples was measured into a pre-weighed evaporating dish which was oven dried at a temperature of 103 to 105°C for two and half hour. The dish was cooled in a desiccator at room temperature and weighed. The total solid was represented by the increase in the weight of the evaporating dish as presented in Equation 1 as described by Ugworah *et al.,(*2015).

$$\text{Total Solids}\left(\frac{mg}{l}\right) = \frac{(w_2 - w_1)mgx100}{ml\ of\ sample\ used} \quad (2)$$

Where: W_1 = initial weight of evaporating dish, W_2 = Final weight of the dish (evaporating dish + residue)

(c) Chemical Oxygen Demand (COD): COD is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. This test allows measurement of a waste in terms of the total quantity of oxygen required for complete oxidation to carbon dioxide and water. Equation 3 will be used for computing the COD. It is determined by the quantity of oxygen required to oxidize the organic matter in the water sample, under specific condition of oxidizing agent, temperature and time. It is done by titration method using indicator solution as reported by Christopher *et al., (*2009).

$$\text{COD}\left(\frac{mg}{l}\right) = \frac{(b-a)\text{xml of ferrous ammonium sulphate x 1000 x 8}}{\text{ml of sample}} \quad (3)$$

Where:

a is the ml of titrant with sample, and

b is the ml of titrant with blank

(d) Turbidity: Turbidity is measure with the help of Digital meter. It is calibrated with the help of standard NTU. It is determined by altering the original sample conditions such as temperature. It cause the higher in concentration of suspended solids in the water is, it dirtier, it looks and the higher the turbidity required WHO, (2019).

(e) Total Dissolved Solids (TDS): these are those dissolve solids present in water after filtering through 1 micrometre pores. These were obtained by heating the water samples at 103C. Equation 4 was used for the determination of TDS using dry weight of suspended particles as reported by Tobin *et al., (*2013).

$$\text{TDS}\left(\frac{mg}{l}\right) = \left(\frac{(\text{Wf}-\text{Wi})\text{x1000x1000}}{\text{Volumeofsample}}\right) \quad (4)$$

where:

W_i is the Initial weight of evaporated dish (g),

W_f is the Final weight of evaporated dish (g).

(f) pH: this is the number of Hydrogen ions in the water and expressed by negative logarithm to the base 10 of the H+ ion number in mole per litres. pH meter (pH meter (0.01 pH, ± 0.05pH, United Kingdom) was used, the device will be calibrated by first standardizing it with a buffer solution of pH 7; water samples was measured out in a beaker and the electrode used will be properly cleansed with distilled water before dipping it in the water sample as described by Ugwuorah *et al.* (2018).

2.4 Model fitting

The optimum volume of water harvested was obtained using Quadratic Data tool of Design Expert Software (Version 10.0.1), the roof material and angle of tilt was set at the range of levels used for the experiment while varying constraints were set for all dependent variable on physico-chemical parameters based on acceptable limits and levels set by WHO standards for rainwater. Therefore, the mathematical models were developed to predict the relationship between the independent and dependent variables by applying multiple linear regressions. Six different models (mean, linear, two factorial interactions, quadratic models, cubic and quartic) were used to represent relationship between roof materials, angle of tilt and the corresponding water quality parameters. A second order polynomial equation was used for estimating the dependent variables as affected by roof materials and angle of tilt.

3. RESULTS AND DISCUSSIONS

The response on dependent variables obtained from the effect of roof materials and roof pitch on selected physico-chemical properties of rainwater harvested from the analysis is presented in Table 1.

Table 1: Experimental summary of dependent variables (responses) on effect of roof materials and roof pitch on the volume and quality of harvested

S/N	Dependent Variable (Response)	Unit	Min	Max	Ave	S. D.	Suggested Model
R1	Volume of harvested water	kg	3.57	6.97	4.77	1.05	Quadratic
R2	BOD	mg/l	16.8	35.75	26.11	5.39	Quadratic
R3	TSS	Ppm	19.5	45.95	34.21	8.82	Quadratic
R4	COD	mg/l	30.6	49.55	40.28	6.47	Quadratic
R5	Turbidity	NTU	2.5	5	3.56	0.7833	Linear
R6	TDS	mg/l	500.01	950.05	697.84	151.42	Linear
R7	pH	UpH	3.6	6.86	6.03	0.9032	Linear

From Table 1 above, the volume of water harvested as the minimum, maximum and average values of dependent variable 3.57, 6.97 and 4.77 respectively. From these results, the suggested model is quadratic, Therefore, one can realize that the entire suggested model is either greater than 1 or less than 1 as indicated by WHO standard limits (Bada *et al.,* 2012; Ezemonye *et al.,* 2016). On the other hand, the suggested model for BOD, TSS and COD are quadratic model at 5.39, 8.82 and 6.47 respectively (Sakshi *et al.,* 2016). Beside this, the turbidity, TDS and pH concentration values indicate liner model interaction as suggested by (Ramon *et al.,* 2015). The experimental study indicates similar method adopted (Olaoye and Olaiyan 2012), TDS had the highest standard deviation regression coefficient and turbidity have lowest standard deviation compare to others. It was observed that, the volume of rainwater harvested as a polynomial order and additional terms are significant and the model is not aliased for each dependent variable.

Figure 1 and 2, the Biochemical oxygen demand (BOD) of the harvested rainwater ranged from 16.8 to 35.75 mg/l with an average value of 26.11 ± 5.39 mg/l respectively compare to other properties (Ugwuorah *et al.,* 2018). The quadratic model so the summary of the tested models and p-values less than 0.0500 indicates model terms is significant according to Rahmon *et al.,* (2014)

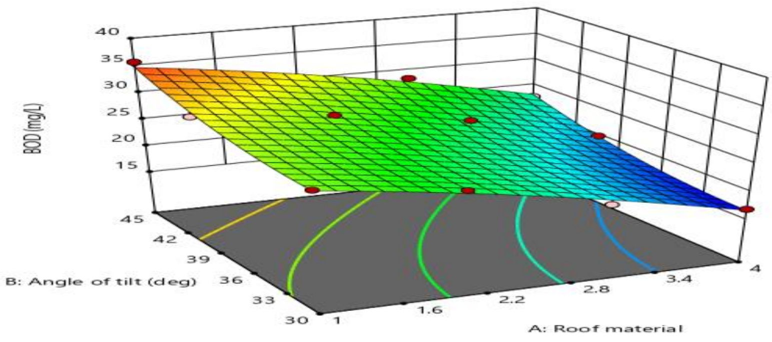

Figure 1: Roof material and angle of tilt on BOD of HR samples

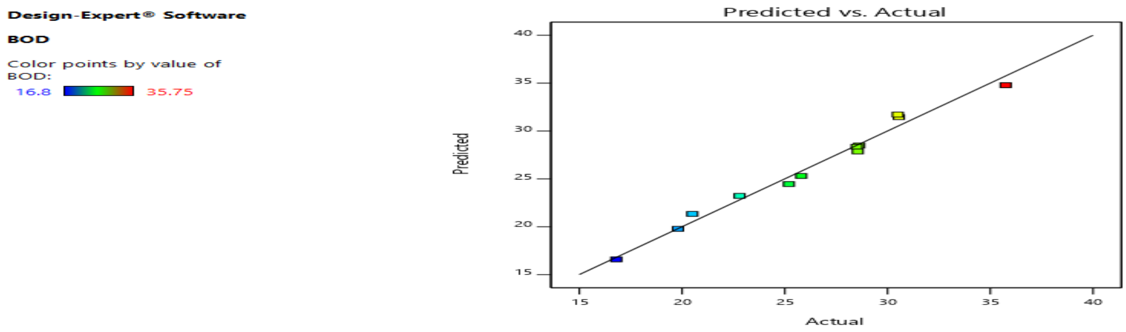

Figure 2: Predicted value versus Actual BOD of HR samples

From figure 3 and 4, the Total Suspended Solids (TSS) of the harvested rainwater and average values ranged from 19.5 to 45.95 ppm and 34.21 ± 8.82 mg/l respectively (Achada *et al.,* 2013). Therefore, the results showed above, the analysis of variance of the TSS proof that roof materials and angle of tilt had significant influence on the TSS of harvested rainwater (Biplob and Babul 2019).

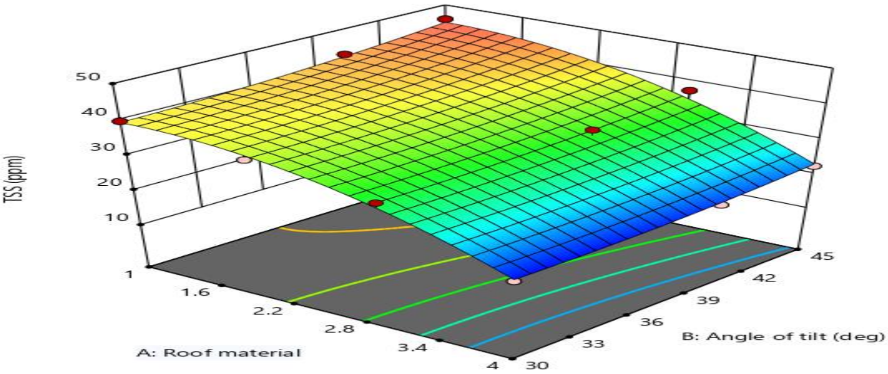

Figure 3: Roof materials and angle of tilt on the TSS

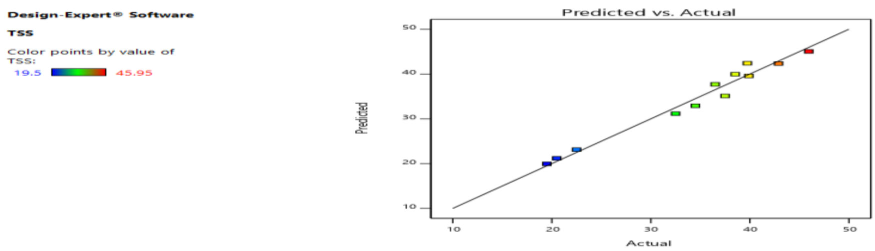

Figure 4: Predicted value versus actual values of TSS

From figure 5 and 6, it was observed that the Chemical Oxygen Demand (COD) of the harvested rain water ranged from 30.6 to 49.55 mg/l with an average value of 40.28 ± 6.47 mg/l is within the water standard limit as described by Devemgees *et al., (*2013). More so, the analysis of variance of the TSS shows that roof materials and angle of tilt had significant influence on the COD of harvested rainwater as agreeded by Ramon *et al., (*2015).

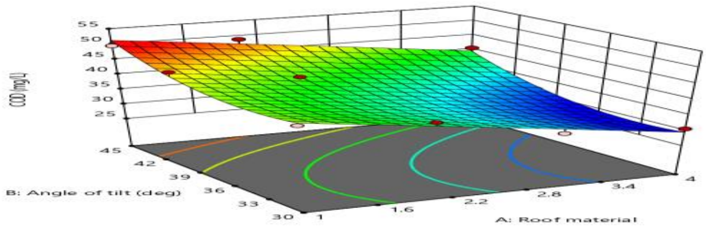

Figure 5: Roof materials and angle of tilt on COD of HR

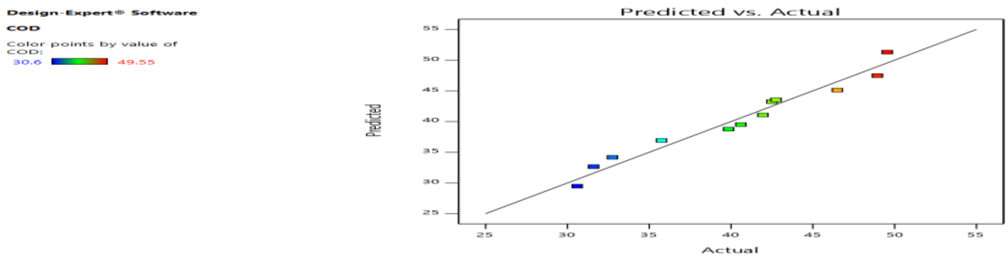

Figure 6: Predicted value versus Actual COD values of the HR

From Figure 7 and 8, the turbidity of the harvested rainwater ranged from 32.6 to 50.55 mg/l with an average value of 40.78 ± 7.47 mg/l (Ugwuorah *et al.*, 2015). However, the analysis of variance of the turbidity shows that all the roof materials and angle of tilt had significant influence on the P-values less than 0.0500 as reported by Benjamin *et al.*, (2019).

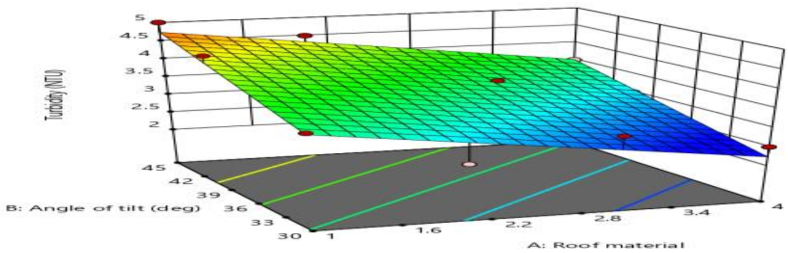

Figure 7: Roof materials and angle of tilt on Turbidity level of HR

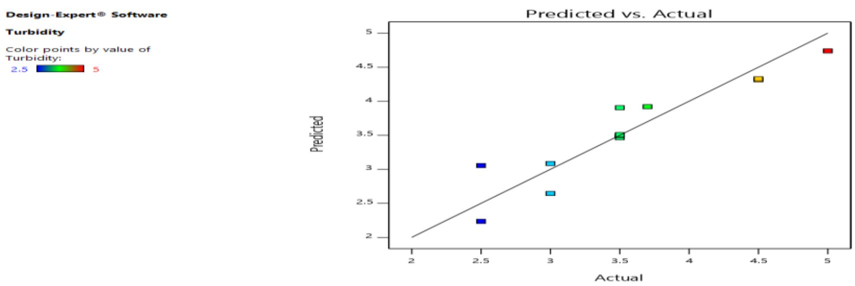

Figure 8: Predicted values versus Actual Values of Turbidity levels of the HR

Figure 9 and 10 show that the Total Dissolved Solids (TDS) of the harvested rainwater ranged from 500.01 to 950.05 mg/l with an average value of 697.84 ± 151.42 mg/l within the water limit (Ugwuorah *et al.,* 2018).

More so, the analysis of variance of the TDS of harvested rainwater shows that Aluminum roof and fibre roof materials and angle of tilt 45 degree had no significant influence on the TDS of harvested rainwater based on the interaction with roof materials (Tobin *et al.*, 2013).

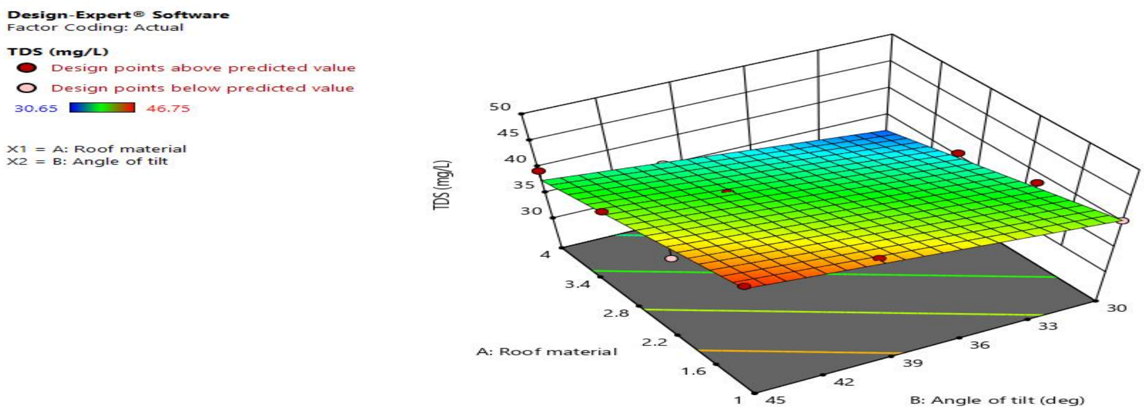

Figure 9: Roof materials and angle of tilt on TDS of HR

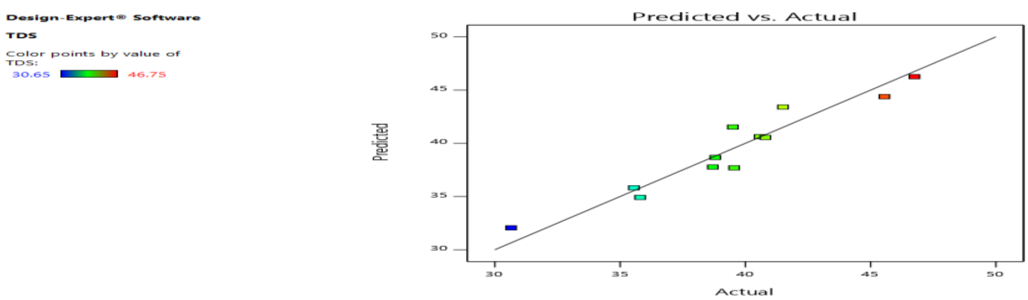

Figure 10: Predicted value versus Actual TDS values of HR

From Figure 11 and 12, the pH value of the harvested rainwater ranged from 3.6 to 6.86 UpH with an average value of 6.03 ± 0.9032 UpH compare to World Health Organization WHO (2019) and EPA (2001) However, the analysis of variance of the pH of harvested rainwater at Asbestos and fiber roof materials shows that the angle of tilt had no significant influence on the pH level of harvested rainwater (Tobin *et al.*, 2013).

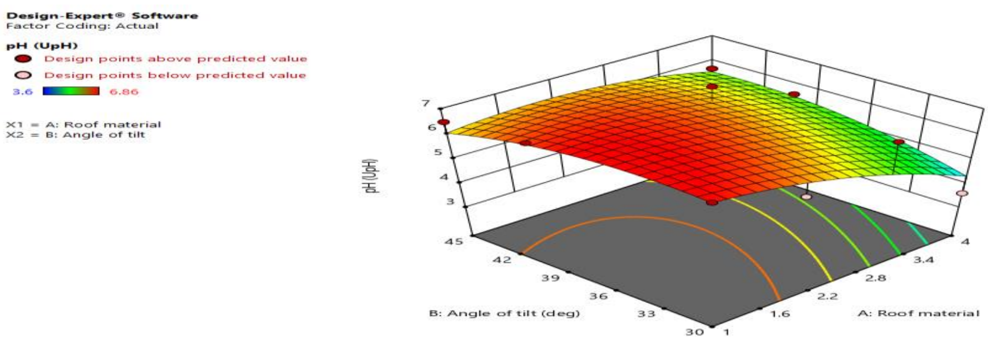

Figure 11: Roof materials and angle of tilt on pH of HR

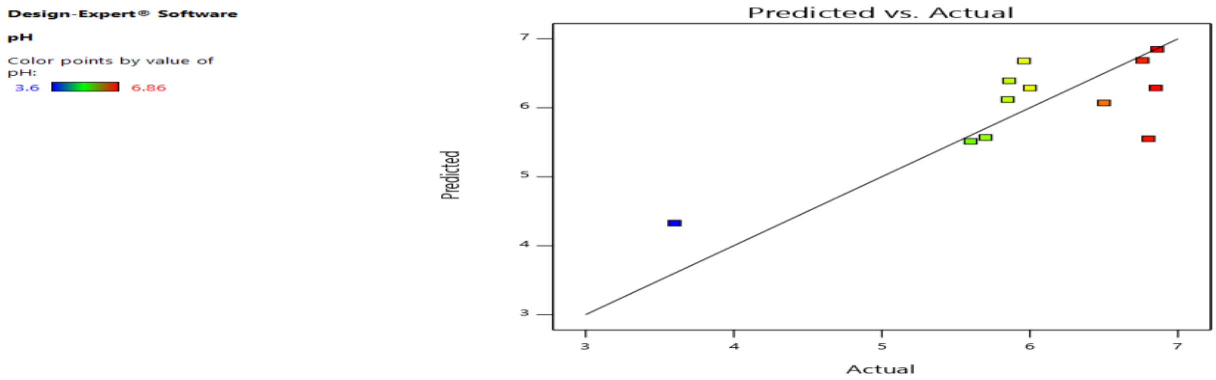

Figure 12: Predicted values versus actual pH values of harvested rainwater

4 Conclusion and Recommendations

The effect of roof material on harvested rainwater harvested sampled reveled that some parameters were within World Health Organization Water Standard. In this experiments, the experimental factors; roof materials and roof pitch have a negative effect on roofs materials at different roof pitch. More so, these water systems can be prevented from pathogenic and microbes that are more harmful to human health.More so, their effects on water quality assessment in university environment that rely solely on this water for drinking and domestic use is highly recommended.

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