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Design and Fabrication of 100 Litres Solar Powered Mobile Rain Water Collector and Disinfection, Using Lines from 3rd Degree Polynomials

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Abstract

The purpose of this study is to use lines obtained from 3rd degree polynomials to design and fabricate solar powered mobile rainwater collector for collecting rainwater for drinking and cooking. The study consists of two parts; the first part is the design and fabrication of the water collector using lines from 3rd degree polynomials. This was done by generating numbers from 3rd degree polynomials and converting the numbers to lines. The lines were then arranged in such a way as to obtain the 2D image of the water collector. The 2D image was turned to 3D image all using 3D visualizer app. The fabrication of the water collector was then carried out. The second part is the design and fabrication of two tanks of 50 and 100 liters respectfully using the same procedure above. The combination of the rainwater collector and the two tanks produces the mobile rain water harvester. The system can collect rain water directly from the sky and can also be connected to a roof to harvest the rain water. Solar-PV system is incorporated in the design to power a UV-sterilizer for disinfection of the collected water. The mobile rainwater collector is designed to provide safe, clean and natural water for the purpose of drinking and cooking. The microbial tests conducted using membrane filtration method of the raw rainwater sample collected from the system indicated that there were 0 E.coli and 5 total coliforms these were all neutralized after passing the water through the UV sterilizer.

Key Words: Design, disinfection, fabrication, rain-water, 3rd degree polynomials

Background to the study

Water is a basic necessity for life, due to the fact that all living organisms depend on it. Nigeria is facing multidimensional problems ranging from high population growth, limited access to nutritious food and potable water, due to rampant insecurity and bad governance (Shibayan, 2025). The Nigerian Institute of Water Engineers (NIWE) reported in March 2024 that about 179 million Nigerians consume unsafe water. Similarly, World Bank Report (2024), ascribed 70,000 deaths of children below the age of five in Nigeria to consumption of unclean water. It has also been reported that, about 55 % to 95 % of Nigerian students rely on satchet water as their primary source of drinking water, thereby generating a lot of waste. About 85% of sachet water waste is improperly disposed of. About (40%) often ends up on streets. Similarly roughly 25% ends up in drainage systems; while 20% in open dumps (Anthomy, 2024). This contributes to the overall plastic waste problem, which is a major environmental challenge. Additionally, the quality of many satchet water is not certain. A recent study shows that many satchet water fail microbiological test. While many boreholes yield water that is physically clear and meets basic needs, but studies frequently reveal high levels of contamination (Akpan, *et al.* 2018), meaning the water is rarely safe to drink without treatment.

The development of rain water harvesters has become an increasingly important area of research and technology, especially in regions where fresh water is scarce. A rain water harvester refers to a system designed to capture, store, and sometimes purify rain water mostly for drinking and domestic activities. The amount of rain water harvested at a location depends largely on how the system is designed (Boyd, 2020).

Mathematics is a powerful social entity that plays a key role in sharpening how individual deals with the various spheres of private social and civil lives (Kajuru and Popoola 2010). Mathematics does not only empower people with the capacity to control their lives, but also provides science, a firm foundation for effective theories. This study presents how mathematical modelling, with emphasis on linear functions, can be used to design and fabricate simple as well as complex appliances such as rain water harvester, that will provide services to countries in Africa and possibly the world.

This is a new innovation and an emerging technology where numbers are generated from 3rd degree polynomials and thereafter the numbers are converted to lines that will form the bases for the design and fabrication of simple and complex shapes. The technology is indigenous, unique and simple. Some simple appliances that may be considered include household appliances such as design and fabrication of frying pans, buckets, dustbins jerry cans, plates, bowls, drums, e.t.c (Kajuru and Popoola 2010).

It can also solve complex problems such as: water sanitation, waste management, and renewable energy, medical and biological problems bedeviling mankind. It is hoped that the new technology will be of immense help to especially teachers and students and by extension to the larger society. This new technology is flexible since it can be used to solve problems from almost all aspect of human endeavor. The study will also emphasize the teaching of practical mathematics rather than theoretical mathematics. The study also aims at encouraging the utilization of mathematics laboratory, where all this work can be carried out. The overall aims of this new technology is to help produce individuals that will be managers of small and medium scale industries across African or beyond. This will provide the needed employment for our teaming unemployed youth in Africa. The mobile rainwater collector is an example of the complex appliances that can be fabricated from lines obtained from 3rd degree polynomials to solve water sanitation problem in the society.

Literature Review

Common Rainwater Collection Techniques

Rooftop Harvesting is the most common method of collecting water from rooftops via gutters and downspouts for storage in rain barrels or large cisterns (Cano, *et al.* 2024). Also Surface Runoff Harvesting is also used for Capturing water flowing over land surfaces, such as gardens or paved areas, and directing it into storage ponds, reservoirs, or tanks. Similarly, Infiltration Pits/Trenches is a structure designed to catch runoff and allow it to recharge groundwater, essentially harvesting water into the water table. Additionally, First Flush diverter; a device that diverts the first dirties runoff water away from the storage tank, so that cleaner water enters the system. Furthermore, Fog/Dew Collection method Uses nets or mesh to collect moisture from the air, a technique often used in arid regions.

The amount of rainwater collected is given by the equation 1:

$$Q = R_{fall} X A_{catchment} X Run-off \qquad (1)$$

where:
Q is the quantity of rain water harvested (m^3);
R_{fall} is the quantity of rainfall at the location (m);
$A_{catchment}$ is the area of the catchment area (m^2);
Run-off is the fraction of the amount of water received.

Though rain water is generally considered to be clean, however, studies such as that by (Cano *et. al.*, 2024 and Khayan *et. al.* 2019) confirmed that, rain water is mostly not pure due to its contamination with impurities and debris from the sky and the runoff. A number of treatment methods are employed to make it pure. These include: Multi-stage Filtration that uses gravel and sand to trap debris and suspended particles (Cescon & Jiang 2020). Also Activated Carbon Filters are employed and are considered to be effective for removing impurities like chlorine, mercury, iodine, and organic compounds. Furthermore, Ultraviolet (UV) Light is used to disinfect water by using UV-C light to kill bacteria and microorganisms, preventing them from reproducing (Musa *et. al.* 2022) Similarly, Chlorination is widely recommended for chemical treatment to kill bacteria and prevent microbial growth (Cano *et. al.* 2024). Additionally, Solar Pasteurization uses the sun's heat to destroy pathogens like *E. coli*. Boiling is an emergency measure effective in killing microorganisms, recommended to be boiled for at least one minute (Musa *et. al.* 2022).

Mathematical Modelling is described as illustrating real life situation in mathematical form and expression. It is usually simplified in the form of an equation. We can easily identify answers to these problems by utilizing such equation. While modelling, the observer's perspective is very important. One should be able to see the modelling through his mind. Engineers and scientist use such technologies to model and design future technologies. Along with the processes prototype are commonly used. This is a compact model of an actual model. Mathematical modelling is applied in design and fabrication in engineering, medicine, agriculture, e.t.c. www.turito com.

Types of Modelling

There are four types of mathematical modelling namely: Exponential decay, Exponential growth, Quadratic functions and linear functions.

This study pays specific attention to the last type i.e. the linear function modelling. A linear model is an equation that describes a relationship between two quantities that show a constant rate of change. It is generally given by the equation 2:

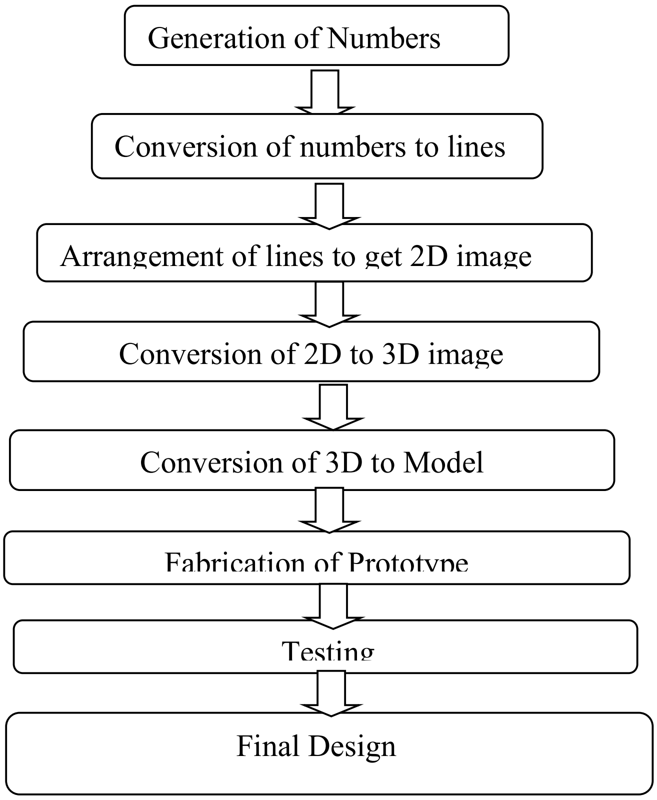
$$y = mx + c. \qquad (2)$$

Methodology

1. **Area of Study**

The area of study is Kaduna city, the capital of Kaduna State in northwestern Nigeria. It features a tropical savanna climate with two strictly defined seasons: a prolonged dry season (November to April) and a distinct wet season (May to October). It is situated in the Northern Guinea Savanna vegetation belt, the city sits at approximately 10°36' N and 7°46' E. Annual Rainfall Volume**:** The city experiences a mean annual rainfall ranging between 1,000 mm and 1323 mm (Ndaraka, and Eyefia, 2021).

The study intends to design and fabricate the mobile rainwater collector using lines from 3rd degree polynomials. The research methodology is as given in the flow chart below:



Definition of 3rd Degree Polynomials and Generation of Numbers from the 3rd Degree Polynomials

A 3rd degree polynomial is a function of degree three. It is generally of the form $y = ax^3 + bx^2 + cx + d$ (Wikipedia 2019).

Ways of Generating Numbers from 3rd Degree Polynomials

There are basically two ways of generating the numbers from 3rd degree polynomials:

(a) From factorization of the 3rd degree polynomials by the method of differentiation (Gambo, and Musa, 2020): This is done by repeated differentiation of the 3rd degree polynomial to its linear form e.g.

$$x^3 + 13x^2 + 54x + 72 \quad (3)$$

when equation 3 is differentiated it yields:

$$3x^2 + 26x + 54 \quad (4)$$

Further differentiation gives:

$6x + 26 = 8 \Rightarrow \frac{-18}{6} = -3 \Rightarrow x + 3 = 0$

$6x + 26 = 2 \Rightarrow \frac{25}{6} = -4 \Rightarrow x + 4 = 0$

$6x + 26 = -10 \Rightarrow \frac{36}{6} = -6 \Rightarrow x + 6 = 0$

2. General Description of the system

The mobile solar-powered rain water collector is made up of the following units:

i. **Water Collector**: This a stainless steel cone with bigger diameter D: 43.5 mm, Smaller diameter d: 12.5 mm, and height H: 440 mm. It is designed using golden ratio so as to capture as much water as possible across its circumference.

ii. **Water tank**: this is 50 L stainless steel cylindrical tank with inner diameter: 368.3 mm and height: 465 mm. It receives the water collected by the water collector and allows it settle down before filtration and disinfection.

iii. **Water Storage tank**: this is 100 L stainless steel cylindrical tank with inner diameter: 521 mm and height: 465 mm. It receives the treated water and stores it for consumption.

iv. **Water filters:** These are two carbides cup filter for the rain filtration.

v. **UV Sterilizer (240 V AC):** This is a disinfection unit having ultraviolet lamp used to disinfect water.

vi. **Solar panels:** These are 2 (200 W) panels that convert sunlight energy to electric energy for the purpose of power supplying the required power to operate the system.

vii. **Inverter 1000VA:** This converts the D.C. received from the solar panels to A.C. for use by the UV Sterilizer. It is rated: Input Voltage: AC: 170V-275V, Output Voltage: AC: 230V ± 6 %.

viii. **Charge Controller (12/24/36/48 V Auto 60 A):** This controls the current that enters the battery form the solar panels.

ix. **Battery (12V, 220AH):** This stores the electric charges received from the solar panels.

x. **Frame:** This is a mild steel structure 1065 mm by 910 mm by 1010 mm the carries the system.

Figure 1 shows a schematic diagram of the system.

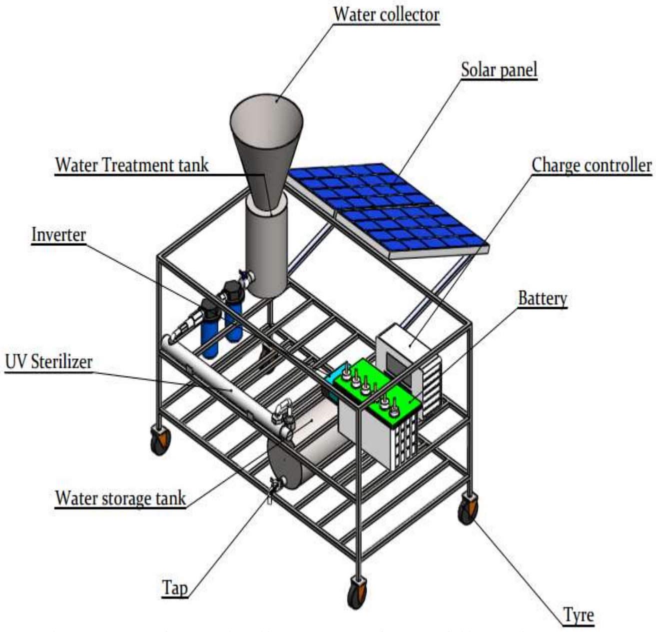


Figure 1: Schematic diagram of the Mobile Rain water Collector

3. Materials and Methods for Water Quality Test

The following were used to determine the quality of water collected from the system as suggested by many researchers such as (Amin, *et. al*., 2009 and Annisa, *et. al*., 2022):
Membrane Filters**:** Sterile nitrocellulose with 47 mm diameter and a 0.45 µm pore size. Sterile funnel, filter base, and a vacuum receiving flask. Vacuum Pump: Connected via rubber tubing to draw the water through. Culture Media: Petri dishes containing selective agar. Sterile Forceps & Alcohol: For flaming and handling the membrane filters. Sterile Rinse Water: sterile distilled water.

4. Sample Preparation and Dilution

Since the water looks clean an undiluted 100 mL sample was used, as contained in (APHA, 2012).
All work were performed inside a clean, sterilized biosafety cabinet to prevent environmental contamination. The vacuum flask was set up and the sterile filter base was placed onto the neck of the flask. The tip of the metal forceps was sterilized by dipping them in alcohol and passing them through a Bunsen burner flame and allowed to cool. The sterile forceps were used to pick up a sterile membrane filter carefully. It was placed flat onto the filter base, grid-side up. The sterile funnel was fixed over the base using clamp mechanism.

5. Sample Filtration Process

a) The water sample was thoroughly mixed by inverting and shaking the container several times.
b) A 100 mL of the sample was poured into the funnel.
c) The vacuum pump was turned on to draw the liquid completely through the membrane filter.
d) With the vacuum still running, the inner walls of the funnel was rinsed with 25 mL of sterile water to wash down any remaining bacteria. The rinse was allowed to pass entirely through the filter.
e) The vacuum pump was turned off after the filter appeared dry.

6. Inoculation and Incubation

i. A Petri dish containing the appropriate agar medium was prepared.
ii. The forceps was heated again in a flame and then cooled.
iii. The funnel was unclamped and the membrane filter was carefully lifted from the base using the forceps.
iv. The filter was placed onto the agar surface with the filtrate (trapped bacteria) side facing upwards and gently rolled onto the agar to avoid trapping air bubbles beneath the filter. The Petri dish was inverted and placed in the incubator. Incubation was done at 35ºC for 24 hrs for total coliforms.

7. Enumeration and Calculations

After the incubation, the distinct colonies growing directly on top of the gridded membrane filter were counted, using a low-power magnification lens (10x–15x).

The microbial density was calculated using the formula:

$$Colonies\ per\ 100\ mL = \frac{Colonies\ counted\ X\ 100}{Volume\ of\ sample\ filtered\ (mL)} \quad (5)$$

Results and Discussions

From the solutions of the polynomial presented in equation 3, the numbers 2, 8 , 10 are the numbers that fit in the linear equation that gives values of x, hence the factorization is (x + 3) (x + 4) (x + 6).

Therefore, the numbers 2, 8 and 10 are the numbers generated. Similarly $x^3 + 14x^2 + 54x + 70$ gives 2, 14, 16. In general the numbers appear to be a pattern thus:

2 8 10
2 14 16
2 20 22
2 26 28
- - - - - - - - - - - -
- - - - - - - - - - - -

(b) From the coefficient of the 3rd degree polynomial and the differentiation of the 3rd degree polynomials to get 3! = 6 (Tata and Gambo, 2023)

1 3 3 1
2 0 4

Add 6 to both sides, gives a pattern

20 14 8 2 0 4 10 16

The sum of any two numbers on the left of zero gives a corresponding value on the right.

2 8 10
2 14 16

Conversion of the Numbers Generated to Lines

The process of converting the numbers generated from the 3rd degree polynomials to lines is done by subjecting the 3 numbers to a test using the cosine rule. It was discovered that the numbers 2 and 8 created an angle O^O respectively, while the number 10 created an angle 180^O. Suggesting that the numbers 2, 8, 10 are collinear lying on a straight line of length 10 units. Similarly 2, 14, 16 is a line of length 16 units. Thus,

2 8 10
________________________________ 10 units

2 14 16
________________________________ 16 units

These lines form the bases of the design and fabrication. They can be arranged either vertically or horizontally to produce the required image. The 2D and 3D images generated using 3D visualizer are as presented in figures 2 and 3 respectively:

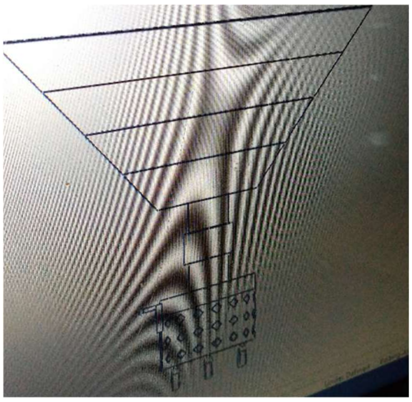


Figure 2 : 2D image generated using the lines

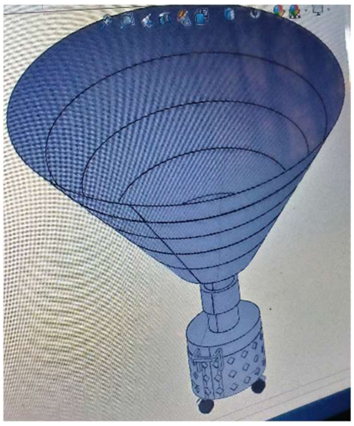


Figure 3: 3D image generated from the 2D

The mobile rainwater collector was successfully constructed and assembled. The collector was found to receive a total rainfall of about 1.5 liters direct from the sky. However, when connected to a roof gutter, the 50 Liters tank got filled in less than 5 minutes. Therefore, the amount of water collected by the system shows that it has almost, 100 % collection efficiency. This is because, the average rainfall in Kaduna is estimated by many researchers such as Atuma *et. al.* (2023), and Ndaraka, and Eyefia, (2021) to be about 250 mm, thereby putting the average rain water per unit area in Kaduna to be about 1.47 Liters.
The microbial test results of the raw rainwater sample collected and the treated water by the UV sterilizer is presented in table1. CFU were calculated using equation 5.

Table1: Microbial Test of Rainwater Samples

Indicator Bacteria	**CFU/100 mL (raw)**	**CFU/100 mL (treated)**	**Remarks**
Total Coliforms	5	0	Low risk before treatment
E.coli	0	0	safe

The presence of coliforms indicates that coliform bacteria are naturally present in the environment (roof and surfaces where the rainwater was harvested). The raw count of 5 means there was slight environmental contamination. However, the treatment process was perfectly effective, bringing the count down to the ideal. Though the tolal coliforms observed, indicates that, care has to be exercised during using the system.
E. coli is the most definitive indicator of fecal (animal or human) contamination. Because it is absent in both the raw and treated samples, the water shows no signs of this dangerous biological contamination. The treatment method was completely effective, eliminating the coliform bacteria and leaving the treated water microbiologically safe for consumption, according to WHO Drinking-water Standards. The result agrees with the results presented by (Morke, 2022). Who showed that rain water is relatively clean and contains mostly minor impurities.

Conclusions

From the work presented so far, the following conclusions can be drawn:

1. Numbers from 3rd degree polynomials have been generated for the purpose of rainwater collector design. The numbers have been successfully converted to lines which were used to obtain 2D and 3D images thereby forming a water collector model.
2. The mobile rainwater collector has been successfully fabricated and assembled;
3. The system has been successfully tested and proved to be capable of collecting rain water both direct and indirect.
4. The solar-power system is capable of running the UV sterilizer for water purification;
5. The collected rain water was relatively clean with low risks of bacteria like coliforms and E. coli.
6. The UV sterilizer has successfully neutralised all colony forming units.

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