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About the Journal

The Journal of Digital Food, Energy & Water Systems (JD-FEWS) is a peer reviewed bi-annual publication that publishes recent and innovative deployment of emerging digital technologies in Food, Energy and Water Systems. Food, energy and water resources are interconnected scarce resources that require systems and technologies that will foster their sustainable management and effective utilization. The journal is also interested in articles that explore the nexus between at least two of these resources. The journal considers the following topics as long as they are deployed in the Food, Energy & Water space:

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- Data mining & Big data
- Human-Computer Interaction
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- Machine Learning
- Mathematical Optimization
- Robotics
- System architectures
- Wireless Sensor Networks

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Design and Implementation of a Quadcopter Based on a Linear Quadratic Regulator (LQR)

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Abstract—The Unmanned Aerial Vehicle (UAV) industry is growing at an unprecedented rated with the emergence of many critical and exciting applications. This growth is also followed by a number of quality requirements including stability and accuracy of trajectory during navigation. This paper presents the design and construction of a quadcopter using robust control strategy with promising stability and accuracy. The frame of the drone was designed using CadDian Software and the parts were printed using a 3D printer. The flight controller was based on Arduino board with GSM, GPS and GPRS boards for sending data over the internet and also enhancing long range flight. A feedback control system based on Linear Quadratic Regulator (LQR) was developed and tested to control the stability of drone. The proposed control strategy of the drone was assessed for a case of trajectory tracking and also for stability of navigation. The findings were positive confirming the appropriateness of the control measures for independent and autonomous flying with promising precision. This UAV fitted with IoT has the capability of collecting and sending data over the internet and therefore can be used in many applications that required data exchange. The developed quadcopter demonstrated superiority in terms of stability and tracking accuracy over counterpart UAVs controlled with PID techniques.

Keywords—Unmanned Aerial Vehicle (UAV), Linear Quadratic Regulator (LQR), PID, stability, accuracy, 3D printing, CadDian, IoT.

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1 Introduction

Over the last decades, Unmanned Aerial Systems (UASs) have gained much attention due to their various applications in medicine, mining, agriculture, surveying [1]–[6]. Drones are a form of UAV that are most often remotely controlled and without humans on board. The principle of drones dates back to the 1940s during World War II. However, over the years it has undergone monumental changes owing to the miniaturization and discovery of advanced electronic components. Even with a general principle relatively easy to understand, the design of drones is rather a complex task requiring skills in many areas such as aerodynamics, electronics, computing and wireless transmission [7]–[9].

Drones were initially developed for military applications, but are now accessible to civilians with a growing number of applications. Although these UAVs have not yet gained widespread use, they are gradually being used in the production of video contents, recording of events etc. Drones have the potential to increase tourism which contribute to socio-cultural development of countries. In addition to recreational applications, drones have a significant development potential in sectors such as agriculture, supervision of power lines, supervision of borders, cartography, security, etc [10]–[13]. In agriculture for instance, drone technology can be used to spread fertilizers, water and monitor crops, and estimate production throughout a season etc. In topography, drones provide new means of mapping plots by aerial photography and facilitate the division of land. Drones are also increasingly used in security of territory and surveillance of sensitive sites.

The main scientific challenge with the conception of drones lies in the complexity of their design, dynamic behavior, speed of response to command and stability during navigation [14]. Even though most of the existing control techniques for drones used simple control techniques including PID controllers, recent advances in technology have brought some robust control strategies with improved results in term of accuracy to follow a given trajectory, stability and speed of response.

This paper demonstrates a new design of UAV based on an artificial intelligence programmed in an Arduino board connected with GPRS and GSM modules. The paper innovatively presents a feedback control system to improve upon the stability of the drone in the air. The control system was based on Linear Quadratic Regulator (LQR) which derives its source from control theory and machine learning. Various parts of the drone were equally designed with the CadDian Software and printed with 3D printer.

2 Literature Review

A study of the literature reveals that emerging issues regarding autonomous navigation has to do with accurate positioning and mapping issues. [15] adopted the "Network-based Real-time Kinematic (NRTK) system" which has been extensively used in other fields including agriculture and surveying to improve upon accurate positioning of drone. The accuracy was mainly limited due to ionospheric conditions in the close environment. [16] worked intensively on the mapping aspect by conducting a survey with drone and assessing the accuracy of different models based on ground control point (GCP) system. Drone stability can also be investigated from a structural perspective [17].

Moreover, stability of UAV is highly dependent on the availability of GPS. In the absence of GPS, UAV stability is highly challenged. There have been a number of studies considering the design of wide area network that can extend over hundred meters with low power consumption to overcome the reliance on GPS [16]. However, the limitations in battery capacity and payload which are necessary for effective operations are highly challenging. Modular design are being considered to reduce the power consumption and sustain the battery capacity for a longer period [18].

Several command strategies have been used previously to control drones. These strategies range from the classic control strategy such as Proportional, Integral, and Derivative (PID) to more advanced control strategies qualified as robust and intelligent control strategies.

The PID control was one of the first methods used to control quadcopter drones. There have been extensive simulation works done to model a quadcopter drone and control it with PID controllers using MATLAB software and its SIMULINK extension. The PID control yielded satisfactory results in controlling the trajectory of drone. In addition, considering the experimental conditions in [19], it can be argued that PID control strategy is sufficient to pilot a quadcopter in environment with little disturbances. However, PID controllers do not overcome the stability challenges in presence of sustained and pronounced disturbances.

In some cases, PID tuning has been combined with Raspberry Pi 3 to control the stability of drone but this still has limited performances under dynamic environmental conditions. An existing approach used to enhance the capability of this control system is to add ANFIS (adaptive neuro-fuzzy inference system) to the PID, so as to make the control system more robust. In [20], for instance the stability of drone was enhanced with the combined ANFIS-PID tuning and yielded improved results than the PID only, although, the stability problem under dynamic environment was still not completely resolved. These findings are similar to [21] that considered a number of newly integrated strategies to augment drone stability.

Robust and optimal control algorithms are generally stronger in determining the right trajectory for a drone to follow while optimizing resources. Thus in [19], [22], the control strategies adopted LQR (Linear Quadratic Regulator) and LQG (Linear Quadratic Gaussian) which resulted in improved performances.

Nevertheless, in the presence of strong disturbances, the performance of these controllers is also considerably degraded. [23]–[25] developed robust adaptive controllers based on linear and nonlinear models of quadrotor. Their proposed technique can

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handle different types of uncertainties, such as external forces and modeling errors using Lyapunov energy function. [24], [26], [27] applied the Non-linear Model Predictive Control (NMPC) technique which is an optimal control method used to solve the trajectory determination problem and resulted in better-quality results.

The modelling of the movement of solid object like drone in space is governed by two main modeling methods. The major difference between the two methods is in the representation of the orientation of the system in three-dimensional space. The first way, more intuitive and easier to visualize, uses Euler and yaw angles while the second, a little more difficult to comprehend, uses quaternions which are hyper-complex numbers with three imaginary parts.

Any system based on a representation by the Euler angles inherits a singularity problem called “Gimbal Lock” [9]. A Gimbal is considered to be a ring that can actually be suspended to rotate about an axis. When nested one within another, Gimbals can accommodate rotation about many axes. The term Gimbal Lock simply mean a loss of one degree of freedom in a three-dimensional space. This occurs as a result of two axes being driven into a parallel configuration forcing the system to behave as if it was a two-dimensional one. This Gimbal Lock is quickly encountered when the determination of angles is based on trigonometric equations. This singularity problem reduces the performance of drone; For instance, if there is a sudden need to inverse flight trajectory, the model based solely on Euler's angles is unable to accurately represent the attitude of the drone.

On the other hand, a quaternion-based attitude representation provides a more complete description of the orientation of drone without having to deal with Euler's angle singularity problem. For vehicles that achieve attitudes greater than about 5 degrees in pitch or roll, the use of many trigonometric functions is necessary with Euler angles. This use of the trigonometric functions is expensive in terms of calculation time and could potentially slow down the speed of the control loop in the drone. Approximate small angles can be used together with the Euler angles for attitudes below 5 degrees, but this severely limits the capabilities of the quadrotor [28].

Additionally, the use of quaternions requires a single trigonometric function only when a non-zero yaw angle is included in the desired orientation. Otherwise, the operations on quaternions are only algebraic and therefore inexpensive in computing time. The main advantage of Euler angles over quaternions is their ease of visualization. With a pitch, roll and yaw angle, it is much easier to visualize the orientation of the drone than with a quaternion.

Contributions of the Study

The contributions of this paper are listed below:

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1) The study designed and constructed the part of the drone using 3D printer and also assembled the overall drone;
2) This study adopted the use of quaternions to model the three dimensional dynamic control of quadcopter;
3) The study developed an innovative control algorithm based on LQR strategy to improve upon the stability and accuracy of the drone (the capability of following complex trajectories with high fidelity);
4) A set of Arduino, GSM, GPS and GPRS boards have been programmed together to implement the develop control strategy and tested on the constructed drone.

3 Methodology

This section presents the list of material used, the block diagram of the drone, the modelling and control of the drone stability.

3.1 Components

The list of components used to assemble the drone is presented in Table 1 below.

Table 1. List of Components

S/N	Name	Specifications
1	Arduino Board	ATMEGA328P
2	2.4Ghz Radio Transceiver	NRF24L01
3	GSM AND GPRS MODULE	SIM900
4	Battery	12volts 5000mAh Li-Po battery
5	Electronic Speed Controller	4 x 15A/30A E300 OPTO ESCs
6	GPS Module	GPS/Compass Module with Mount
7	4 x Propellers	Gemfan 1045(CW+CCW) Black Propeller
8	Telemetry	3DR Telemetry

3.2 Diagram of Electronic Section of the Drone

Figure 1 shows the diagram of electronic section of the drone. It comprises of an Arduino board which acts as the brain of the system and it is interconnected to a number of modules including GPS module, GSM module and GPRS modules in addition to a set of four brushless motor needed to control the movement of the drone.

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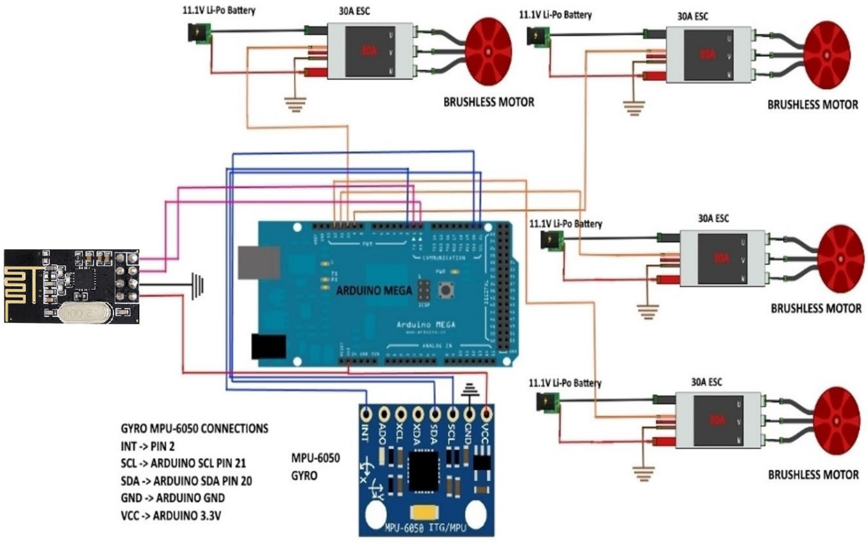

Fig. 1. Diagram of the electronic section of the drone

3.3 Modelling and Control of the Quadcopter

A quaternion is an extension of complex number representation that provides a convenient mathematical notation for representing orientations and rotations of objects in three dimensions. The positions of the drone in the space has been modelled in this study with quaternions. The model of a quadcopter using Newton-Euler equations with quaternions is described as follows:

$$\dot{x} = \frac{d}{dt}\begin{bmatrix} p \\ \dot{p} \\ q \\ \omega \end{bmatrix} = \begin{bmatrix} \dot{p} \\ q \circ \frac{F_{th}}{m} \circ \bar{q} + g \\ \frac{1}{2} q \circ \omega \\ J^{-1}\left(\tau + G_a - \omega \wedge J \cdot \omega\right) \end{bmatrix} \tag{1}$$

Where $p \in \mathbb{R}^3$ *and* $\dot{p} \in \mathbb{R}^3$ are the position and velocity vectors with respect to the inertial frame, $F_{th} \in \mathbb{R}^3$ defines the thrust vector generated by the Quadcopter;

Parameters m *and* $g \in \mathbb{R}^3$ represents the vehicle mass and gravity vector respectively, q describes the quaternion that represents the vehicle orientation with respect to the inertial frame, $\omega \in \mathbb{R}^3$ denotes the angular velocity of the Quadcopter with respect to the body-fixed frame, $J \in \mathbb{R}^{3\times 3}$ represents the multi-copter moment of inertia, $\tau \triangleq [\tau_x, \tau_t, \tau_z]^T$ represents the moments generated by the propellers in the body axes and $G_a \in \mathbb{R}^3$ represents the gyroscopic torques

The relationships between the inputs and the propellers angular velocity is described as follows:

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$$\begin{bmatrix} \tau_x \\ \tau_y \\ \tau_z \\ F_{th} \\ G_a \end{bmatrix} = \begin{bmatrix} l\frac{\sqrt{2}}{2}\ (k_1\overline{\omega}_1^2 - k_2\overline{\omega}_2^2 - \ k_3\overline{\omega}_3^2 + k_4\overline{\omega}_4^2) \\ l\frac{\sqrt{2}}{2}\ (-k_1\overline{\omega}_1^2 - k_2\overline{\omega}_2^2 - \ k_3\overline{\omega}_3^2 + k_4\overline{\omega}_4^2) \\ \sum_{i=1}^{4} (-1)^i\ (d_i\overline{\omega}_i^2) \\ \sum_{i=1}^{4}\ k_i\overline{\omega}_i \\ \sum_{i=1}^{4} J_{RP}\ (\omega \wedge e_3)\ (-1)^{i+1}\ \overline{\omega}_i \end{bmatrix} \tag{2}$$

Where the coefficient k_i and d_i are respectively the coefficient of thrust and the drag of the propeller $i, \overline{\omega}$ its angular velocity, l the lengh of the Quadcopter's arm (from the center of mass to the motor axis of action), $e_3 \triangleq [0, 0, 1]^T$ the axis around which the gyroscopic torque is acting and J_{RP}, the total moments of inertia of the entire rotor and the propeller about their axis of rotation.

The control scheme is divided in two control loops; the inner and the outer loop controller. The inner loop is the attitude controller, which is used to control the pitch, roll and yaw angle. The outer loop is designed to control the trajectory (x, y and z) of the quadcopter in the earth frame. A summary of the feedback control system is depicted in Figure 2.

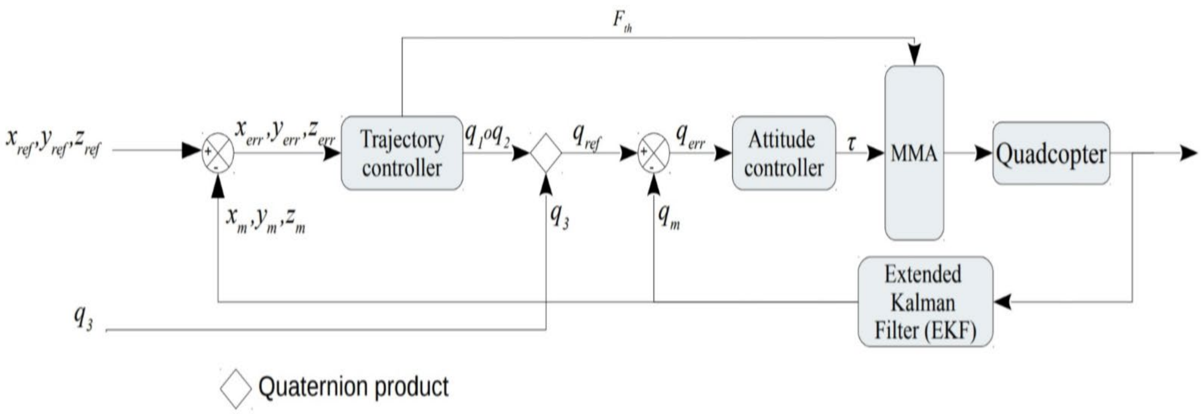

Fig. 2. Proposed Feedback Control System for Drone Stability

3.4 Assembly

Figure 3 below illustrates the different stages of the drone assembly.

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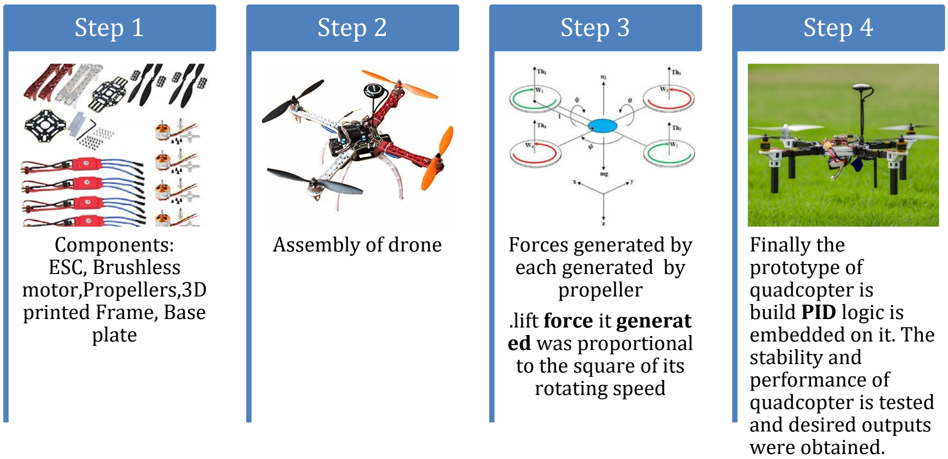

Fig. 3. Drone Assembly

4 Results

This section presents simulation results of the proposed control systems as illustrated in Figure 4. It further covers results on the 3D printing and the operation of the assembled drone.

Figure 4 has the shape of a linear time invariant, first order systems with interesting parameters. The settling time seems much reduced indicating a short transient regime while the maximum overshoot is merely negligible. There are sustained oscillations in permanent regime, however they have been sufficiently damped.

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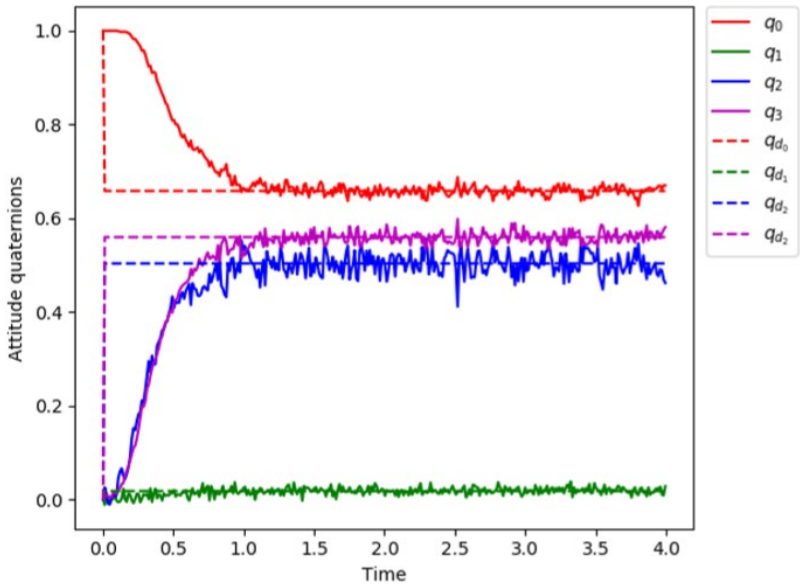

Fig. 4. Control system output on the altitude stability

Figure 5 shows the 3D printing of various parts of the drone while Figure 6 illustrates the constructed drone in a flight mode.

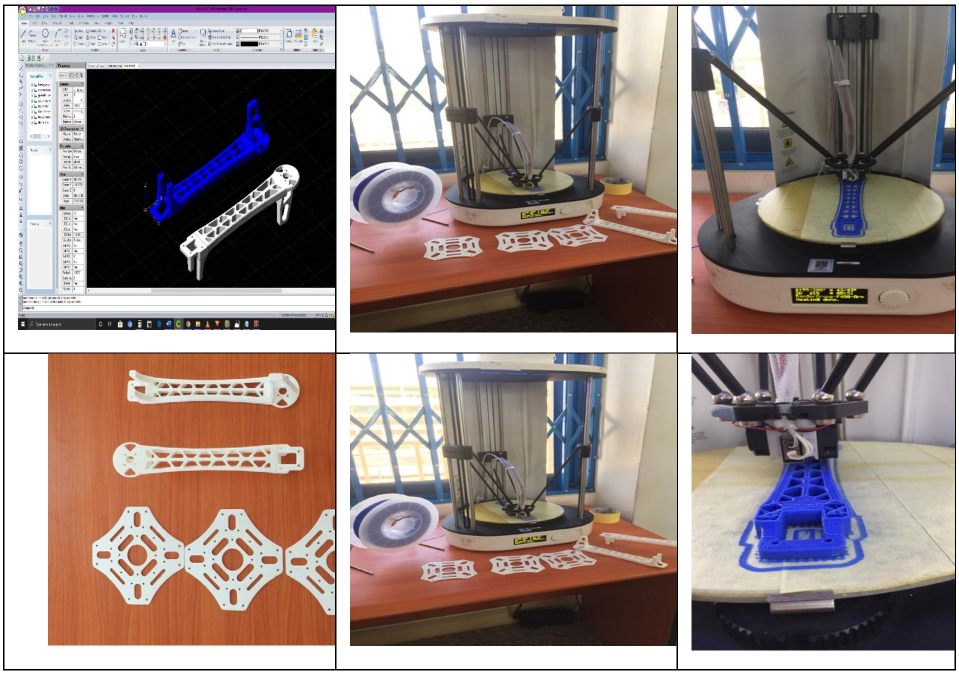

Fig. 5. 3D printing of drone's part

Figure 6 illustrates the constructed drone in operation.

Fig. 6. Pictorial view of the constructed drone

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Additionally, the main advantage of a position controller is to follow defined trajectories with accuracy. To assess this functionality on our proposed control strategy in this paper, this section considers as trajectory, a circle of diameter 7 m and this to be covered in 8 s as well as a rotation of the drone on itself equivalent to 1 revolution in 8 s all at a distance of 7 m from the ground. The commands to be sent to the system over time are expressed as follows:

$$x_{ref} = 7sin\left(\frac{2\pi}{8}t\right) \tag{3}$$

$$y_{ref} = 7cos\left(\frac{2\pi}{8}t\right) \tag{4}$$

$$z_{ref} = 7 \tag{5}$$

$$\varphi = \frac{380}{8}t \tag{6}$$

Figure 7 shows the trajectories obtained for these commands and the desired trajectories for a simulation made over 15 s. Figure 7a shows the evolution of the position in a 3D space. In this same Figure, the dotted blue graph represents the reference trajectory and the red graph represents the trajectory made by the drone. Considering the fact that a rotation of the drone on itself was requested during the same simulation, Figure 7b displays the evolution of the orientation of the drone over time. The dotted curves represent the desired evolution of each component of the quadrotor describing the orientation and the second curve in solid line represents the orientation obtained.

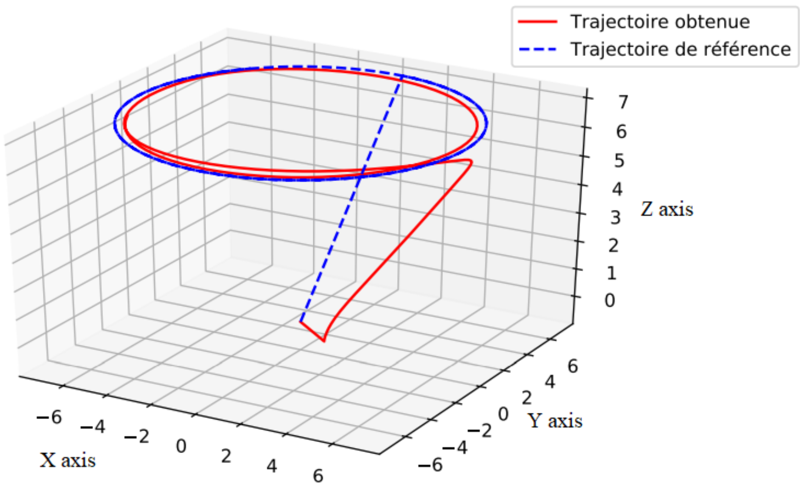

Fig. 7a. Trajectory tracking

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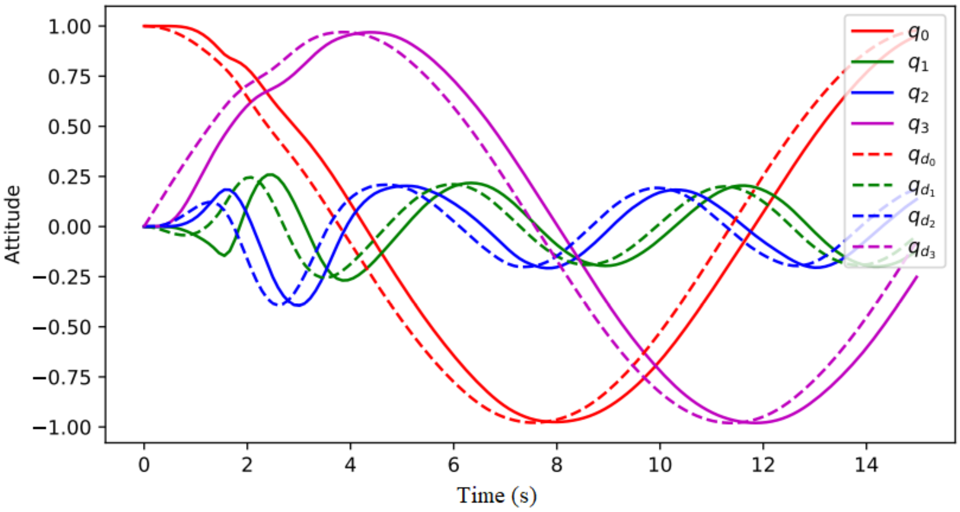

Fig. 7b. Orientation tracking

It is remarkable from Figures 7a and 7b above that the drone is able to follow a Complex trajectory without with negligible deviation. The accuracy of the proposed control strategy is therefore commendable and the controller can thus be recommended for autonomous flying. These findings corroborate previous studies in the same line including [7], [9], [19], [22], [24], [26], [27], [29]–[31].

5 Conclusion

In summary, this paper presents the design and construction of drone. The parts of the drone were designed with the CadDian Software and printed using a 3D printer. The parts were further assembled and the control system for the drone covering its stability and tracking of trajectory, was designed with feedback control system using a Linear Quadratic Regulator that was implemented on an Arduino board. Findings revealed that the drone demonstrated a great stability during navigation. The drone was further tested for tracking of arbitrary trajectory and also was equally proved to be accurate, and reliable in this regard. The constructed drone has the advantage to cover large distances and communicate data in real-time.

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Fuzzy Axiomatic Approach to Blue-green Infrastructure Strategy Selection: A Sustainability Perspective

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Abstract— Flood risk management (FRM) is a global problem that has received significant attention from scholars. Their interest is on the minimisation of flood occurrence and its aftermath. This study uses FRM sustainability criteria to contribute a framework to the interest mentioned above. It designed the framework for a blue-green technology selection using a best-worst method, fuzzy axiomatic method and VIKOR method. Data from Lekki, Lagos, Nigeria, was used to test this framework applicability. Six blue-green technologies, which include bypass floodway, rainwater and floodwater harvesting, and porous pavement, were considered as potential technology for the case study. From the framework implementation results, this study observed that techno-economic criteria contributed about 88.18% to the ranking of blue-green technology. The framework identified rainwater and floodwater harvesting as the most suitable blue-green technologies for a community. It also identified a bypass floodway as the least suitable blue-green technologies for a community. With these results, the proposed framework will aid decision-makers strategic and tactical criteria that can be used to evaluate blue-green technology selection.
Keywords— Flood, multi-criteria, blue-green technology, sustainability, fuzzy logic.

1 Introduction

As the earth experiences climate change, stakeholders have organised several fora on how to handle the effect of this change effectively. Flood and drought are among the aftermath of this change. Scholars have reported that flood destroys several communities annually, especially in developing countries with urban plans [1], [2]. One of the recommendations of scholars is the use of a sustainability approach to arrest this problem [3], [4]. The issue of flood management should not be considered as an engineering problem [4]. It requires a multi-disciplinary approach to harness the contributions from other disciplines during flooding management. For instance, the decision on appropriate blue-green technology for flood-prone areas can be solved from a multi-disciplinary perspective.

This perspective is desired because of the need to find a sustainable solution to flooding. It is, therefore, the responsibility of stakeholders to include sustainability into consideration when such a solution is recommended. Sustainability - which is the analysis of technical, social, economic and environmental requirements of a system - helps to cater to the present and future needs of different generations. The criteria that constitute sustainability requirements are system dependent. Hence, decision-makers are required to carry out a preliminary analysis of these requirements and present them in a framework to stakeholders – investors, government, and public. Since some of the criteria in a sustainable framework can only be expressed in linguistic forms, it is the duty of decision-makers to make their findings as simple as possible to the stakeholders. To create a simplified framework that embeds sustainability requirements, scholars have accepted multi-criteria modelling approaches as being robust for this purpose.

Multi-criteria decision-making (MCDM) tools combine a system's requirements to determine the best course of action. Examples of MCDM tools are VIKOR, TOPSIS, and axiomatic method, just to mention a few. Their applications involve careful planning of system requirements to generate practical solutions for real-world problems. Currently, research domains such as energy, maintenance, and supply chain management have established fundamental elements that constitute system requirements for the design of MCDM frameworks for domains mentioned above [5]. Unfortunately, scholars in flood risk management (FRM) domain are yet proposed a framework that contains sustainability requirements. This study aims to use stakeholders' perspectives requirements to develop a sustainability framework for FRM. In the framework, the socio-economic requirements of a community were considered [2]. Apart from these needs, this study considered the technical, environmental, and policy requirements for blue-green technology adoption. Three MCDM tools were used to combine the requirements mentioned above synergically. The framework determines sub-criteria importance using a best-worst method. A fuzzy axiomatic method was used to relate design requirements with system requirements for alternative solutions to blue-green technology adoption. VIKOR was used to combine the sustainability criteria to determine the most suitable blue-green technology for a system.

2. Flood Risk Management

FRM is an activity that deals with flood preparation, prevention and mitigation, just to mention a few [6]. Because of the importance of FRM to human survival, several studies have been published on FRM[1], [7]–[9]. For example, [9] stated that the justification for selecting a flood risk strategy could be improved when information on flood-risk design is combined with a decision-making model for FRM. [10] presented a methodology for household vulnerability assessment to flood. Their work considered the damages caused by flood to property, water contamination, physical and mental impairments, and exposure to hazard. [7] noted that while pushing for a flood strategy, there is a need to incorporate the issue of landscape quality to protect cultural heritage, and to account for the spatial and building requirements of a community.

To deploy an FRM strategy, the contributions of stakeholders are required. When their contributions are considered, it will not only address the immediate need for flood control; it will also sustain the environment for the next generation [11]. To improve the FRM decision-making process, [12] presented a framework that aggregates social requirements, such as household vulnerability, to flood management. Beyond such requirements, it is equally essential that a decision support system for FRM contains economic, technical, and environmental requirements. This consideration is suitable for long-term analysis of flood control [13]. Another critical issue in the design of an FRM strategy is uncertainty consideration.

The uncertainty in an FRM strategy can be understood by classifying a model as a preventive or mitigation model [14]. This classification improves how an FRM model adjusts to the emerging needs of communities [2]. Scholars have used different approaches to solve this problem. For instance, [15] used a hydraulic modelling approach to evaluate policies for FRM. They generated flood risk maps using used a regular levee system. The generated maps showed that the non-structural method reduces the damages caused by a flood. Apart from policy uncertainty, financing an FRM strategy introduces uncertainty into flood management [16]. It is, therefore, imperative that government policies and the socio-economic needs of a community are understood before settling for any FRM strategy. This issue can be addressed by using stakeholders inputs to design an FRM programme [2], [17].

Since stakeholders' inputs increase the dynamics of FRM, scholars need to understand a community's evolving social and physical needs. Hence, attention must be given to the relationship between policy-makers' expectations and human behaviours [8]. This is because robust flood management depends on a community's socio-economic and environmental needs, as well as its flood policy [17]. There are several aspects of this relationship that should be considered as scholars seek a robust FRM strategy for a community. First, governments should continuously evaluate the effectiveness of water channels and storage systems, and flood warning and evacuation systems. The evaluation process should cover the techno-economic considerations of these systems [18]. Second, insurance policy needs to be provided for people living in flood-prone areas [17]. Third, more emphasis should be given to the non-structural measures of FRM over the structural measures [2].

From the forthgoing, three facts emerged from the literature. FRM problem is a multi-criteria problem, and analysis on this problem must include the socio-economic benefits for adopting a strategy. Stakeholders' inputs are essential to the success of an FRM strategy. Uncertainty must be considered when selecting an FRM strategy for a community. Motivated by these findings, the current study presents a framework that used the facts as mentioned above to design a decision-making tool for blue-green technology selection for developing countries.

3. Methodology

This study considered the FRM problem as a decision-making problem because there is often a conflict of interest among stakeholders that constitute a team for an FRM strategy adoption [19]. Hence, it uses multi-criteria tools to address the blue-green technology problem. Figure 1 illustrates the relationships between the different MCDM tools in this work. Because of the difficulty of using a quantitative approach to select flood management strategy, this study considers qualitative information for the current problem analysis.

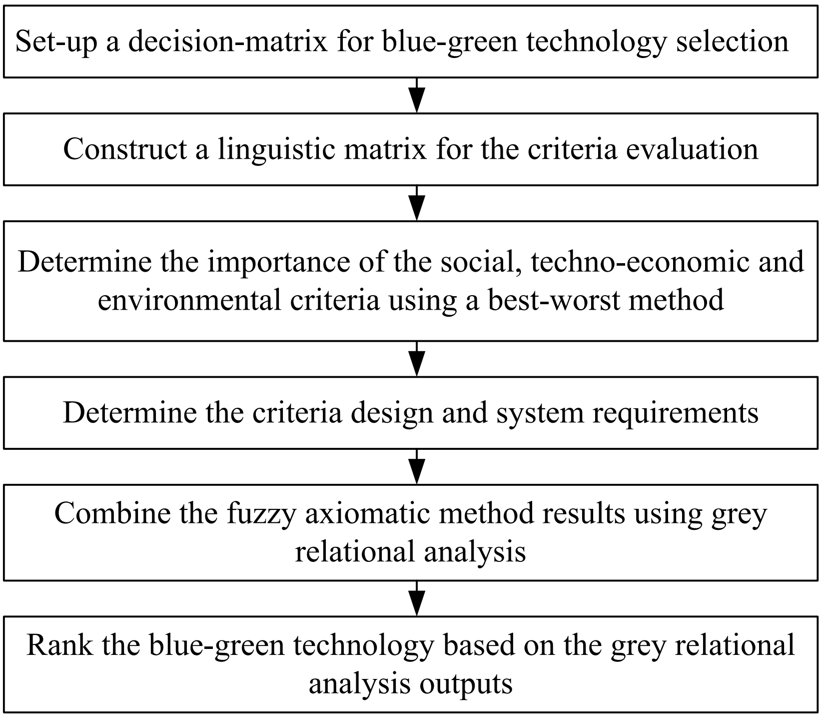

Fig. 1. Schematic flow of the proposed methodology

3.1 Best worst method

This study addresses the problem of optimal weight determination for criteria using a best-worst method. The method uses sets of non-linear equations to determine criteria importance. It synchronises experts' judgments through non-linear equations. The equations are organised in a way that the distance between the best and worst criteria are optimised for all sub-criteria [20]; this makes the best-worst method a unique method for criteria importance evaluation. Furthermore, this attribute gives it an edge over an analytical hierarchy process [21]. The steps for implementing a grey best worst method are expressed as follows [22]:

Step 1: Select the criteria for the blue-green technology evaluation.

Step 2: Determine a scale for the socio-economic, technical, and environmental criteria evaluation.

Step 3: Constitute a panel of experts that will evaluate the criteria importance.

Step 4: Determine the best (Equation 1) and worst (Equation 2) criteria.

Error! Bookmark not defined. $A_B = \{a_{B1}, a_{B2}, a_{B3}, \ldots, a_{Bn}\}$ (1)

$$A_W = \{a_{1W}, a_{2W}, a_{3W}, \ldots, a_{nW}\} \tag{2}$$

where A_B and A_W denote the vector of the best and worst criteria for a decision-making process, respectively.

Step 5: Construct a pairwise comparison of the criteria, starting from the best criterion to other criteria in decreasing order.

Step 6: Use Equations (3) to (7) to determine the criteria importance.

$$Min\ \xi \tag{3}$$

s.t.

$$\left|\frac{w_B}{w_i} - a_{Bi}\right| \leq \xi \tag{4}$$

$$\left|\frac{w_i}{w_B} - a_{wi}\right| \leq \xi \tag{5}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{6}$$

$$0 \leq w_i \leq 1 \qquad i = 1,2,3,\ldots n \tag{7}$$

Where w_i denotes criterion i weight.

3.2 Fuzzy axiomatic method

Axiomatic method is a multi-criteria approach that incorporates design requirements into a decision-making process. It uses information content to rank alternatives based on the relationship between design and system requirements. Because of the uniqueness of this method, scholars have used fuzzy logic to increase its application [23]. Its fuzzy version uses fuzzy numbers to convert linguistic terms to crisp values using either triangular or trapezoidal fuzzy numbers. The steps below give a summarised description of a weighted fuzzy axiomatic method:

Step 1: Identify alternative solutions to a decision-making process.

Step 2: Select the criteria for the evaluation process and state linguistic terms for the criteria. Also, select an appropriate method for the criteria importance evaluation.

Step 3: Identify experts that will evaluate the identified alternatives in step 1.

Step 4: Define the criteria's design requirements using the use of the experts' judgements.

Step 5: Aggregate the experts' judgement using an appropriate method. The current study used [24] aggregation expressions in Equations (8) to (11) to aggregate experts' judgements and [23] weighted expression for trapezoidal fuzzy numbers to generate the weighted aggregated values for functional requirements (Equation 12).

$$l_i = \min\{(l_{ik})\} \tag{8}$$

$$m_i^2 = \frac{1}{k}\sum_{k \in K} m_{ik}^1 \tag{9}$$

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$$m_i^2 = \frac{1}{k} \sum_{k \in K} m_{ik}^2 \tag{10}$$

$$u_i = \max\{(u_{ik})\} \tag{11}$$

$$fr_i = ((l_i + (m_{1i} - l_i) \times w_i), m_{1i}, m_{2i}, (u_i + (u_i - m_{2i}) \times w_i)) \tag{12}$$

Step 6: Evaluate the alternatives common areas using Equation (13). This area is the triangle created by the intersection between a system and design requirements (Figure 2).

$$CR = \frac{(\delta_2 - \alpha_1)^2}{2(\delta_2 - \beta_2 + \beta_1 - \alpha_1)} \tag{13}$$

Step 7: Compute the alternatives' system requirements using Equation (14).

$$SR = \frac{\tau_1 \delta_1 + \frac{1}{3}(\tau_1 + \delta_1)^2 + \beta_1 \alpha_1 + \frac{1}{3}(\beta_1 + \alpha_1)^2}{\tau_1 + \delta_1 - \beta_1 - \alpha_1} \tag{14}$$

Step 8: Calculate the alternatives' chance of meeting the design requirements using Equation (15)

$$p_{ij} = \frac{CR}{SR} \tag{15}$$

Step 9: Compute the criteria information contents using Equation (16) and the alternatives' total information content using Equation (17).

$$I_{ij} = \log_2\left(\frac{1}{p_{ij}}\right) \tag{16}$$

$$A_i = \sum_{j=1}^{n} I_{ij} \tag{17}$$

Step 10: Rank the alternative based on the lowest total information content, the better the alternative.

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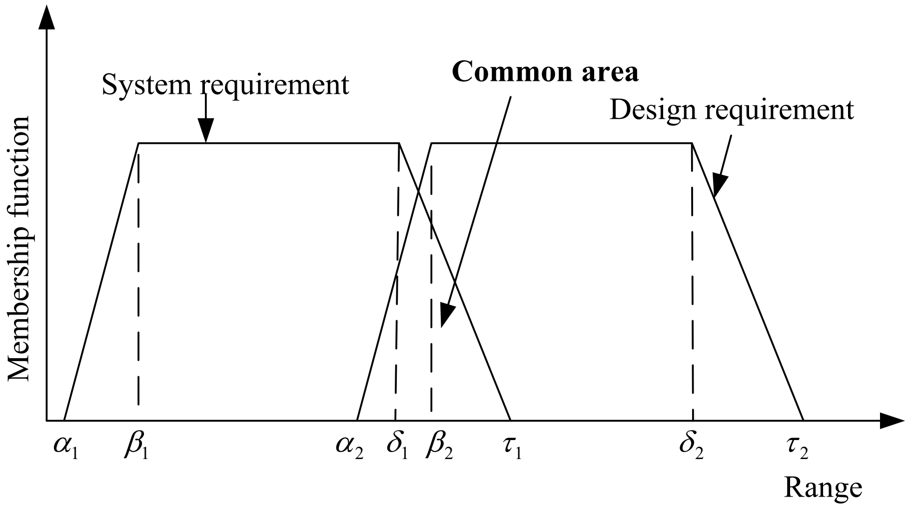

Fig. 2. Common area between a design and a system requirement

3.3 Grey relational analysis

The steps below outlines the procedure for this method application [25], [26]:

Step 1: Construct a decision-matrix for a MCDM problem (Equation 18)

$$D = \begin{bmatrix} r_{11} & r_{12},\ldots, & r_{1m} \\ r_{21} & r_{22},\ldots, & r_{2m} \\ r_{n1} & r_{n2},\ldots, & r_{nm} \end{bmatrix} \quad (18)$$

Step 2: Normalise the information in the matrix. Criteria which are benefit-oriented are normalised with Equation (19), while Equation (20) is used to normalised criteria which are cost-oriented.

$$x_i(k) = \frac{r_i(k) - r_i^{\min}}{r_i^{\max} + r_i^{\min}} \quad (19)$$

$$x_i(k) = \frac{r_i^{\max} - r_i(k)}{r_i^{\max} + r_i^{\min}} \quad (20)$$

where $x_i(k)$ and $r_i(k)$ denote the normalised and real values for criteria k for alternative i, $r_i^{\max}$ and $r_i^{\max}$ denote the maximum and minimum values of criterion k.

Step 3: Specific an ideal sequence $(x_0(k))$ for the evaluation process.

Step 4: Evaluate the deviation of the normalised decision matrix from the specified ideal sequence. The process requires that an identification coefficient value be defined for the evaluation process.

$$\xi_i(k) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{o,i}(k) + \xi\Delta_{\max}} \tag{21}$$

$$\Delta_{o,i}(k) = \left\| x_o(k) - x_i(k) \right\| \tag{22}$$

$$\Delta_{\min} = \min_{\forall i} \min_{\forall k} \left\| x_o(k) - x_i(k) \right\| \tag{23}$$

$$\Delta_{\max} = \max_{\forall i} \max_{\forall k} \left\| x_o(k) - x_i(k) \right\| \tag{24}$$

Step 5: Determine the alternatives' grey relational grade by combining the grey relational coefficients with criteria importance (Equation 25).

$$\gamma(k) = \frac{1}{n}\sum_{i=1}^{n} w_i \xi_i(k) \tag{25}$$

Step 6: Rank the alternatives using a higher-the-better approach.

4. Case Study

Lekki, a community in Lagos, Nigeria, was used as a case study. This community, which was designed as a blue-green city, has about 3.4 and 1.9 million for residential and non-residential people, respectively. Its large population is because it is a free trade zone. Dangote oil refinery is among the multi-billion-dollar project in this community. Its annual temperature is about 3.3°C annual, while its maximum monthly rainfall is 91.6 mm. This location's geographical coordinates are 6° 25' 0" North and 4° 6' 0" East (Figure 3). This community has been transformed from a rural community to an urban community. However, the poor implementation of its urban development plan has made it to become a flood-prone community. This problem is affecting its commercial activities, such as fishing and tourism.

During the implementation of the proposed framework (Figure 1), this study considered six blue-green technologies (Table 1). These technologies were evaluated based on the criteria in Table 2. This study used a well-structured questionnaire to obtain information for the evaluation process [27], [28]. The questionnaire has two sections. Information about the criteria importance is contained in the first section; blue-green technologies information is contained in the second section. Three of the decision-makers, i.e., experts, were selected from academics and industry. These experts' minimum working experience and qualifications are eight years and a masters' degree in civil and environmental engineering. Their contributions to the evaluation process are 0.2 for Expert 1 (E1), 0.3 for Expert 2 (E2), and 0.5 for Expert 3 (E3) [29]. The experts were asked to evaluate the criteria importance based on the linguistic variables in Table 3.

Fig. 3. Lekki spatial location [30]

Table 1. Selected blue-green technology

Blue-green Technology	Description
Rainwater and floodwater harvesting (A_1)	This technology harvests runoff waters for agriculture purposes.
Pumped hydropower systems (A_2)	This technology uses flood water stored in a reservoir to generate hydropower.
Transport basin (A_3)	This technology is used to manage stormwater runoff. It has the capacity to prevent improve water quality in an area.
Porous pavement (A_4)	This technology uses a porous pavement to manage stormwater.
Retention lake (A_5)	This technology uses an artificial pond to prevent downstream erosion and flooding.
Bypass floodway (A_6)	This technology uses a sizeable man-made channel to control excess flood waters.

Table 2. Evaluation criteria

Criteria	**Description**
Economic criteria	
Investment cost (C_{11})	This criterion measures the cost that will be incurred in order to purchase a blue-green technology for a community [31].
Operation and maintenance cost (C_{12})	This criterion measures the running expenses that will be incurred in order to provide acceptance flood management service to a community [31].
Ease of partnership funding (C_{13})	This criterion measures the ease of getting a public-private partnership that will be used to execute a blue-green technology in a community (Experts).
Implementation cost (C_{14})	This criterion measures the cost of implementing a selected blue-green technology in a community [7].
Environmental	
Adaptability to climate change (C_{21})	This criterion measures the ease of incorporating a blue-green technology into the climate change policy of a community [4].
Land use (C_{22})	This criterion evaluates looks that the impact of a blue-green strategy at it affects the use of land for other productive use (Yazdandoost and Bozorgy, 2008)
Air quality improvement (C_{23})	This criterion looks at the impact of a blue-green technology concerning its implications of air quality in an area (Experts).
Habitat connectivity (C_{24})	This criterion measures the impact of a blue-green technology as it affects the relationship among different habitats in a community (Experts).

Social	
Improvement in water quality (C_{31})	This criterion evaluates the impact of a blue-green technology on the provision of quality water for a community (Experts).
Public realm improvement (C_{32})	This criterion measures how a blue-green technology will affect areas that are allocated for public use [11].
Job generation (C_{33})	This criterion evaluates the opportunity opportunities that will be created based on a selected blue-green technology for a community (Experts).
Technology acceptability by the public (C_{34})	This criterion measures the level of acceptance that a blue-green technology will receive from the members of a community (Experts).
Technical (C4)	
Ease of integration into an urban plan (C_{41})	This criterion evaluates the ease at which a blue-green technology can be incorporated into an urban community plan (Experts).
Resistance (C_{42})	It denotes the capacity of a blue-green technology to prevent floods [31] [31].
Resilience(C_{43})	It denotes the capacity of the blue-green technology system to recover from floods [31].
Technological capacity and support (C_{44})	This criterion looks at the level of technical skills that are available for the implementation of a blue-green technology in a community (experts).
Sensitivity (C_{45})	The ability of technology to adapt to change in the operating condition of an environment; this criterion overs the robustness and flexibility of a technology [31].
Safety (C_{46})	This criterion measures how safe blue-green technology is when installed in a community [9].

The selected experts evaluated the criteria importance using the linguistic terms in Table 3 - their responses are presented in Table 4. This study developed four optimisation models. The first model was developed for the economic criteria evaluation, the second model was developed for the environmental criteria evaluation, the third model was developed for the social criteria evaluation, and the last model was developed for the technical criteria evaluation. The formulated models were solved using Microsoft excel solver (Table 5).

Table 3. Linguistic terms and their crisp values

Linguistic variable	Crisp value
Equal importance (EI)	1
Weak importance (WI)	3
Moderate importance (MI)	5
Strong importance (SI)	7
Very strong importance (VS)	9

Table 4. Linguistic variables for the blue-green technologies importance

	Economic criteria					
	C_{11}/C_{12}	C_{11}/C_{13}	C_{11}/C_{14}	C_{12}/C_{13}	C_{12}/C_{13}	C_{13}/C_{14}
E1	EI	MI	SI	SI	MI	SI
E2	VS	SI	VS	VS	VS	VS
E3	MI	MI	SI	SI	WI	SI
	C_{21}/C_{22}	C_{21}/C_{23}	C_{21}/C_{24}	C_{22}/C_{23}	C_{22}/C_{23}	C_{23}/C_{24}
E1	SI	MI	VS	VS	VS	SI
E2	VS	SI	VS	SI	VS	SI
E3	SI	SI	SI	VS	SI	SI
	C_{31}/C_{32}	C_{31}/C_{33}	C_{31}/C_{34}	C_{32}/C_{33}	C_{32}/C_{33}	C_{33}/C_{34}
E1	MI	SI	SI	MI	MI	MI
E2	MI	WI	WI	SI	WI	VSI
E3	MI	SI	MI	MI	MI	M1
	C_{41}/C_{42}	C_{41}/C_{43}	C_{41}/C_{44}	C_{41}/C_{45}	C_{41}/C_{46}	C_{42}/C_{43}
E1	SI	MI	MI	MI	VS	VS
E2	VS	SI	VS	SI	VS	VS
E3	VS	SI	VS	SI	SI	SI

	C_{42}/C_{44}	C_{42}/C_{45}	C_{42}/C_{46}	C_{43}/C_{44}	C_{43}/C_{45}	C_{43}/C_{46}
E1	SI	MI	VS	MI	SI	VS
E2	VS	VS	VI	SI	VS	VS
E3	MI	SI	SI	SI	MI	VS
	C_{44}/C_{45}	C_{44}/C_{45}	C_{45}/C_{46}			
E1	MI	VS	VS			
E2	VS	VS	VS			
E3	VS	SI	VS			

Table 5. Best worst method results

Economic	C_{11}	C_{12}	C_{13}	C_{14}		
0.6730	0.46	0.37	0.13	0.04		
Environmental	C_{31}	C_{32}	C_{33}	C_{34}		
0.0647	0.49	0.36	0.10	0.05		
Social	C_{41}	C_{42}	C_{43}	C_{44}		
0.0528	0.53	0.27	0.13	0.07		
Technical	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
0.2088	0.31	0.37	0.21	0.03	0.05	0.03

Table 6 presents the linguistic terms used to evaluate technology appropriateness for the case study. Using these terms, Table 7 shows the experts' rating of the technologies' appropriateness for the case study.

Table 6. Linguistic terms for the technologies evaluation

Benefit-based criterion		Cost-based criterion	
Linguistic terms	Trapezoidal fuzzy numbers	Linguistic terms	Trapezoidal fuzzy numbers
Very low	0.0, 0.1,0.2,0.3	Very low	0.6,0.7,0.8,0.9
Low	0.2,0.3,0.4,0.5	Low	0.4,0.5,0.6,0.7
High	0.4,0.5,0.6,0.7	High	0.2,0.3,0.4,0.5
Very high	0.6,0.7,0.8,0.9	Very high	0.0, 0.1,0.2,0.3

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Table 7. Linguistic values for the blue-green technologies

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
									E1									
A1	H	H	H	VH	VH	VH	H	H	VH	VH	L	H	VH	H	VH	H	H	VH
A2	VH	VH	H	VH	H	L	L	L	L	L	H	L	VH	H	H	H	VH	VH
A3	VH	VH	H	H	H	L	L	H	H	L	L	H	H	H	H	H	L	VH
A4	VL	H	L	H	H	H	H	L	H	H	L	H	VH	H	H	L	L	VH
A5	H	H	L	L	H	H	L	L	H	H	VL	L	VH	H	H	L	H	VH
A6	VH	L	H	L	H	L	VL	L	VH	H	L	L	VH	VH	VH	VH	L	VH
									E2									
A1	VH	H	L	VH	VH	VH	H	VH	H	H	VH	H	L	VH	H	VH	L	VH
A2	VH	VH	H	VH	H	H	H	VH	H	H	VH	H	H	H	L	H	VH	H
A3	VH	L	L	VH	VH	H	L	H	H	H	L	VH	H	H	H	H	L	H
A4	H	H	L	VH	L	H	L	H	L	VL	H	H	L	L	H	VH	H	L
A5	VH	H	L	VH	L	H	L	H	H	L	L	H	VL	L	VL	L	L	H
A6	H	L	H	H	H	VH	H	H	VH	VH	H	H	H	H	H	H	VL	H
									E3									
A1	H	H	VH	H	H	H	H	H	H	H	VH	H	VH	H	H	VH	H	VH
A2	VH	H	H	H	L	H	L	H	L	L	L	VH	H	H	H	H	L	H
A3	H	H	L	L	H	H	H	H	H	H	L	H	H	H	L	L	L	L
A4	L	H	L	L	L	L	L	L	H	L	VL	L	L	H	H	L	L	H
A5	H	L	VH	H	L	L	H	L	L	H	L	H	H	H	L	VH	H	L
A6	L	VH	L	L	H	H	L	H	L	H	L	VH	L	H	L	H	L	L

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Using Equations (8) to (11), the linguistic values in Table 7 were converted and aggregated into fuzzy values (Table 8). Equation (12) is used to generate the weighted aggregated values for the technologies' based on the information tables 5 and 8. Table 9 presents the results obtained for these values. This study used the concept of optimistic (a), pessimistic (m) and most likely design requirements (b) to generate the design requirements (Table 10). It considered Expert 1 has an optimist, Expert 2 has a realist, and Expert 3 has a pessimist.

$$DR = \frac{a + 4m + b}{6} \tag{26}$$

Equation (13) was used to generate the common requirements for the technologies using the information in tables 9 and 10. Furthermore, Equation (14) was used to compute the system requirements of the technologies. Table 11 presents the results for the technologies common and system requirements. Equation (15) was used to calculate the technologies' probabilities of meeting the design requirements. This study used Equation (16) to compute the technologies' information contents (Table 12).

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Table 8. Aggregated values of the technologies

	C_{11}	C_{12}	C_{13}	C_{14}		
A1	(0.00, 0.23, 0.33,0.50)	(0.20, 0.30, 0.40, 0.50)	(0.00, 0.37, 0.47, 0.90)	(0.00, 0.17, 0.27, 0.50)		
A2	(0.00, 0.10, 0.20, 0.30)	(0.00, 0.17, 0.27, 0.50)	(0.20,0.30,0.40, 0.50)	(0.00, 0.17, 0.27, 0.50)		
A3	(0.00, 0.17,0.27, 0.50)	(0.00,0.37,0.47,0.90)	(0.20,0.57,0.67,0.90)	(0.00, 0.37, 0.47, 0.90)		
A4	(0.20,0.43,0.53,0.90)	(0.20,0.30,0.40,0.50)	(0.60,0.70,0.80,0.90)	(0.00,0.37,0.47,0.90)		
A5	(0.00,0.23,0.33,0.50)	(0.20,0.43,0.53,0.90)	(0.00,0.50,0.60,0.90)	(0.00,0.37,0.47,0.90)		
A6	(0.00,0.37,0.47,0.90)	(0.00,0.50,0.60,0.90)	(0.20,0.43,0.53,0.90)	(0.20,0.57,0.67,0.90)		
	C_{21}	C_{22}	C_{23}	C_{24}		
A1	(0.40,0.63,0.73,0.90)	(0.40,0.63,0.73,0.90)	(0.40,0.50,0.60,0.70)	(0.40,0.57,0.67,0.90)		
A2	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)		
A3	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.40,0.50,0.60,0.70)		
A4	(0.20,0.37,0.47,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
A5	(0.20,0.37,0.47,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
A6	(0.40,0.50,0.60,0.70)	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.20,0.43,0.53,0.70)		
	C_{31}	C_{32}	C_{33}	C_{34}		
A1	(0.40,0.24,0.29,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.57,0.67,0.90)	(0.40,0.50,0.60,0.70)		
A2	(0.20,0.16,0.20,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)	(0.20,0.37,0.47,0.70)		
A3	(0.40,0.21,0.26,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.30,0.40,0.50)	(0.40,0.57,0.67,0.90)		
A4	(0.20,0.19,0.23,0.70)	(0.00,0.30,0.40,0.70)	(0.00,0.30,0.40,0.70)	(0.20,0.43,0.53,0.70)		
A5	(0.20,0.19,0.23,0.70)	(0.20,0.43,0.53,0.70)	(0.00,0.23,0.33,0.50)	(0.20,0.43,0.53,0.70)		
A6	(0.20,0.24,0.29,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
A1	(0.20,0.57,0.67,0.90)	(0.40,0.50,0.60,0.70)	(0.40,0.57,0.67,0.90)	(0.40,0.63,0.73,0.90)	(0.20,0.43,0.53,0.70)	(0.60,0.70,0.80,0.90)
A2	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.40,0.50,0.60,0.70)	(0.20,0.57,0.67,0.90)	(0.40,0.63,0.73,0.90)
A3	(0.40,0.50,0.60,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.30,0.40,0.50)	(0.20,0.57,0.67,0.90)
A4	(0.20,0.43,0.53,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.90)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)
A5	(0.00,0.47,0.57,0.90)	(0.20,0.43,0.53,0.70)	(0.00,0.33,0.43,0.70)	(0.20,0.43,0.53,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.57,0.67,0.90)
A6	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.90)	(0.20,0.57,0.67,0.90)

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Table 9. Weighted aggregated values of the technologies

	C_{11}	C_{12}	C_{13}	C_{14}
A1	(0.11,0.23,0.33,0.58)	(0.24,0.30,0.40,0.54)	(0.05,0.37,0.47,0.96)	(0.01,0.17,0.27,0.51)
A2	(0.05,0.10,0.20,0.35)	(0.06,0.17,0.27,0.59)	(0.21,0.30,0.40,0.51)	(0.01,0.17,0.27,0.51)
A3	(0.08,0.17,0.27,0.61)	(0.14,0.37,0.47,1.00)	(0.25,0.57,0.67,0.93)	(0.01,0.37,0.47,0.92)
A4	(0.31,0.43,0.53,1.00)	(0.24,0.30,0.40,0.54)	(0.61,0.70,0.80,0.91)	(0.01,0.37,0.47,0.92)
A5	(0.11,0.23,0.33,0.58)	(0.29,0.43,0.53,1.00)	(0.07,0.50,0.60,0.94)	(0.01,0.37,0.47,0.92)
A6	(0.17,0.37,0.47,1.00)	(0.19,0.50,0.60,1.00)	(0.23,0.43,0.53,0.95)	(0.21,0.57,0.67,0.91)

	C_{21}	C_{22}	C_{23}	C_{24}
A1	(0.51,0.63,0.73,0.98)	(0.48,0.63,0.73,0.96)	(0.41,0.50,0.60,0.71)	(0.41,0.57,0.67,0.91)
A2	(0.31,0.43,0.53,0.78)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.22,0.50,0.60,0.92)
A3	(0.48,0.57,0.67,1.00)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.41,0.50,0.60,0.71)
A4	(0.28,0.37,0.47,0.81)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.21,0.37,0.47,0.71)
A5	(0.28,0.37,0.47,0.81)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.21,0.37,0.47,0.71)
A6	(0.45,0.50,0.60,0.75)	(0.31,0.50,0.60,1.00)	(0.23,0.50,0.60,0.93)	(0.21,0.43,0.53,0.71)

	C_{31}	C_{32}	C_{33}	C_{34}
A1	(0.32,0.24,0.29,1.23)	(0.45,0.57,0.67,0.96)	(0.25,0.57,0.67,0.93)	(0.41,0.50,0.60,0.71)
A2	(0.18,0.16,0.20,0.97)	(0.25,0.37,0.47,0.76)	(0.24,0.50,0.60,0.94)	(0.21,0.37,0.47,0.72)
A3	(0.30,0.21,0.26,0.93)	(0.26,0.43,0.53,0.75)	(0.21,0.30,0.40,0.51)	(0.41,0.57,0.67,0.92)
A4	(0.19,0.19,0.23,0.95)	(0.08,0.30,0.40,0.78)	(0.04,0.30,0.40,0.74)	(0.22,0.43,0.53,0.71)
A5	(0.19,0.19,0.23,0.95)	(0.26,0.43,0.53,0.75)	(0.03,0.23,0.33,0.52)	(0.22,0.43,0.53,0.71)
A6	(0.22,0.24,0.29,1.23)	(0.45,0.57,0.67,0.96)	(0.22,0.37,0.47,0.73)	(0.21,0.37,0.47,0.72)

	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
A1	(0.31,0.57,0.67,0.97)	(0.44,0.50,0.60,0.74)	(0.44,0.57,0.67,0.95)	(0.41,0.63,0.73,0.91)	(0.21,0.43,0.53,0.71)	(0.60,0.70,0.80,0.90)
A2	(0.45,0.57,0.67,0.97)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.40,0.50,0.60,0.70)	(0.22,0.57,0.67,0.91)	(0.41,0.63,0.73,0.91)
A3	(0.43,0.50,0.60,0.73)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.21,0.43,0.53,0.71)	(0.21,0.30,0.40,0.51)	(0.21,0.57,0.67,0.91)
A4	(0.27,0.43,0.53,1.00)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.21,0.43,0.53,0.91)	(0.21,0.37,0.47,0.71)	(0.21,0.50,0.60,0.91)
A5	(0.14,0.47,0.57,1.00)	(0.29,0.43,0.53,0.76)	(0.07,0.33,0.43,0.76)	(0.21,0.43,0.53,0.91)	(0.21,0.43,0.53,0.71)	(0.21,0.57,0.67,0.91)
A6	(0.29,0.50,0.60,0.99)	(0.31,0.50,0.60,1.00)	(0.26,0.50,0.60,0.96)	(0.41,0.57,0.67,0.91)	(0.21,0.43,0.53,0.92)	(0.21,0.57,0.67,0.91)

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Table 10. Design requirements

	Trapezoidal fuzzy numbers
C_{11}	(0.27,0.33,0.43,0.57)
C_{12}	(0.28,0.34,0.44,0.58)
C_{13}	(0.37,0.46,0.56,0.67)
C_{14}	(0.32,0.42,0.52,0.62)
C_{21}	(0.34,0.44,0.54,0.64)
C_{22}	(0.36,0.46,0.56,0.66)
C_{23}	(0.31,0.41,0.51,0.61)
C_{24}	(0.34,0.44,0.54,0.64)
C_{31}	(0.34,0.44,0.54,0.64)
C_{32}	(0.34,0.44,0.54,0.64)
C_{33}	(0.26,0.36,0.46,0.56)
C_{34}	(0.41,0.51,0.61,0.71)
C_{41}	(0.33,0.42,0.50,0.59)
C_{42}	(0.29,0.38,0.46,0.54)
C_{43}	(0.26,0.34,0.43,0.51)
C_{44}	(0.33,0.41,0.49,0.58)
C_{45}	(0.25,0.33,0.42,0.50)
C_{46}	(0.36,0.44,0.52,0.61)

Table 11. The alternatives' common and system areas

	A1	A2	A3	A4	A5	A6	A1	A2	A3	A4	A5	A6
	Common area						System area					
	Economic											
C_{11}	0.025	0.002	0.004	0.225	0.025	0.144	0.320	0.180	0.300	0.610	0.320	0.560
C_{12}	0.064	0.002	0.132	0.064	0.210	0.324	0.370	0.280	0.530	0.370	0.600	0.580
C_{13}	0.030	0.004	0.240	0.484	0.144	0.072	0.470	0.360	0.600	0.760	0.520	0.550
C_{14}	0.006	0.006	0.056	0.056	0.056	0.306	0.240	0.240	0.450	0.450	0.450	0.580
	Environmental											
C_{21}	0.380	0.090	0.272	0.042	0.042	0.169	0.720	0.520	0.700	0.500	0.500	0.580
C_{22}	0.342	0.072	0.072	0.072	0.072	0.144	0.700	0.500	0.500	0.500	0.500	0.620
C_{23}	0.210	0.064	0.064	0.064	0.064	0.210	0.560	0.450	0.450	0.450	0.450	0.570
C_{24}	0.272	0.169	0.169	0.042	0.042	0.090	0.640	0.560	0.560	0.440	0.440	0.470
	Social											
C_{31}	0.008	0.070	0.021	0.043	0.043	0.008	0.600	0.440	0.480	0.440	0.440	0.560
C_{32}	0.272	0.042	0.090	0.009	0.090	0.272	0.670	0.470	0.500	0.400	0.500	0.670
C_{33}	0.420	0.289	0.049	0.049	0.012	0.110	0.600	0.580	0.360	0.380	0.280	0.450
C_{34}	1.960	0.563	3.063	1.103	1.103	0.563	0.560	0.560	0.650	0.470	0.470	0.560
	Technical											
C_{41}	0.304	0.304	0.192	0.105	0.152	0.192	0.630	0.680	0.570	0.580	0.550	0.610

C_{42}	0.253	0.152	0.152	0.152	0.152	0.253	0.570	0.510	0.510	0.510	0.510	0.620
C_{43}	0.467	0.203	0.203	0.203	0.080	0.321	0.670	0.490	0.490	0.490	0.400	0.590
C_{44}	0.444	0.203	0.111	0.111	0.111	0.321	0.670	0.550	0.470	0.530	0.530	0.640
C_{45}	0.218	0.490	0.063	0.134	0.218	0.218	0.470	0.590	0.360	0.440	0.470	0.530
C_{46}	0.538	0.380	0.267	0.160	0.267	0.267	0.750	0.670	0.580	0.560	0.580	0.580

Table 12. The alternatives' information contents

	A1	A2	A3	A4	A5	A6
			Economic			
C_{11}	0.272	0.158	0.161	0.695	0.272	0.510
C_{12}	0.395	0.144	0.499	0.395	0.661	1.190
C_{13}	0.253	0.154	0.757	1.536	0.540	0.341
C_{14}	0.190	0.190	0.333	0.333	0.333	1.085
Total	1.110	0.646	1.751	2.959	1.806	3.128
			Environmental			
C_{21}	1.086	0.396	0.734	0.281	0.281	0.562
C_{22}	0.969	0.358	0.358	0.358	0.358	0.475
C_{23}	0.708	0.355	0.355	0.355	0.355	0.695
C_{24}	0.811	0.579	0.579	0.296	0.296	0.420
Total	3.573	1.688	2.026	1.290	1.290	2.152
			Social			
C_{31}	0.162	0.377	0.223	0.299	0.299	0.165
C_{32}	0.770	0.288	0.405	0.183	0.405	0.770
C_{33}	1.947	0.995	0.348	0.338	0.222	0.493
C_{34}	1.426	2.039	0.25	3.419	3.525	1.426
Total	4.305	3.699	1.226	4.239	4.451	2.854
			Technical			
C_{41}	0.952	0.862	0.637	0.406	0.538	0.599
C_{42}	0.853	0.571	0.571	0.571	0.571	0.773
C_{43}	1.920	0.784	0.784	0.784	0.432	1.139
C_{44}	1.689	0.694	0.481	0.444	0.444	1.005
C_{45}	0.901	3.732	0.396	0.585	0.901	0.779
C_{46}	2.084	1.224	0.893	0.553	0.893	0.893
Total	8.398	7.867	3.762	3.343	3.779	5.189

Aggregation of the information in Table 12 was carried out using GRA. During this process, an identification coefficient of 0.5 to analyse the blue-green technologies [32]. Equation (20) was used to normalised the information in Table 13 because of the FA method rank output in terms of the smaller-the-better. Table 14 presents the GRA output for the blue-green technology problem.

Table 13. Normalised decision-matrix for GRA application

	C1	C2	C3	C4
A1	0.187	1.000	1.000	0.955
A2	0.000	0.895	0.174	0.767
A3	0.445	0.083	0.322	0.000
A4	0.932	0.000	0.000	0.934
A5	0.467	0.086	0.000	1.000
A6	1.000	0.365	0.378	0.505

Table 14. GRA outputs for the blue-green technology problem

	C1	C2	C3	C4	Grade
A1	0.647	0.308	0.298	0.211	0.132
A2	1.130	0.336	0.878	0.251	0.225
A3	0.406	1.156	0.651	1.019	0.153
A4	0.239	1.539	1.490	0.215	0.148
A5	0.394	1.144	1.490	0.204	0.153
A6	0.226	0.626	0.593	0.338	0.085

Discussion of Results

The best-worst results for the current problem showed that the techno-economic criteria contributed about 88.18% to the ranking of blue-green technology. In terms of the economic sub-criteria, the contributions of C_{11} and C_{12} to the technology selection was about 83% (Table 5). In comparison, Table 5 showed that C_{21} and C_{22} contributed about 85% to the technology selection. The contributions of C_{31} and C_{32} to the selection problem in terms of social criterion were about 8%. This study observed that at least three technical sub-criteria account for about 80% of the sub-criteria that affect these technologies selection. Another unique feature of the technical sub-criteria is that the first criterion was not ranked as the most important criterion; instead, it was C_{42} that was the most crucial criterion.

Figure 3 shows the selected blue-green technologies rank in terms of the FA and GRA methods. When the FA method results aggregated with the GRA method, the most and least suitable technology for the case study was A1 and A6, respectively; these rankings are consistent with the economic criteria ranks for the case study. The GRA method results showed that the suitability of A3 and A5 for the case study area is the same (Figure 4). The technical and environmental criteria FA method results showed A4 is the most suitable technology, while A1 is the least suitable technology (Figure 4). In terms of the social criterion, the most suitable technology is A3, while A5 is the least suitable technology.

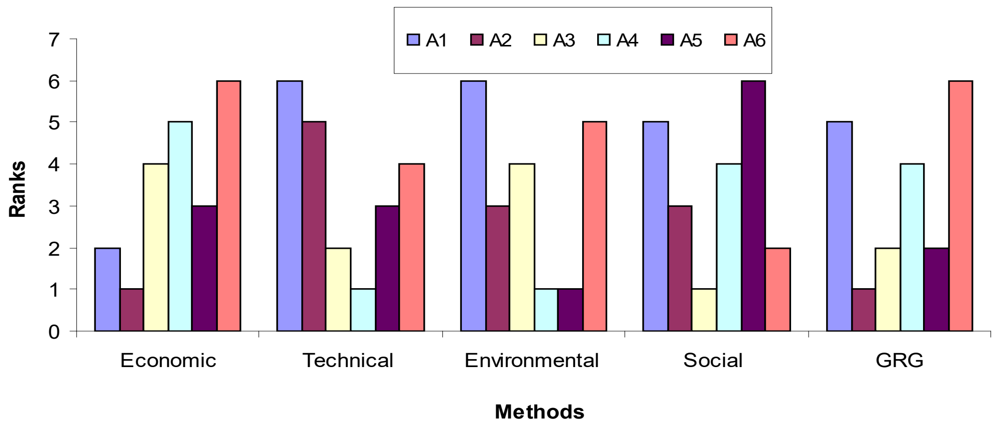

Figure 4: Comparison of different methods for blue-green technology ranking

Policy implications

This study outputs have several policy implications to FRM problem in developing countries. First, it has been able to establish that MCDM tools can be used to provide bounded-rational on the most suitable technology for flood control. With this knowledge, corporate responsibility can be taken whenever a technology fails. This identification process will absolve a particular person from bearing the effect of a policy failure. Second, policy failure can be tacked from strategy and tactical level. When considering a strategic level to policy failure, policy-makers can trouble-shoot failure by considering economic, social, environmental and technical requirements for this technology selection. On the other hand, policy failure can be traced to the sub-criteria that constitute each of the criteria, as mentioned earlier at a strategic level.

5. Conclusion

This study has developed a framework for blue-green technology selection. It used a multi-criterion modelling approach to developed the framework. Sustainability criteria were embedded into the framework to account for stakeholders' requirement during the selection process. Lekki, a community in Lagos, Nigeria, was used as a case study for the framework evaluation. Based on three experts' responses about six blue-green technologies, which include bypass floodway, rainwater and floodwater harvesting, and porous pavement, the most and least suitable technologies were identified for the case study. The framework identified rainwater and floodwater harvesting as the most suitable blue-green technologies for a community. It also identified a bypass floodway as the least suitable blue-green technologies for a community.

The use of a best-worst method to address the problem of optimal weight determination for criteria is a contribution of this study. Another contribution of the current study is the fuzzy axiomatic method to incorporate decision-makers' preference into blue-green technology selection. Also, this study contributed to the use of optimistic, pessimistic and most likely design requirements approach to fuzzy axiomatic method application as another contribution to FRM. Also, it applied GRA to FRM problem as a contribution to FRM. One of the limitations of this study is that it did not consider the political and institutional constraints that affect blue-green technology selection. This study, therefore, expects future studies to incorporate these factors into blue-green technology analysis.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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Status of water security in inland South African cities

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Abstract
Most cities in South Africa are in dire need of water security. Intervention measures to reduce the risk of water shortages now and the near future are urgently needed. This can possibly be attained through the diversification of water sources and the application of smart or digital technologies to reduce water wastage. Meaning that, cities which are at risk of water scarcity may consider a variety of alternative means, which includes smart technologies and efficient use of recycled water to meet the ever-increasing demand. In this study the status of water security and sanitation in two inland cities (i.e. Mbombela (Nelspruit) and Polokwane (Pietersburg)) was investigated. A gap between supply and demand for water to households was found to be large. The primary demand for water derives from households that are connected to the municipal reticulation system and used for drinking and sanitation. Water security concerns were found to be from households in need of water supply and unmeasured demands from informal settlements that are illegally connected to the system. The uncertain nature of water availability due to climate change meant that the risk of water insecurity in studied cities was high. To ameliorate this, municipalities need to adopt new ways of managing water. This may include the use of digital technologies and the promotion of harvesting rainwater as an alternative source. Maintenance of existing infrastructure is highly recommended to improve efficiencies in water usage. Overall, results reflect the high risk of water security in Mbombela and Polokwane. Of great concern is the need to manage water to improve the efficiency of its use to meet the ever-increasing demand.

Keywords: Water demand, Water security, South Africa, Water supply

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1 Introduction

From the city dynamics perspective, especially in South Africa, challenges linked to water and sanitation have escalated due to rapid urban migration, which took place since 1994 and the subsequent transformation of cities [1],[2]. Signs of water shortages in the cities have become imminent in many cities in South Africa. This have been experienced in coastal cities of Cape Town (Province of Western Cape), Port Elizabeth (Province of Western Cape) and Richardsbay (Province of KwaZulu Natal). Some cities and towns (e.g. Port Elizabeth, Beaufort West) are continuously experiencing unpredictable weather patterns that oscillates between droughts and floods. These have drastically affected water security in these cities and towns.

Water availability in any urban system is determined by a combination of enough precipitation (i.e. rainfall), well managed catchment area, healthy river system and the reliable infrastructure in the form of dams, reservoirs, pipes and taps. Quality of water consumed in each household relies on quality tests conducted by designated authorities.

Monitoring of consumption to improve water use efficiency has been increasingly performed through digital technologies. All these provide a basis for assured household water supply that is clean and drinkable. For South Africa, household water supply is dependent on total surface water available and the maintenance of infrastructure for bulk supply to consumers and households. The total surface water available for urban household consumption is estimated to be 49,200 million cubic meter (m^3) per year. In general, South Africa has relatively low per capita water availability compared to the global average, with only 9% of rainfall entering its river systems [3]. Thus, South Africa have low ratio of Mean Annual Precipitation to Mean Annual Run-off.

The question this brings forward, is whether emerging digital technologies can help the country enhance it water use, which have proved to be a scarce resource. South Africa's Department of Water Affairs and Forestry as a designated authority for water supply in the country has identified water security as a concern for major cities. It has acknowledged that cities anchor country's economy, and therefore, require investments to diversify water sources to ameliorate imminent water scarcity [4].

While this reality has emerged in the coastal city of Cape Town, developing trends point to the fact that almost all cities in South Africa are likely to face water shortages and this requires focused studies, adoption of new technologies (such as digital technologies) and collaboration among stakeholders to implement holistic water security and management strategies that will support both national and regional water security initiatives.

Given the context of South Africa, water scarcity and declining surface water quality, cities have no choice but to adopt smart water management that will allow them to efficiently use and manage available water resources. Smart water management in cities seeks to minimize challenges of urban water scarcities by integrating information and communication technologies to water management and administration [5],[6]. These technologies are adapted to continuously monitor water resources and diagnose problems, allowing to prioritize and to manage maintenance more effectively, as well as to gather data needed to optimize all aspects of water management in the city and feed information back to planners, operators and technical service providers. These technologies entail water smart metering being implemented in number of municipalities [7],[8]. For South Africa the extent of deploying these technologies has not been ascertained. In this study it has been hypothesized that inland cities are more vulnerable to water scarcity as they do not have alternative sources of water such as saline water from the sea, which they can process through desalination technologies and use as an alternative to freshwater. Therefore, adoption of technologies such as digital technologies to augment the monitoring and efficient use of water resources is the viable option for these cities.

Access to water in South Africa as reported by the Department of Water and Sanitation highlights the institutional roles (i.e. provincial government, catchment management authorities, local government etc) in the management of water supply to households. This implies that in South Africa the provision of water and sanitation services lies squarely on the hands of local governments and municipalities. These are the ones that need to give digital technologies a serious consideration.

This study considered water challenges in South Africa as emanating from:

- service delivery backlogs-people who have never enjoyed access to water supplies since 1994;
- refurbishment backlogs-infrastructure that has deteriorated due to poor maintenance;
- extension backlogs-existing infrastructure that needs to be extended to under services areas and new developments;
- upgrade requirements-enhancement of infrastructure that does not meet the minimum standards;
- operation and maintenance backlogs-infrastructure that has not been properly operated and maintained but can be brought to the mainstream if funds are allocated.

With the unpredictable nature of climate change and its impact on water security, assuring the provision of water under times of uncertainty present a complex scenario that requires new scientific approaches, which might include the use of digital technologies. The rationale for this study was therefore to unbundle the complex nature of water supply, its security and management in inland cities, which unlike coastal cities (that can harvest marine water through desalinating technologies) have limited options.

2 Related work and contribution

Across the World, competing interest for water has increased. This results from various uses of water. While in the past, water use and demand has largely been from household, agriculture, recreation and industrial operations, the intensification of the World to migrate to renewable energy and investments made on hydropower has brought the World's attention to the sustainability of available water.

Its continuous use for energy has become a bone of contention among scholars, policy makers and regulators. The additional threat from climate change on water security

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and its availability has help develop many perceptions about the value of water. As a result, increased research efforts has been given to predicting the future availability of water [9],[10], mapping the amount of water available for human use [11],[12], raising concerns about the nature and extent of water pollution [13], [14] and predicting effects of climate change on water and the associated systems like rivers and catchment areas [15]. In addition, some scientists have been developing technologies for either averting water crisis [16],[17]), proposed methods for reuse of contaminated water or looking at new sources of water [18],[19],[20]). Digital technologies are also being investigated as part of improving the efficient use of water resources.

The United Nations, through the Sustainable Development Goal number 6 expressed its desire to guide the World towards ensuring access to clean water, improve water quality and ensure its sustainable management, and further support and strengthen the participation of local communities in improving water management.

This together with the growing awareness for securing the availability of water for sustainable development has inspired researchers to generate more knowledge on water security, its management, availability and technologies that can be adopted to secure future availability of water.

As a contribution to the body of knowledge that is being developed, this article seeks to contribute to the body of knowledge that has so far generated. The location (two provinces in South Africa) of the study and its participants (communities from Polokwane and Mbombela cities) makes it unique and original. However, to ensure comparison to other studies conducted elsewhere, research methods applied, and the approaches used to analyze data are in line with the common acceptable scientific norms and procedures.

While concerns on water are increasing around the globe, this study focused on household water demand and supply. It sought to determine the status of water security in Mbombela and Polokwane and the vulnerability of these cities to water shortages, possibly due to climate change.

Data presented was collected (i.e. end of 2018) at the time when cities in South Africa were concerned about their state of water security as the city of Cape town was experiencing a possibility of running out of water.

3 Study Method

The study used structured household survey method for data collection, with special focus given to key informants as sources of information. The data was collected using questionnaires. Data from each questionnaire was captured into Cspro software saved into SAV file that was later loaded into SPSS software for analysis and interpretation.

The design of the study was as follows:

3.1 Sample size estimation

The sample size was calculated at 95 % level of confidence with the value of Z being 1.96 and precision being at 5 %. Sample size estimation is a mathematical procedure used to determine the number of individuals to be included in the investigation from the population.

Determining the minimum required sample size is of extreme importance in achieving a scientifically and statistically acceptable results [21]. The formula developed by Naing, et al. [22] was used to calculate the required number of household to be targeted for each study area. The formula used is defined as:

$$n = \frac{Z^2_{\alpha/2} P(1-P)}{d^2} \qquad (1)$$

Where :

n is the sample size

Z is the Z statistic for a level of confidence

P is the prevalence or proportion of event of interest for the study

d is the precision/margin of error with which the researcher wants to measure something.

The sample size only provides an indication of the number of households to be targeted. It does not accout for non-response and incomplete surveys [23]. A proportion of participant were expected not to grant consent to participate in the survey. To account for this, the sample size was adjusted accordingly. Adjustments were made using the following formula:

$$N' = \frac{N}{1-q} \qquad (2)$$

Where N is the sample size

q is the proportion of the attrition and is generally 10 %

The study assumed a non-response rate of 10 %. As such the final adjusted sample size was 385 (Polokwane) and 360 (Mbombela). Forty-five households were added for Polokwane to adjust the final acceptable sample size to 430 households and, thirty-six were added to adjust the final sample size to 400 households.

3.2 Household sampling

Households included in the study were randomly selected using ArcGIS software. A shape file obtained from Statistic South Africa with households and streets was over laid on ArcGIS. Based on the sample size, Small local area layers (SALs) were generated using ArcGIS (Figure 4.3 and Figure 4.4). Visiting points were allocated unique number for ease of reference and recording.

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3.3 Data Analysis

Quantitative data analysis was performed on Statistical package for Social Sciences. Data analysis conducted was limited to descriptive analysis. This was supplemented with data interpretation using systems thinking and interpretation. This method was used to determine the linkages between various elements of water supply and demand processes through which water is provided to households of studied cities.

The application of system dynamics perspectives as a quantitative policy analysis technique has increased within the international water sector, with its use being frequently applied to investigate challenges of water supply and demand in urban systems.

By comparison, the application of systems science to urban water management in the developing world in general, and Africa is inadequate. Few applications of the application of this technique in South Africa include the determination of the relation between a municipality and the physical dynamics of an estuary [24], and as part of modelling the South African Green economy. Qualitative data from key informants was synthesized by examining the recurring responses.

4 Description of the study area

4.1 Polokwane city

Polokwane city is in the central part of the Limpopo Province, within the Capricorn District Municipality. It shares boarders with three local municipalities including Mopani and Waterberg. Polokwane city covers an extensive surface area of 3775 Km^2, accounting for 3 % of the Limpopo Province total surface area. Within the Capricorn District, Polokwane city has the highest population.

The majority (71 %) of Polokwane is rural, with only 23 % of the total area being urban. The remaining 6 % of Polokwane is comprised of smallholdings, institutional, industrial and recreational land. Because of its central location the city of Polokwane being is located at the nexus of important national and provincial roads which radiates like the spokes of the wheels thus connecting countries such as Zimbabwe to other provinces like Gauteng in South Africa

3.1.1 Demographic

Polokwane is a home to 702 190 people which is 11.63 % more than in 2011 (628 999) (Table 1). Currently there are 214 646 households 17 % more than in 2011 (178 001). The number of households are increasing at a faster rate that the population. The average size of households is four persons per household. From 2007, the population growth rate was 2.8 %. Seshego (a large township in the city) has the highest population density (i.e. 27.2 person/ha) followed by the city cluster with 8.5 person/ha (Table 1).

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Table 1: Population in Polokwane municipality from 1996 to 2016 (Stats SA)

	1996	2001	2011	2016
Total number of people	424 835	508 277	628 999	702 190
Total number of households	85 373	124 975	178 001	214 464

3.1.2 Climate

Polokwane Local municipality is characterized by a semi-arid climate. Frost rarely occurs. It has a dry climate with summer rainfall and pronounced dry spells in winter. Rainy season last from October to March with peak rainfall in December/January. Rainfall occurs in a form of thunderstorms. The mean annual rainfall is 478 mm. The mean maximum and minimum air temperatures are 22°C and 4.4°C respectively. These occur in January and July. Dry season lasts from May to October.

3.1.3 Water resources

Most of the river within the municipality are non-perennial rivers [25] as they are often dry in winter. Rivers within the Polokwane city include Blood, Sand, Brak, Diep, Nkumpi, Chuene and Mphogadiba River [26]. There are also no major dams within the municipality [27]. Until 1958, Polokwane municipality solely depended on groundwater. When demand for water could not be met by groundwater sources, water had to be imported from the neighboring drainage regions. Dap Naude dam located in the upper reaches of the Great Letaba River started supplying water to the municipality in 1958, followed by Ebenezer in 1974. About 60 % of the Polokwane Local Municipality water is sourced outside the municipal boundaries therefore is water scarce. Surface water is transferred from outside the municipal boundaries through Ebenezer, Dup Naude and Olifants Sand water transfer mains. Polokwane city supplements surface water with ground water. In rural or distant areas, groundwater is the only source of water. However, in these areas there is low potential for ground water. Underdeveloped high potential ground water sources occur in Polokwane/Seshego, Sebageng, and Molepo. However, they are not fully utilized because of regional water schemes. The municipality has five medium size dams namely: Seshego, Houtriver, and Molepo, Mashashane, and Chuene/Maja dam. Provision of water in the municipality is divided into Regional Water Schemes. At Polokwane city, there are currently 14 regional water schemes namely: Mothapo, Moletjie East, Moletji North, Moletji South, Houtriver, Chuene/Maja, Molepo, Laastehoop, Mankweng, Boyne, Segwasi, Badimong, Sebayeng/Dikgale and Olifant Sand. The daily average demand for the municipality is 80.83 MI/Day with peak demand of 163 MI/Day. The municipality receives 80-90 MI/Day and it is therefore not able to meet its peak flow demand of 163 MI/Day. Because of water supply limitation, on 15 April 2013 a moratorium on new property development was issued for Polokwane city but has since been lifted. When it comes to water, the municipality experiences following challenges:

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- Lack of sustainable water sources for current and future demand
- Overreliance on borehole water in rural areas where there is a risk of water contamination by pit latrines
- Aging and deterioration of water infrastructure, which leads to frequent pipe, burst in Polokwane city, Seshego, Annandale.
- Lack of maintenance plan
- Limited operation and maintenance of infrastructure due to lack /shortage of funds
- Significant water loses within the distribution water networks
- Illegal house expansion (Backyard rooms)
- Pollution threat to underground water in the sand river catchment form the Polokwane cemetery and Seshego Sewerage works
- High levels of water loss (48 %)

Table 2: Regional water schemes sources and capacity [28]

Water sources	RWS supplies	Average supply	Source capacity
Ebenezer	Mankweng RWS	10 MI/Day	19 MI/Day
Olifants Sand	Rural (Mothapo RWS,Molepo RWS,Segwasi RWS,Bonye RWS,Badimong RWS,Sebayeng Dikgale RWS)	9 Ml/Day	
Olifants Sand	Chuene/Maja RWS,Olifants Sand RWS (Seshego, some portion of City and Mmotong wa Perikisi)	26.29 MI/Day	27 MI/Day
Dap Naude Dam	Olifants Sand RWS (Polokwane City)	15 MI/Day	18 MI/Day
Seshego Dam	Olifants Sand RWS(Seshego RWS)	1.6 MI/Day	3.9 MI/Day
Seshego Borehole	Olifant Sand RWS (Seshego)	1.2 MI/Day	2.0 MI/Day
Ebenezer	City	19 MI/Day	19 MI/Day
Boreholes	Supplement water from dams	5.5 MI/Day	25.33 MI/Day
Rural Dams			
Houtriver Dam	Houtriver RWS	2.0 MI/Day	3.9 MI/Day
Chuene/Maja Dam	Chuene/Maja RWS	2.7 MI/Day	2.7 MI/Day
Molepo Dam	Molepo RWS	6.0 MI/Day	6 MI/Day

Mashashane Dam	Aganang RWS	1.0 MI/Day	
Total		99.29 MI/Day	124.83 MI/Day
Peak flow demand		163 MI/Day	

3.1.4 Acess to water and sanitation

Currently, 83 % (196 371) of the households in city of Polokwane has access to safe drinking water. The municipality has 17 % (42 745) households with no access to piped water (Table 3). The elimination of the water backlog is challenged by limited and /or unsustainable source of water found in rural areas and continuous increase of new settlements in some clusters in the municipal areas.

According to 2016 community survey, 36 % (86 132) of households in Polokwane Local Municipality do not have access to healthy and dignified health facilities (Table 4). Even though over the years the municipality has made progress in provision of the sanitation services the municipality did not meet the Millennium Development Goals. The municipality needs R500 000 000t o eradicate the current sanitation backlog [29].

4.2 Mbombela city

The City of Mbombela (Nelspruit) is in the Ehlanzeni District Municipality, Mpumalanga Province. The municipality was formed in 2000 by the merger of Hazyview, Nelspruit and White River Local Councils. It is situated in the north eastern part of South Africa within the Lowveld sub-region of the Mpumalanga Province. It is bordered by six other Municipalities i.e. Bushbuck Ridge to the north, Nkomazi, Umjindi and Albert Luthuli to the south east and south and Highlands and Thaba Chweu to the south west and north-west.

The urban and peri-urban nodes of the municipality include Matsulu, kaNyamazane, Daantjie and Kabokweni. The rural nodes are Hazyview-Mganduzweni planning area, the Nsikazi planning area, Luphisi/Mpakeni villages and Elandshoek in the Ngodwana planning area [30].

3.2.1 Demographic

The population of Mbombela has had a 1.25% growth since 2011 till 2016, with the total population increasing from 588,794 to 695,914 [31]. The growth rate however form the 2016 Community Survey has been projected to 2.11%. The working population of Mbombela has varied from 66.2% in 2011 to 63.9% in 2016. The youth unemployment rate stood at 28.1% of the economically active. The increasing population

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and the ever-increasing unemployment rate in South Africa have led to several households not being able to make ends meet, thus the increase in the dependency ratio on the government resources and services from 51.6% in 2011 to 56.6% in 2016.

Table 3: Population distribution according to race in Mbombela local municipality

Race/Population Group	**2016**	
	Number of People	**Percentage (%)**
Blacks (African)	667 827	95.96%
Whites	18 695	2.69%
Coloureds	6 535	0.94%
Asian	2 855	0.41%

Source: Stats SA, Community Survey 2016

3.2.2 Climate

Mbombela features a humid subtropical climate with mild winters and hot summers. Due to the altitude, summers are not as hot as one might expect. Summers are hot and somewhat humid, complete with high precipitation. Winters in the city are dry, with relatively warm temperatures during the day and chilly temperatures at night.

Like in many other parts of the country, the rainfall is unevenly distributed in the Inkomati Water Catchment Area where most of the rainfall occurs in the mountainous regions. Future predictions of hotter wetter summers and long drier winters as a result of climate change could greatly impact or affect water availability for in the area.

3.2.3 Water resources

Water availability is mainly driven by rainfall patterns that are strongly seasonal, and highly variable between places and between years. The Mean Annual Precipitation (MAP) varies from about 500 mm in the lowveld, to 1,500 mm on the escarpment at Kaapsehoop. The MAP in Nelspruit is 783 mm, whereas White River has a MAP of 936 mm [32]. Some years receive up to 1.8 times the MAP, while other years receive as little as 0.55 times the MAP.

Mbombela local municipality (MLM) water needs are met through the Inkomati Water Management Area (WMA) and straddles the Crocodile (East) and Sabie River catchments. Much of the water flowing through the municipal area is derived from upstream catchments. The municipality obtains all their water from these catchments with a very small percentage obtained from groundwater.

Most of Mbombela is situated within the Crocodile River Catchment, and a small portion in the vicinity of Hazyview is situated in the Sabie River Catchment. Major tributaries within Mbombela include the lower Elands, Ngodwana, Nels, White, White

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Waters, Gutshwa, North Sand and Nzikazi Rivers. The river corridors provide important migration routes for various plants and animals, playing an important role in linking lowveld areas with the escarpment and highveld.

There are six major water storage reservoirs within Mbombela, but the most important storage facility for the area, Kwena Dam, is situated outside the municipal boundary (Table 6). Much of the water on which Mbombela depends is therefore generated outside of the municipal boundary.

Table 4: Significant dams in the Crocodile River catchment

Dam	**Fully supply capacity (FSC)**		**Full supply area (FSA) (km2)**		**Yield (million m3/a)**	
million m3	***Natural MAR (million m3/a)***		***FSC as %MAR***	***Historic***	***1 in 50***	
Kwena Dam	158,9	119	134%	12,5	83,2	87,5
Witklip Dam	12,7	19,8	64%	1,88	8,1	8,5
Klipkopje Dam	11,9	188	63%	2,31	Operated as system with Longmere	
Longmere Dam	4,32	25,4	17%	0,96	10,3	10,6
Primkop Dam	1,97	39,4	5%	0,41	9,9	10,3
Ngodwana Dam	10,0	58,8	17%	1,00	21,0	22,4
TOTAL	**199,8**	**450,4**	**44%**	**19,06**	**132,5**	**139,3**

Source: DWS 201

The Inkomati River originates in South Africa, passes through Swaziland, back through South Africa and finally drains into the Indian Ocean in Mozambique. The basin covers roughly 31,230 square kilometres with irrigated agriculture utilising 57% of the average water requirements [33]. On other hand, the water resources of the Crocodile and Sabie River catchment have two components; the yield available from dams (including farm dam) and the yield available from run-of-river. The significant dams in the Crocodile and Sabie River catchment are listed in Table 7.

Table 5: Significant dams in the Sabie River catchment

Dam	**Fully supply capacity (FSC)**		**Full supply area (FSA) (km2)**	**Yield (million m3/a)**
Million m3	**Natural MAR (million m3/a)**	**FSC as %MAR**	**Historic**	**1 in 50**

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Inyaka Dam	125,0	79,9	156%	8,1	41,9	50,7
Da Gama Dam	13,6	20,3	67%	1,3	10,3	10,8
Maritsane Dam	2,1	24,9	8%	0,5	7,5	10,5
TOTAL	**140,7**	**125,1**	**113%**	**9,9**	**59,7**	**72,0**

Source: DWS 2014

3.2.4 Acess to water and sanitation

According to Stats SA community survey [34]), number of households with access to safe drinking water was reported higher (80.4%) compared to those without access to safe drinking water (19.6%). However, not all households had piped water inside the dwelling/house, and some households were still having access to water from flowing river (Table 8).

In terms of access to basic sanitation, city of Mbombela still faced with huge challenge to provide dignified sanitation facility to all households. Stats SA community survey [35] reported that 114 163 households still using pit latrine toilet facility, and 67.2% of those are without ventilation pipe (Table 9).

5 Results

4.1 Polokwane

4.1.1 Community perspectives

Household data

Of total surveyed household in Polokwane, 83.7 % were staying in a house constructed with bricks or concrete that was located on a separate stand (Table 10). The number of occupants per household ranged between 1 and 15 with mean number of 5.38 (STD = 3.29) people.

Table 6: Type of dwelling that the household occupies

Type of dwelling	n	%
Dwelling /house or brick/concrete block structure on a separate stand or yard or on farm	349	83,7
Dwelling/house/flat/room in backyard	33	7,9
Shack (Plastic /semi-permanent material/corrugated iron/cardboard)	35	8,4
Total	**417**	**100**

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Sources of water for the households

The main source of water for the most households (61.5%) was piped tap that was located either inside the house (15.2%) or somewhere in the yard (12.6%) (Figure 1). For households that did not have tap inside the house or in the yard a communal tap was located 200 meters away from the household (Table 11). Small proportions were ether obtaining water from the neighbour, tank or borehole (Figure 2).

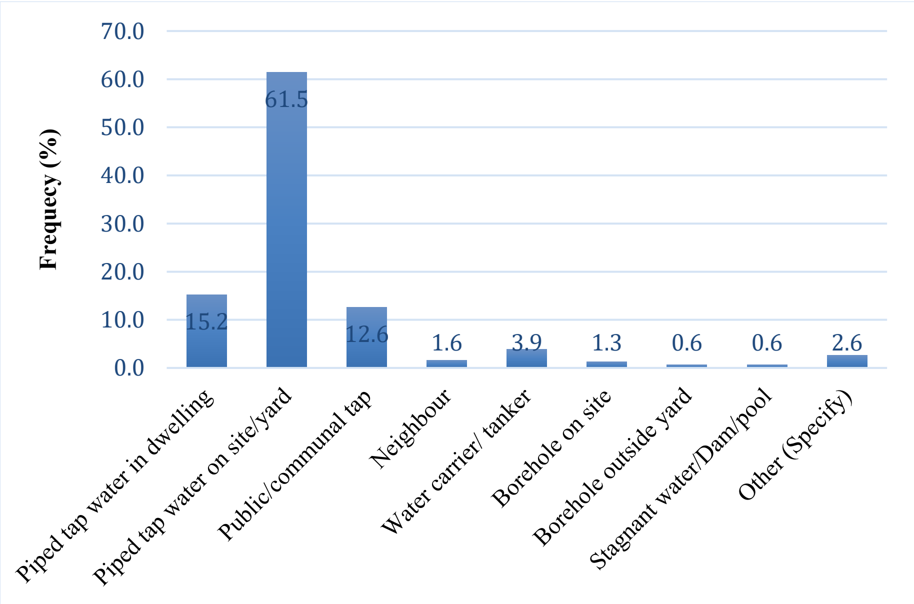

Figure 1: Sources of water for the household

Table 7: Distance of main source of water away from the dwelling

Distance of main source of water from the household	n	%
Water source is inside the house	230	55,8
Water source is located less than 200 metres from the household	147	35,7
Water source is located between 201 - 500 metres from the household	19	4,6
Water source is located between 501 metres - 1 kilometre from the household	8	1,9
Water source is located more than 1 kilometre away from the household	5	1,2

Don't Know	3	0,7
Total	**412**	**100**

Access to safe drinking water

The majority of sampled household (92 %) were using tap water as their main source of drinking water while only 7 % used the bottled water. The community perception towards safety of tap water was also observed, and 90 % of the participants believed that the water was safe to drink, clear, good in taste and free from bad smell (Figure 2).

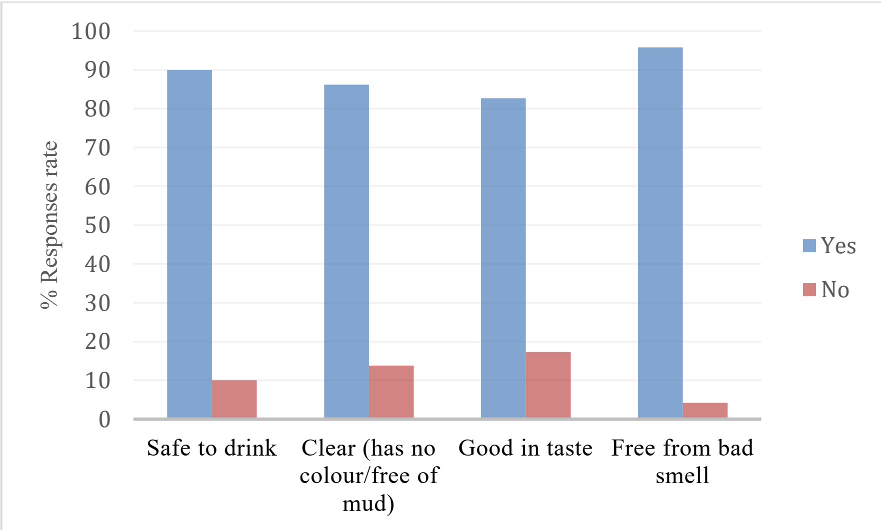

Figure 2: Proportion of study participants indicating whether water from the main source is safe or not

Water supply services

In the 87 % of households, the main provider of drinking water was the municipality. However, only 41% of the household was paying for the municipal water service (Figure 6). There was various reason why household were not paying the municipal water services, which could be blamed on both the community and municipality (Table 13).

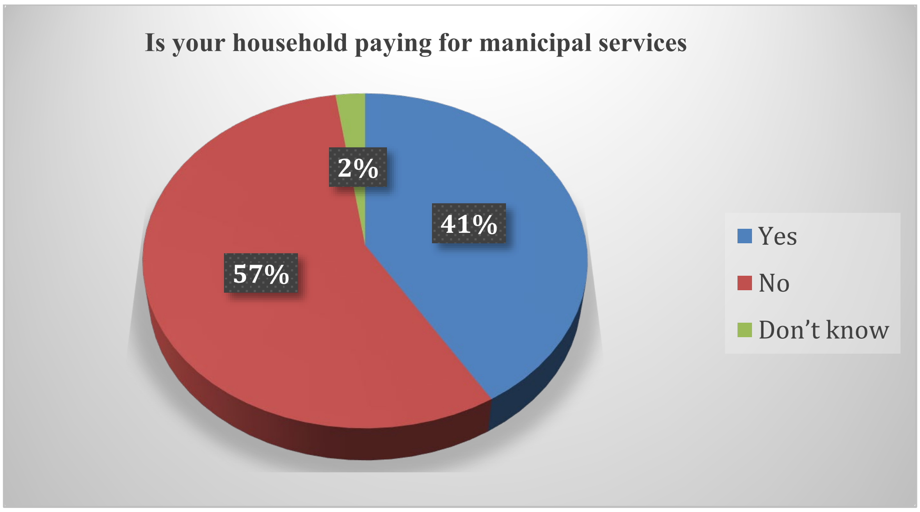

Figure 3: household paying for municipal water services

Table 8: Reason for not paying municipal water cited by the participants in the study area

Reason provided	n	%
Use own source of water	12	6,1
Use a free water source	31	15,7
Pay directly to landlord as part of rent	32	16,2
Payment included in levy	4	2,0
Permission from municipality not to pay	29	14,7
Do not have water meter	26	13,2
Water meter not working/broken	14	7,1
Do not receive water bill	10	5,1
Community decision not to pay	6	3,0
Cannot afford to pay	11	5,6
Water supply irregular	10	5,1
Water supply has been stopped	3	1,5
Other (specify)	9	4,6
Total	**197**	**100**

Water supply interruption

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About 86% percent of the household had water interruption in the past 12 months before the survey (Figure 4). In most cases, the water interruption was longer than 2 days (Figure 5), and these could happen up to five (5) times in a month (Table 13). While the reason for water interruption could be due to scheduled maintenance, burst pipe or regular water cut routine, 47% household didn't know the reason why water had been interrupted (Table 14). However, the people had the alternative sources of water during the interruption, in which include the municipal water tank (Table 14).

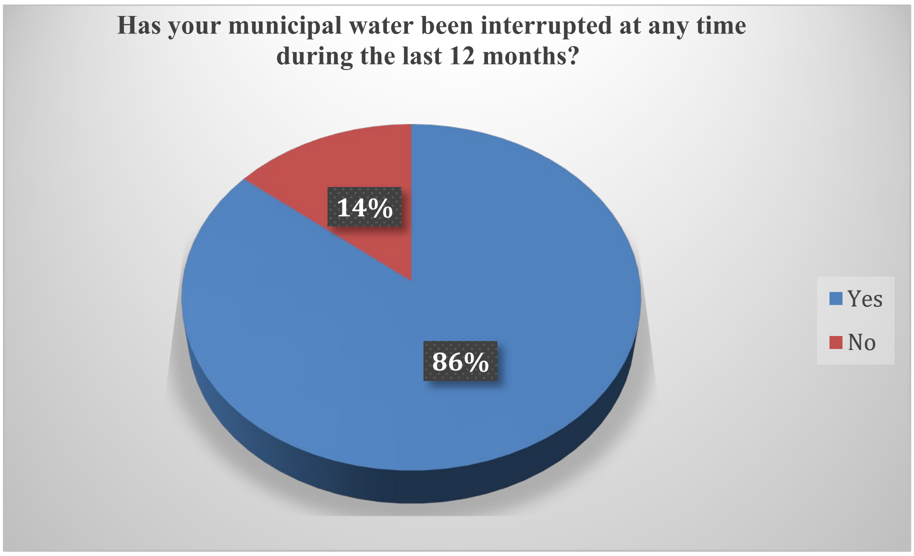

Figure 4: Water interruption in the past 12month

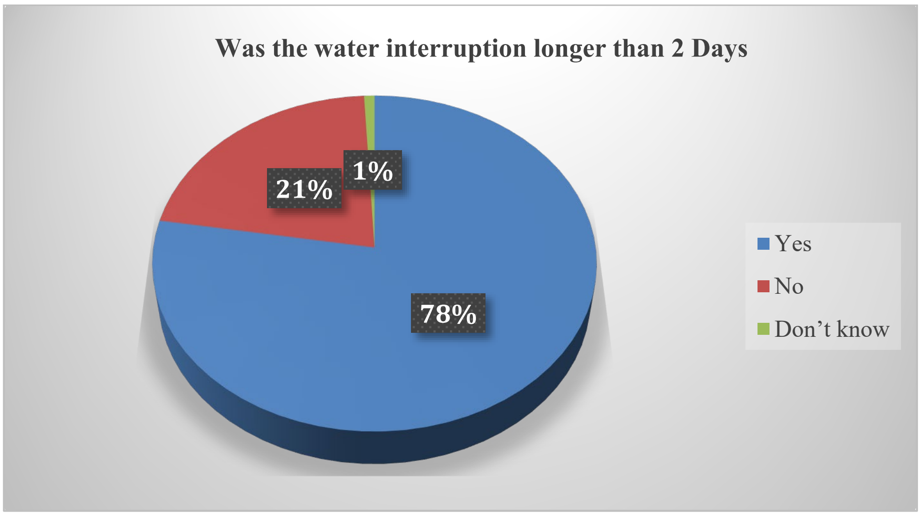

Figure 5: Duration of water interruption

Table 9: Household water interruptions situation in Polokwane

	% Responses	
How often do you get water interruptions in a month?	1-3 times	61,7
	4-5	30,7
	Never	7,7
Total		**100**
	% Responses	
Alternative source of water during the interruption	Bottled water/stored water	75,9
	Municipal water tankers	24,1
Total		**100**
	% Responses	
Main reason for water interruption	Scheduled maintenance	17,1
	Burst pipe	20,6
	Daily regular water cuts	9,4
	Pressure	5,6
	Do not know	47,4
Total		**100**

Household water quality control measures

On their own capacity, the results show that only 2% of households always treat the water before drinking, while 8% do treat the water on occasional basis. Of those households who perform treatment on water, 56% used boiling as the standard water treatment method, while others used chemical and natural filtering methods (Figure 9).

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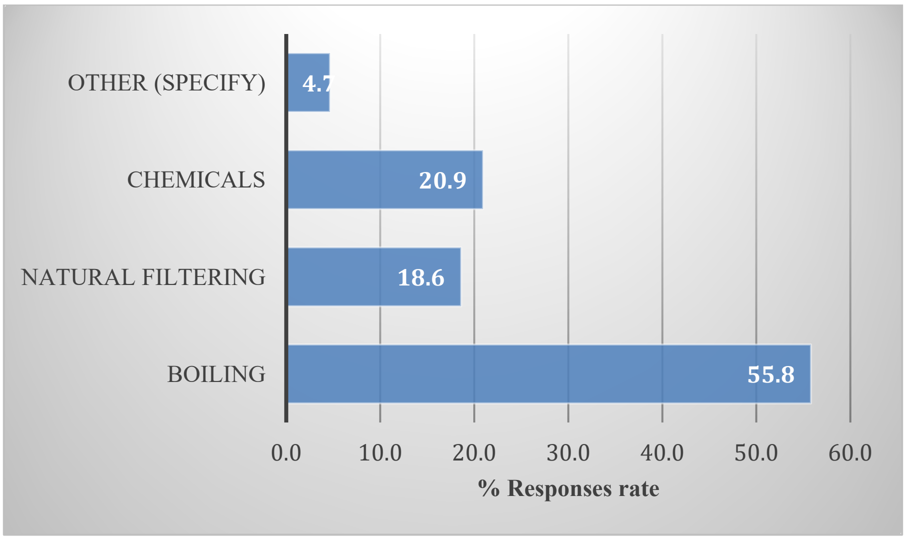

Figure 6: Methods used to treat water before drinking cited by the study participants

Sanitation services

As indicated in figure 7, over half (53.9%) of visited households had flush toilet which is connected to the municipal sewage. Flush toilet connected to a septic tank also recorded in the area, but only accounted for 2.9 %. Pit latrine either ventilation pipe or without ventilation pipe accounted for 40.8 % of total household. The use of chemical toilet as well as using nearby veld was not prevalent in the area. The general prevalence of wastewater or sewage spillage was not considered high in the area. However, 52% of the households felt that the rate at which municipality respond to emergence breakage or spillage is low.

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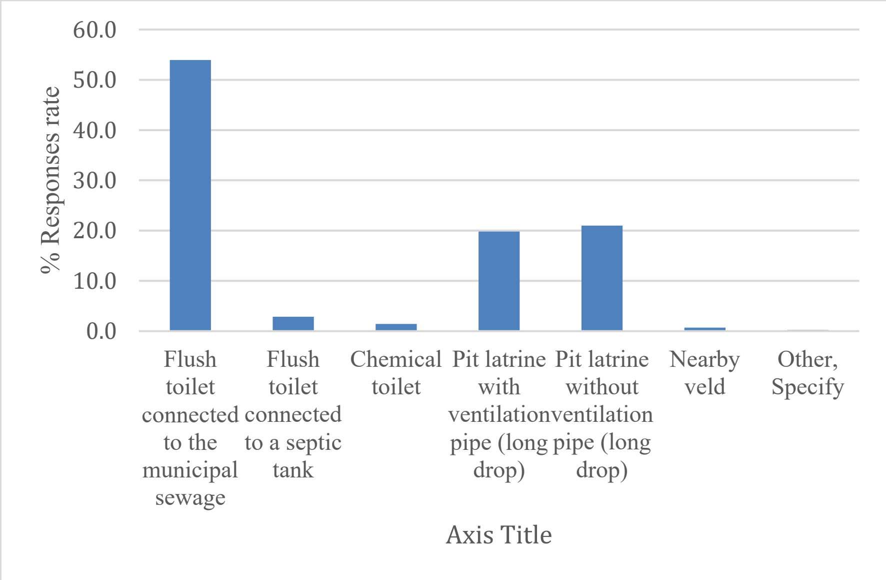

Figure 7: Type of toilet facility used by study participants in Polokwane city

Perspective from stakeholders

Stakeholders and service providers interviewed during the survey included officials from the Polokwane Local Municipality, Provincial Department of agriculture, and the Provincial office of the National Department of Water and Sanitation. Other role players in water and sanitation provision were LIMA rural development foundation, Oxfam Australia, Mvula trust and Private Service providers. According to the Polokwane local municipality, the status of water and sanitation is such that:-

a) The municipality is currently receiving between 80 to 99Ml/d of water and is unable to meet the peak flow demand of 163Ml/day.
b) The Infrastructure is lacking behind the population growth and emerging settlements.
c) Pit latrines still exist, although there are efforts to provide flush toilets and improved structures of pit latrines (i.e. those with ventilation pipe).
d) There are still communities that do not have access to clean water especially in rural areas

The views expressed by the local municipality were also shared by the department of water and sanitation, which indicted that Polokwane city lacks sustainable water sources, and more than 60% of its water is sourced outside the boundaries of the Municipality. The primary concern raised was the amount of water lost during distribution due to aging infrastructure and lack of timely maintenance of burst pipes.

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To address this challenge, the municipality council in partnership with department of water and sanitation intends to invest more than R420 million to replace asbestos pipes in the Central Business District and the surrounding settlements.

To ensure the sustainability of limited water available to the municipality, the provincial department of agriculture indicated that it was encouraging farming households to employ water conservation farming practices and enhancing the capacity of households' harvest rainwater.

Regarding the monitoring of water quality, officials indicated that the water quality tests were conducted regularly. Water and sanitation experts from the University of Limpopo were concerned that there is a risk of ground water being contaminated in some areas due to backlog sanitation service that was not according to approved standards.

4.2 Mbombela City

4.2.1 Community perspectives

Household data

Of total surveyed households in Mbombela, 92 % were staying in a household that was constructed with bricks or concrete that was located on a separate stand (Table 10). The number of occupants per household were varied among households with mean number of 4.59 people.

Table 10: Type of dwelling that the household occupies

Household dwelling type	n	%
Dwelling /house or brick/concrete block structure on a separate stand or yard or on farm	350	92,8
Traditional dwelling /hut/structure made of traditional materials (wattle & Daub1/Mud)	8	2,1
Double story dwelling	5	1,3
Dwelling/house/flat/room in backyard	4	1,1
Shack (Plastic /semi-permanent material/corrugated iron/cardboard)	9	2,4
Shipping container	1	0,3
Total	**377**	**100**

Sources of water for the households

Majority of households (80%) surveyed, the main source of water was the tap located either inside the house or somewhere in the yard (Figure 13). For households that did

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not have water taps inside the house or in the yard, a communal tap was located 200 meters away from the household (Table 11).

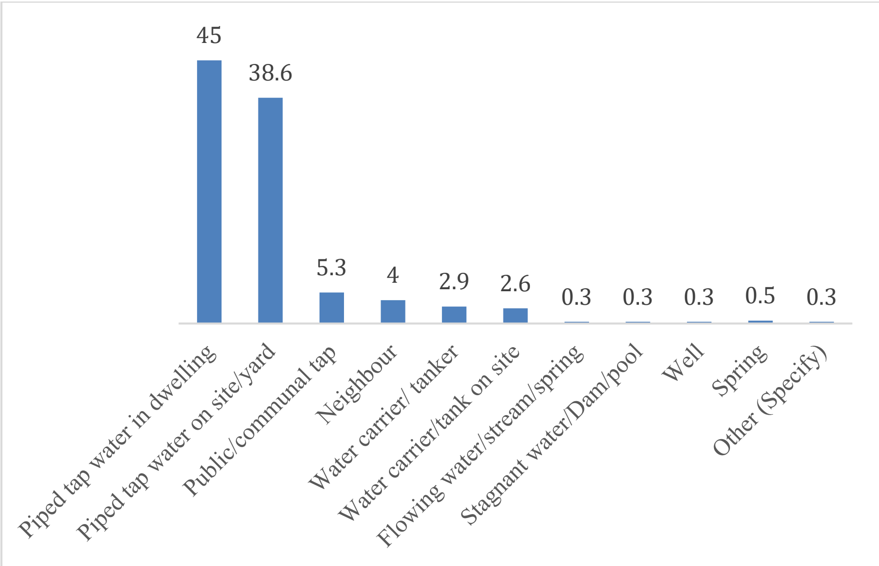

Figure 8: Main source of water for the surveyed household in the study area

Table 11: Distance of main source of water from the household dwelling

Distance of main source of water from the household	n	%
Water source is inside the house	127	34
Water source is less than 200 metres from the house	216	57.9
Water source is between 201 - 500 metres from the house	30	8.0
Total	**373**	**100**

Access to safe drinking water

61 % of households were obtaining water from the tap and 38% indicated that they were using bottled water. Most participants (91.5 %) believed the water from the sources was safe to drink (Table 12).

Table 12: Household perception on water safety

Characteristics	***Yes***	***No***
	Percentage (%)	

Safe to drink	91.5	8.5
Clear (has no colour /free of mud)	82	18
Good in taste	87.6	12.4
Free from bad smell	89.9	10.1

Water supply services

Of total participants, 93% indicated that the municipality was the main provider of drinking water. But only 29% of households indicated that they regularly pay for water services. There were various reasons provided for not paying for water services (Table 13).

Table 13: Reason for not paying municipal water

Reasons	**n**	**%**
Use own source of water	22	8,7
Use a free water source	42	16,5
Pay directly to landlord as part of rent	8	3,1
Payment included in levy	2	0,8
Permission from municipality not to pay	47	18,5
Do not have water meter	46	18,1
Water meter not working/broken	20	7,9
Do not receive water bill	10	3,9
Community decision not to pay	10	3,9
Cannot afford to pay	41	16,1
Water supply irregular	4	1,6
Other (specify)	2	0,8
Total	**254**	**100**

Water supply interruption

In terms of water interruptions, 96% of the households indicated that they had experienced water interruption in the past 12 months. In most cases, the water interruptions were longer than 2 days (Figure 9), and that was happening for up to five times in a month (Table 14). While at times water interruptions were a result of scheduled maintenance, burst pipe and regular water cut routine were some of the reasons why water supply was interrupted. As an alternative, various sources of water supply were used during the interruption, including the municipal water tank.

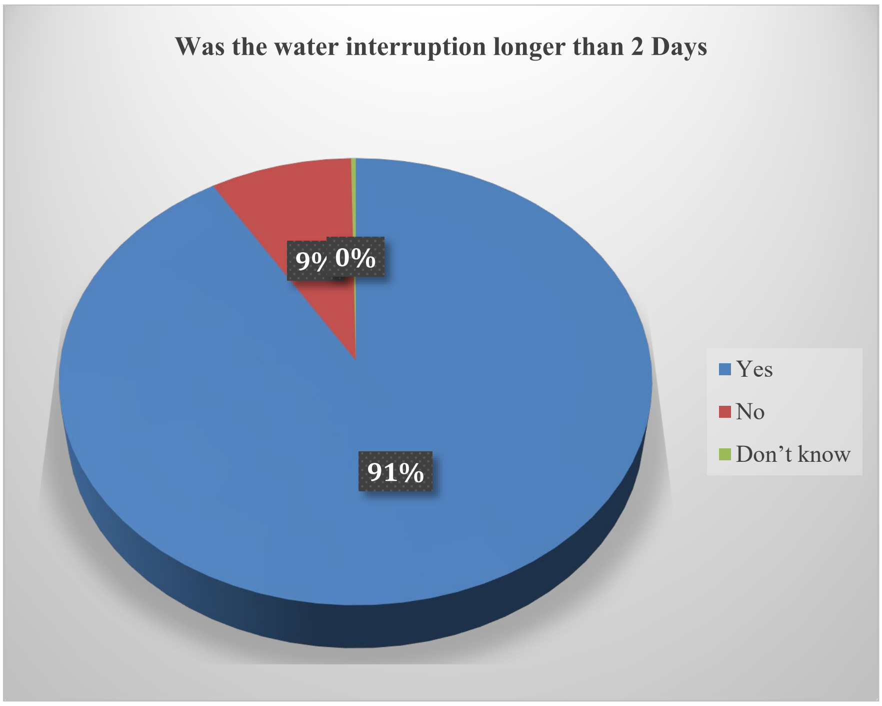

Figure 9: duration of water interruption

Table 14: Household water interruptions situation in Mbombela

How often do you get water interruptions in a month?	**% Responses**	
	1-3 times	58,4
	4-5	41,6
Total		**100**
Alternative source of water during the interruption	**% Responses**	
	Bottled water/stored water	69,2
	Municipal water tankers	26,8
	River/spring	4,0
Total		**100**
Main reason for water interruption	**% Responses**	

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	Scheduled maintenance	16,2
	Burst pipe	4,1
	Daily regular water cuts	71,4
	Pressure	2,0
	Do not know	12,0
Total		**100**

Household water quality control measures

Only 5% of surveyed households indicated that they regularly treat water before drinking and 21% indicated that they occasionally treat water before use. Of total households that treat water before use, 56% indicated that they use chemicals as the standard water treatment method, while the remaining proportion use heat to boil water before drinking.

Sanitation services

Just over half (52.4%) of surveyed households had flushing toilets in their households that were connected to the municipal sewage system. Flush toilet connected to a septic tank accounted for 14.3% of the total household sanitation service provided to community by the municipality (Figure 19).

Pit latrine with ventilation pipe accounted for 32.3 % of total recorded sanitary services. Over half (52%) of the participants felt that the rate at which municipality responds to sewage spillage and breaks was slow.

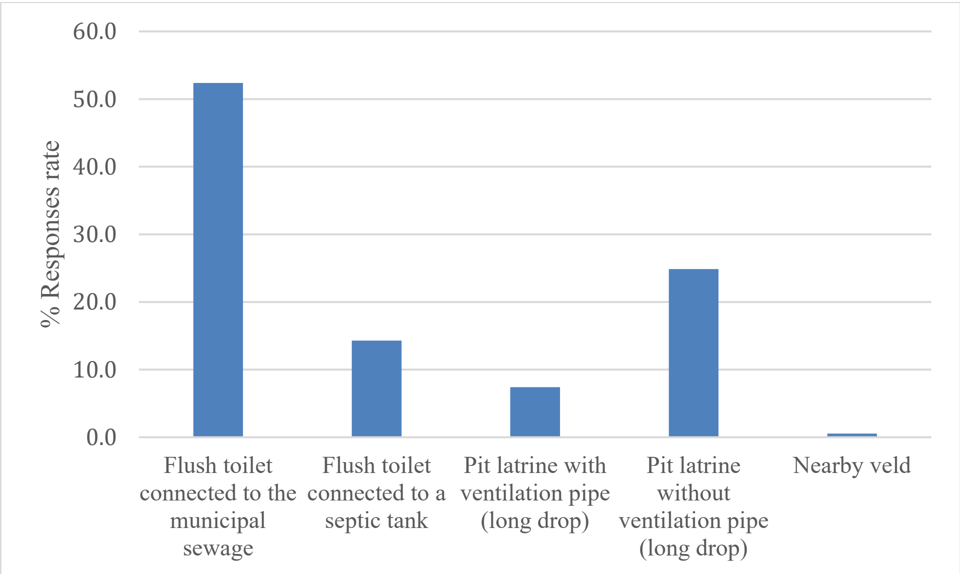

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Figure 10: Type of toilet facility used by study participants in Mbombela city

Perspective from stakeholders

The stakeholders and service providers interviewed during the survey included officials from the Ehlanzeni District Municipality, Mbombela Local Municipality, Provincial Department of agriculture, Inkomati-Usuthu Water Catchment Management Agency and the Provincial office of the National Department of Water and Sanitation.

The National Department of water and sanitation indicated that at the District municipal level (i.e. Ehlanzeni District Municipality), the level of water supply was at 91%. The department thus indicated that it has a backlog of less than 10%. At provincial level the water supply to communities was at 97% with a backlog of 3%.

Regarding the provision of sanitation services (i.e. toilets) the department indicated that it was almost close to eliminate the bucket toilet system in the province.

The Inkomati-uSuthu Management Agency was worried about the fact that water demand was coming closer to exceeding supply. The major concern was a lack of collaborative planning between the Agency and other role players, which included municipality and government departments. The constant urbanisation was also cited as a cause for concern as new settlements required water.

These views were also shared by the officials of the local municipality, who indicated that promises of houses by politicians were fuelling informal settlement and this was disrupting the implementation of strategies and plans. The consequential effect of this was a huge infrastructure backlog with little management of the infrastructure.

The supply of water infrastructure and its maintenance in informal settlements was lacking. This was despite the municipality having operational and maintenance plans. Resources in the form of funds were constantly being channeled into infrastructure development and management with little allocations to new and emerging settlements.

6 Discussion

Service delivery protests linked to water that are prevalent in South Africa [36] indicates the status of water demand and supply in the country. Inland cities like Polokwane and Mbombela are more vulnerable to this as they have little alternative sources and the emerging trend of water scarcity in South Africa is a course for great concern. For cities like Mbombela and Polokwane, smart or digital technologies that can improve the efficient use and management of water are desirable.

In both Polokwane and Mbombela water shortage might escalate as the gap between supply and demand is narrowing. This was obvious in both cities. The gap increases with the total water demand and decreases with water delivered [37]. The main demand for water comes from households that are connected to the municipality reticulation system and used for drinking and sanitation [38].

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What is clear in both cities are increasing households due to additional settlements, from new formal and informal dwellings. For Mbombela there is additional demand from agricultural sector, especially sugarcane plantations that have low water use efficiency. In general households, agriculture and industrial developments are the major sources of water demand and sanitation services, which both municipalities cannot meet.

As a result, they try to control demand by increasing connection rates [39]. This has a circular impact. As the number of households connected to water supply system increase, this in turn increases the total water demand as well as the gap between demand and supply. With this circular connection, local catchment management agencies as institutions responsible to manage water availability become concerned, especially as there is little consultation among the stakeholders assigned to manages water and ensure its security. It emerged in this survey that stakeholders do not coordinate the planning for water supply and demand. Hence, integrated water resource management emphasizes the necessity for multidisciplinary, multi-sectoral and multi-stakeholder integration in the planning, management and decision making for water management [40].

With current predicament and uncertainty of water security in South African cities, it is obvious that water availability in South Africa has declined due to climate change and usage. The country has an average annual rainfall of almost half of the global average (450 mm compared to a global average of 860 mm). To counteract this, cities are sourcing water from areas that fall outside their boundaries. This requires the allocation of extra financial resources and investment in building infrastructure needed to transport and store water sourced elsewhere.

Thus, storage of water in reservoirs has become an integral part of managing water resources in South Africa. Investment in this type of infrastructure requires steady sources of revenue. Unfortunately, this seem to be thwarted by communities are not willing to pay for water services. In ideal situation, the more water delivered to users, the more the potential billable water for municipality.

The overall extension of infrastructure carries the concomitant effect of increasing how fast municipal infrastructure decreases in value and use (i.e. obsolescence rate) [41]. The longer the water supply infrastructure operates above its design capacity, the quicker the infrastructure obsolesces and the quicker it requires refurbishment and replacement [42]. Both cities studied here are likely to experience this

As indicated by Clifford-Holmes et al.[43], the socio-political and institutional context of South Africa's water landscape is varied. This context includes:

- A history of segregation in the form of institutionalized preferences of water supply to certain areas;
- The effects of this segregation are evident in South Africa's high levels of both poverty, inequality and uneven distribution of infrastructure and resources;
- A post-apartheid water management framework that embodies the ambitions of integrated water resource management to rectify mistakes of the past;
- The recognition of the freshwater needs of marine and coastal water bodies e.g. lagoons and estuaries and their subsequent inclusion in the freshwater systems;

- ➢ Developmental planning being enshrined across all the three spheres of government in the country.

Rectifying this has not been a straightforward journey for the South Africa, with many operational manifestations of institutional dysfunction evident and continual challenges in addressing 'who gets what water, when, and how' (Clifford-Holmes et al. 2018[44]). As a norm, effective water resource management requires:

a) Long term accurate assessment of water availability – Planning
b) Short term transition of water in time and space –Operations
c) Reconciliation of demand and supply on a real-time basis without compromising the long-term sustainability of the catchment
d) It is a complex and multi-disciplinary modelling approach and is mainly modelled independently
e) Requires integration

Despite many challenges linked to service delivery and water supply to households, South Africa has committed itself to the ideals of sustainable development goals as a result it is mandatory that the communities be provided with affordable and reliable water and sanitation services. However, with the increasing scarcity of water the supply for water to households, especially in inland cities cannot be guaranteed.

As cities are looking for alternative sources including desalination of marine water, inland water cities do not have this alternative source. These cities need to incorporate water security in their disaster management plans and constantly monitor water availability. Information about water fluctuations and their status of supply can be consistently monitored using digital technologies. Affected cities need to adopt new water technologies to efficiently manage water resources and improve performance. Many innovative technologies are being deployed across the world to monitor water resource usage and leakages.

The importance of supply of water to households has been magnified during Covid-19 pandemic, and digital technologies were deployed to monitor water level in the tanks installed where water supply infrastructure is still lacking.

As could be observed in this study, the household water demand in South Africa is increasing. How this can be reduced is the subject for future assessment and analysis. In addition, this study highlighted how water supply and demand are intertwined. This reality presents the complex nature of household water supply and despite. This can potentially be analyzed through systems science and modelling.

7 Acknowledgment

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Towards the Development of a Mobile Agriculture System for Poms Poultry Farm (PPF), Oyarifa-Accra, Ghana

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Abstract—This paper seeks to propose the implementation of a mobile agriculture (m-agriculture) system for Poms Poultry Farm (PPF) to solve problems such as low patronage of farm products and customer relationship management among farmers and customers. To corroborate the successful implementation of an m-agriculture system at PPF, we employed a questionnaire research instrument concerning the Technology Acceptance Model (TAM) model as a theoretical framework. Closed-ended questionnaires were administered to a sample size of 130 PPF customers. Based on the responses received, we established optimistic responses towards technological acceptance which paved the way for us to propose and develop a suitable m-agriculture application for PPF. It is envisaged that successful implementation of our proposed system will practically increase productivity and help PPF reach out to their target customers.

Keywords—customers, mobile agriculture, Oyarifa-Accra, Ghana, poms poultry farm, technology acceptance model.

1 Introduction

After gaining independence, Ghana was the world's largest producer of cocoa beans (the main ingredient in the manufacture of chocolate) and boasted of one of the highest GDP per capita incomes in the region [1]. Ghana is also involved in both animal production and crop production. The principal crop produce of Ghana can be divided into three subsectors, namely, the industrial crops (which include cocoa, oil palm, coconut, coffee, cotton, kola, rubber, cashew, and shea), the starchy and cereal staples (which include cassava, cocoyam, yam, maize, rice, millet, sorghum, and plantain) and fruits and vegetables (which include the likes of pineapple, citrus, banana, pawpaw, mango, onions, tomatoes, pepper, and eggplant or garden eggs) [2].

The animal products of Ghana can also be summed up as livestock (which includes cattle, sheep, goats, pigs) and poultry (referring to chickens, turkeys, geese, and guinea fowls) [2]. Ghana has abundant viable land and a reasonably well-educated population that can support different types of agriculture including crop production and animal husbandry. Unfortunately, in the last several years, the agricultural sector has been performing poorly and poultry production has unfortunately encountered liberal trade policies that have exposed it to competition from imported products, compelling an almost exclusive focus on egg instead of meat production [2].

The term poultry is used collectively to designate those species of birds that have been domesticated to reproduce and grow in captivity thereby rendering products of economic value [3]. Chickens, turkeys, ducks, and geese generally meet the above criteria. They provide meats, eggs, feathers, animal food, and other by-products such as pharmaceuticals [3]. The poultry industry is perceived to be a major contributor to Ghana's development through employment creation and the enhancement of nutrition and food security. Despite these contributions, the poultry industry is entangled with several challenges that hinder the exploitation of its full potential to the economic contribution [2], [4]. Some of the challenges that farmers encounter include lack of effective customer service, reconciliation of records between farmers and traders, lack of an effective way to collect farm produce data, records farm input expenses, and receive information from other stakeholders [4], [5].

Alternatives to approach such problems are signaled in previous studies. For example, new architectures for poultry houses [6], [7] promote the literal flow and sensor networks technologies collect more reliable samples of climatic conditions inside poultry houses [8], [9]. These novel perspectives suggest that poultry houses could be both architecturally and logically exploited to improve automatic control.

Besides agriculture, ICT and specifically mobile technology have been widely used in other sectors of development especially in developing countries such as Ghana. In such places, mobile technology has been majorly viewed as a reaction to different challenges and different limitations usually infrastructure, poverty, distance, and sparsity [10]. For example, mobile agriculture (m-agriculture) supports the stakeholders in the agriculture value chain through the use of mobile technology. Consequently, the purpose of this study is to determine how activities within Poms Poultry Farm (PPF) at Oyarifa, Accra-Ghana are operationalized and examine the prospects and challenges that confront the awareness and visibility of PPF. Then, we provide a computerized solution by developing an m-agriculture system that will help address the current state of visibility and awareness of services provided by PPF.

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With the aid of the Technology Acceptance Model (TAM) and Mobile Application Development Framework (MADF), this paper employs a quantitative (closed-ended questionnaire) approach to verify and examine the benefits, drawbacks, and implementation of a mobile agriculture application system at PPF. The rest of this paper is structured chronologically as follows: Problem Statement, Literature Review and Related Work, Materials, Methods and Analysis, Discussion and Evaluation of Proposed M-Agriculture System for PPF, and finally Concluding Remarks.

2 Problem Statement

Currently, PPF finds it difficult to the awareness of their poultry products to reach out to the general public. This is because only a few people know about them and their poultry products and the physical venue to activate any purchase. Due to the lack of modern technological customer service and customer relationship management (CRM), sometimes PPF needs to give some of their poultry products out freely because they are aging and no one is buying them. As a result of this, PPF has stopped breeding other types of birds such as broilers, turkeys, geese, guinea fowls, etc., and is compelled to focus only on layers that produce eggs. The income of PPF is generated only from the egg production, which does not give rise to enough income/earnings as compared to the selling of the other type of birds which are used as meat. Because of these problems, PPF cannot meet up with the cost being incurred in the breeding of the birds and they soon run into losses as a result of the little income they receive from selling the eggs. Consequently, regarding the advancement of ICT in agriculture, the focus of this paper is aimed at developing an m-agriculture system for PPF to display their products ubiquitously online. This will help them to reach out to the target audience to attract more customers to purchase their poultry products for the generation of more income to boost their business.

2.1 Research Questions

To tackle our research problem stated above, we seek to relevantly answer the following research questions below:

- What is the current state of visibility and awareness regarding the services provided to customers by PPF?
- What are the challenges of the current state of visibility and awareness regarding the services provided by PPF?
- What steps are required to improve the identified challenges through the proposal and development of an m-agriculture system for PPF?

3 Literature Review

In this section, we review the literature and related work about the study. The review concentrated on the following key issues: (i) concept of m-agriculture, (ii) why a smartphone over PC (iii) M-agriculture adoption in African Countries, (iv) M-Agriculture adoption in Ghana, (v) Challenges in M-agriculture (vi) Benefits of M-Agriculture (vii) Theoretical Framework - Technology Acceptance Model (TAM) and (viii) Related Work. Consequently, to achieve our research objectives, the literature review focused on research literature related to mobile agriculture application acceptance and implementation in developing countries. Acceptance and implementation in the context of this study refer to establishing, adopting, and utilizing an m-agriculture system for accessing poultry-related services.

3.1 Concept of M-Agriculture

M-Agriculture is a subset of e-agriculture referring to the delivery of agriculture-related services via mobile communication technology [10]. Mobile agriculture includes the provision of agricultural services and information, using mobile devices such as cell phones, Personal Digital Assistants (PDAs), tablets, and other handheld communication or computing devices [5], [11]. M-Agriculture also involves gathering relevant data through mobile technologies such as automated weather stations (AWS) or systems and sensors for local-based collections [12]. In recent years, mobile technology has been widely adopted in most parts of the world. Currently, a developing country like Ghana is also recording high mobile penetration rates [13].

3.2 Smart Phones Versus Desktop PCs

Mobile computing devices have advantages over the use of a Personal Computer (PC), especially in the developing world [5], [19]. The cost of purchasing a typical smartphone is lower than that of a PC as are the recurring costs. Furthermore, workers in Poms Poultry Farm are conversant with the use of mobile devices than the use of PCs. With these facts, a mobile device is the most appropriate medium to introduce technology to users in Poms Poultry Farm. Moreover, mobile devices provide an environment for interaction between different systems and people. This interaction ensures a more effective and timely way of acquiring information, which is a key requirement in efficient M-Agriculture applications [5], [11].

In many developing countries, more people have access to mobile phones than to older technologies [14]. Many studies have confirmed that mobile phones are indeed improving farmers' production and adoption of new practices [15]. An interview of some Indian farmers and fishermen reviewed that information delivered via their mobile devices allowed them to increase yields [16]. Smartphone coverage has also improved market efficiency and reduced consumer prices for certain commodities [15].

The functionality and flexibility of smartphone use allow marketers and practitioners to implement their marketing strategies efficiently, to accomplish the organizational objectives as well as to ensure good customer services [17], [18]. In the context of our paper, customer service refers to the act of taking care of the poultry needs of customers by providing and delivering professional, helpful, high-quality ICT service and assistance to ensure that the customer's requirements are met. Therefore, the use of M-Agriculture application in Poms Poultry Farm might be an important target for mobile marketing.

3.3 M-Agriculture Adoption in Ghana

As a result of high smartphone penetration rates in Ghana [39], the modernization of agriculture has been recognized as one of the ways to accelerate Ghana's medium-term economic development plan. To improve agricultural sustainability and productivity in developing countries, technology adoption by smallholder farmers is a key strategy. Anang [21] therefore investigated the factors influencing the adoption of technology for agricultural mechanization in Ghana. The results indicated farm size, extension visits, herd ownership, the production system, age and gender of the household head, the degree of specialization in production, household size, and location of the farm were significant factors that have to be considered in technology adoption [21].

3.4 Challenges in M-Agriculture

According to Minghetti & Buhalis [23], having access to technology does not necessarily mean that people will use it. Many people have access but are unable to use technology effectively for a variety of reasons. Despite the numerous m-agriculture interventions in different parts of the world, most of them have faced challenges that have rendered them non-impactful in their areas of implementation.

- **Technological Challenges:** the world of technology is constantly developing and advancing. As mentioned by Verbelen et al. [24], application developers find it difficult to design applications for the mobile market because of the constant improvements that alter mobile devices. Consumers may also find it hard to accept available technologies.
- **The Up-Front Investment:** required for m-agriculture application solution is larger due to developmental costs. Budgets, finance, accounts, and cash flows will need to be available and negotiated.
- **Infrastructure:** whether additional technology expenditures can be justified and whether compatibility of all software and hardware can be achieved. Limited network coverage, actual network quality, unreliable SMS due to increasing traffic loads creating network bottlenecks and crippling SMS service, non-existent GPRS and G3 service.
- **Handset Limitations:** preference for simple, affordable, and low-end phones with small screen-size.
- **Language Barrier and High Illiteracy Levels:** that play a factor include whether the farmers and consumers are conversant with the use of smartphones, non-literate and semi-literate users of ICT, and plenty of local languages.

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3.5 Benefits of M-Agriculture

M-Agriculture applications play a decisive role in vibrant economies as a mechanism that reflects and shapes producer and consumer incentives in supply and demand [25], [26]. The following are some of the advantages of m-agriculture:

- **Reachability and Accessibility of Products:** is the single most influential factor in adopting m-agriculture. The elimination of costs associated with consumers traveling from their comfort zones to the poultry farm to purchase products and make enquires of the prices of the products. In this case, services and products can be made available to consumers wherever and whenever a need arises [25].
- **Consistent Delivery of Products:** is possible with Mobile agriculture applications. In this sense, the consumer can place an order in advance for the farmer to make a reservation for that order.
- **Information Sharing** is one of the advantages of Mobile agriculture applications. With this sense, the farmer can post available products and their prices on the application for consumers. This will facilitate connections between farmers and consumers, thereby creating more efficient markets [27].

3.6 Related Work

In this section, we present a review of existing m-agriculture applications in the literature to substantiate the proposal of our m-agriculture application model in PPF.

In Ghana, an m-agriculture platform called Vodafone Farmers' Club (VFC) has implemented an m-nutrition service as well as other mobile services [40]. The m-nutrition is a 'bundled solution', offering agriculture and nutrition information through SMS and voice message (provided by Esoko), as well as free calls to others with Vodafone Farmers' Club SIM cards [40].

Gichamba & Lukandu [5] introduced a model for designing an m-agriculture application for dairy farming. In line with the Agricultural Policy in Kenya [20], their proposed model concentrates specifically on dairy farming and shows how various stakeholders in this sector can share a mobile platform that meets their various needs.

Abhishek et al. [41] developed a mobile application that serves as a platform for the movement of agricultural products from the farms directly to the consumers or retailers. Their mobile and web application provides privilege for both farmers and consumers or retailers to buy and sell required farm products without the involvement of a middleman at its right profitable price.

Łukowska et al. [42] developed an autonomous mobile platform with a soil sampling device for agriculture. In their system, soil samples are analyzed to determine the composition, characteristics, or nutrient levels and the smallholder farmers can use simple hand-held field-testing kits.

Chen et al. [43] developed a system that supports android and IOS system mobile phones, the Widgets technology, and HTTP communication technologies were used to develop a real-time agricultural information collection system, which is based on cross-platform mobile Geographical Information System (GIS).

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Zhang et al. [44] present a Cordova framework based on GeoPackage mobile application to support field operations in agriculture. By implementing GeoPackage Software Development Kit (SDK) on a mobile application, GeoPackage files could easily be accessed, managed, and visualized in agricultural field operations.

Roy et al. [45] developed a system called AgroTick. AgroTick is an innovative hybrid system for smart agriculture that is supported with a mobile interface and designed using IOT technology modules such as cloud computing, embedded firmware, hardware unit, and big data analytics.

Shriram et al. [46] developed a system that provides market information to a farmer using its user-friendly interface on the mobile application. The mobile application is intended to be used for fast and updated information delivering system for farmers. Furthermore, it has native language support to make the transaction easy for farmers.

3.7 Technology Acceptance Model (TAM)

According to Oliveira and Martins [28], the Technology Acceptance Model (TAM), is a theoretical model that explains how users come to accept and use technological innovations. Perceived usefulness and ease of use are the major theoretical constructs of the TAM. Chuttur [29] asserted that the perceived usefulness is the extent to which individuals view the benefits of using technology. The Technology Acceptance Model (TAM), predicts how individuals use technology. Additionally, the perceived ease of use is a highlight of how difficult or easy the Technology is, to the user. Thus, a connection exists between these two constructs.

TAM has been used in the context of several studies on user acceptance technology, including the World Wide Web [30], mobile banking, [31] and healthcare [32]. However, along with the relationships suggested by TAM, many researchers have also examined the antecedents of both Perceived Ease Of Use (*PEOU*) and Perceived Usefulness (*PU*) [33], [34]. Most importantly, the majority of technology acceptance models have been developed and modified in Western countries, particularly in Europe and South America [35].

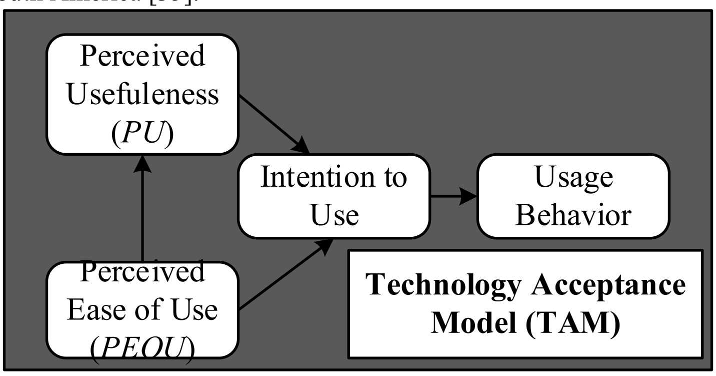

Fig. 1. TAM

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Figure 1 [36], [37], [38] shows the relationship between the components of TAM. This indicates that *PU* and *PEOU* jointly predict the attitudes towards using technology. PU also influences the user's Behavioral Intention (*BI*) or Usage Behavior in using technology. Intention to Use (*ITU*) also determines the actual use of technology.

With regards to the relationship between PU and Usage Behavior, "within organizational settings, people form intentions toward behaviors they believe will increase their job performance, over and above whatever positive or negative feelings may be evoked toward the behavior per se". Additionally, the model posits that PEOU is likely to influence *PU*, where the increase of *PEOU* leads to improved performance. Consequently, *PEOU* has a direct influence on *PU* [36], [37], [38].

4 Materials and Methods

In this section, we elaborate on the methodology applied in the research project to gather/acquire the relevant data for effective analysis. Information regarding the population and the sample of the study, research/data collection instruments as well as the results of the study are discussed in this section. This section also elaborates on a detailed analysis of data which provides an insight into the findings of the study, accompanied by numerical representations of the data and interpretation of results.

4.1 Research Methodology and Data Collection Instrument

The research methodology adopted for this study was a mixed research approach consisting of quantitative (questionnaire/google forms) and a software development life cycle (SDLC) approach for designing the proposed mobile agriculture application. The questions which constituted the questionnaire were made up of both close-ended and open-ended questions. Furthermore, the questionnaire did not ask the participants to provide any personal details. The quantitative method which involved the administration of questionnaires was selected due to the benefit of reaching out and obtaining more information from a large number of people who are not situated in one place. Figure 2 illustrates the research process of this study.

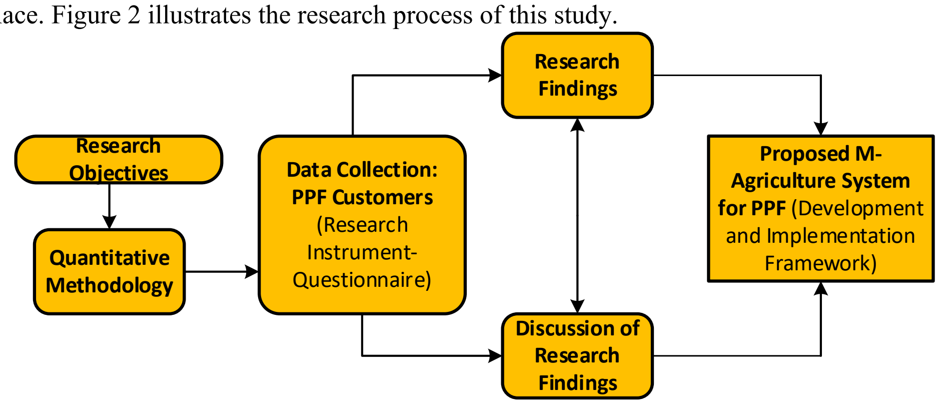

Fig. 2. Research Process

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The questionnaire targeted customers to identify the possibility of adopting technology for an m-agriculture application in Poms Poultry Farm. The questionnaire and field interviews were aimed at collecting information on smartphone devices among the target stakeholders, the usage and experience with general mobile applications, and the usage and experience with m-agriculture applications. The questionnaire consisted of 22 questions in all with three (3) subdivisions consisting of Demography (two questions), Customer/Farmer Information (eight questions), and Technology Acceptance (twelve questions). The questionnaires were distributed to customers electronically through the means of google forms.

4.2 Population and Sample of the Study

The participants considered in the study involved customers of PPF. PPF has customers within and outside Oyarifa in Accra (the area that the farm is located). The places outside Oyarifa are Madina and Adenta. The population that was considered were the customers outside Oyarifa because they form the majority of the population size that purchase his products. Customers of PPF were purposively sampled from within and outside Oyarifa. The target population that was initially considered were customers outside Oyarifa from two different places namely; Madina and Adenta. This resulted in a total target population of 130 customers (N=130). One hundred and thirty (130) questionnaires were administered to the customers. We received one hundred (100) questionnaires from the customers representing a 76.92% response rate. This response rate shows that we received enough questionnaires for data analysis.

To ensure the reliability and validity of our sample size for customers we utilized a standard formula/equation shown in (1) below from Kothari (2004) as follows:

$$n = \frac{Z^2 \times p \times q \times N}{e^2 \times (N-1) + Z^2 \times p \times q} \quad (1)$$

where n = Sample Size, Z = Confidence Level, p = Probability of Success, q = 1-p, N = Population and e = Level of Precision. We, therefore, computed our estimated sample size (n) using equation (1). In our computation for n, we employed the following in (1), Z = 1.96, p = 5% (0.05), q = 1-0.05 = 0.95, N = 130 and e = 0.02. This computation is shown in equation (2) below.

$$\boldsymbol{n = \frac{1.96^2 \times 0.05 \times 0.95 \times 130}{0.02^2 \times (130-1) + 1.96^2 \times 0.05 \times 0.95} = \frac{27.37}{0.185} = 101.34} \quad (2)$$

The result of equation (2) shows the computation of our estimated sample size as 101.34. However, 1 questionnaire was fully not answered so had to take them off from the total responses received which enabled us to use the remaining 100 as the

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sample size for effective data analysis. Results of the study are presented in descriptive statistics and percentages below.

Table 1. Profile of respondents

S/N	Variable		Customers	
		Category	**Number**	**%**
1	Gender	Male	44	44
		Female	56	56
		Total	**100**	**100**
2	Age Group	16-25 years	41	41
		26-35 years	47	47
		36-45 years	12	12
		46-55 years	0	0
		Above 56 years	0	0
		Total	**100**	**100**
3	Highest Qualification	University	42	42
		WASSSCE	43	43
		BECE	4	4
		No Formal Education	0	0
		Other	10	10
		Total	**100**	**100**
4	Residence	Oyarifa	31	31
		Madina	42	42
		Adenta	27	27
		Total	**100**	**100**

4.3 Results of the Study

4.3.1 Profile of Respondents

With reference to table 1 above, 44% (44) of the customers were males and the remaining 56% (56) were females (Table 3.1). Furthermore, the results in Table 3.1below shows that majority of the customer respondents in this study were within the age group of 26-35 as they constituted about 47% (47) of the total number of customers engaged followed by 16-25 years representing 41% (41) followed by 36-45 years representing 12% (12).

In terms of qualification of customers, a majority (43) of them hold WASSCE qualification representing 43%. Customers with university qualifications represented 42% (42), other forms of qualifications constituted approximately 10 (10%) each, and customers with BECE qualification constituted 4% (4). Also, Table 3.1 shows that majority of the customer respondents reside in Madina representing 42% (42), followed by customers in Oyarifa representing 31% (31). Lastly, 27% (27) of the customers reside in Adenta.

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4.3.2 Technology Acceptance of Customers of PPF

The results in Table 2 below displays frequency analysis of the technology acceptance for the customers. Results in Table 2 shows that 95% representing 95 customers use smartphones and 5 (5%) do not use smartphones. Furthermore, 93 (93%) customers stated that they use smartphone programs such as games and communication applications. However, 7 (7%) customers stated that they don't use smartphone programs such as games and communication applications. The results in Table 2 also show that 34% representing 34 customers are aware of the existence of m-agriculture applications for poultry services and 66% representing 66 customers are not aware of the existence of m-agriculture applications for poultry services.

Table 2. Technology acceptance by customers

		Customers		
S/N	**Questions**	**Category**	**Number**	**%**
1	Do you own a smartphone?	Yes	95	95
		No	5	5
		Total	**100**	**100**
2	Do use smartphone programs such as games and communication applications?	Yes	93	93
		No	7	7
		Total	**100**	**100**
3	Do you know whether there is an m-agriculture application for poultry services?	Yes	34	34
		No	66	66
		Total	**100**	**100**

4.3.3 PEOU of Respondents

In our study, the Perceived Ease of Use (PEOU) is a highlight of how difficult or easy the technology is, to the user (Chuttur, 2009). As shown in Table 3 below, the highest M value in terms of PEOU (M = 2.31, SE = 0.12, SD = 1.24, V = 1.53) shows that, concerning the responses from customers, they will find the m-agriculture application to be flexible to interact with. This analysis is followed by customers asserting that their interaction with the m-agriculture application would be clear and understandable (M = 2.26, SE = 0.12, SD = 1.24, V = 1.55). Furthermore, the results in Table 3 shows that, they will find it easy to become skillful at using the m-agriculture application (M = 2.16, SE = 0.12, SD = 1.19, V = 1.41).

Also, most customers will find it easy to learning how to operate the m-agriculture application (M = 2.09, SE = 0.12, SD = 1.16, V = 1.36), followed by customers asserting that, they will find the m-agriculture application easy to use (M = 2.08, SE = 0.11, SD = 1.13, V = 1.27). Finally, most customers would find it easy to get the m-agriculture application to do what they want it to do. (M = 2.00, SE = 0.10, SD = 1.02, V = 1.04).

Table 3. Inferential statistics of the PEOU of customer respondents

PERCEIVED EASE OF USE (PEOU)	**TN**	**M**	**SE**	**SD**	**V**

Learning to operate the m-agriculture application would be easy for me.	100	2.09	0.12	1.16	1.36
My interaction with the m-agriculture application would be clear and understandable.	100	2.26	0.12	1.24	1.55
I would find the m-agriculture application to be flexible to interact with.	100	2.31	0.12	1.24	1.53
It would be easy for me to become skillful at using the m-agriculture application.	100	2.16	0.12	1.19	1.41
I would find the m-agriculture application easy to use.	100	2.08	0.11	1.13	1.27
I would find it easy to get the m-agriculture application to do what I want it to do.	100	2.00	0.10	1.02	1.04

4.3.4 PU of Respondents

In our study, Perceived Usefulness (PU) is the extent to which an individual views the benefits of using technology (Chuttur, 2009). As shown in Table 3.4 below, the highest M value in terms of PU (M = 1.84, SE = 0.09, SD = 0.90, V = 0.80) shows that, in relation to the responses from

customers, using an m-agriculture application in poultry activities would enable them to accomplish tasks quickly, followed by customers asserting that Using an m-agriculture application would enhance their effectiveness in poultry activities (M = 1.83, SE = 0.10, SD = 0.96, V = 0.93) and the usage of the m-agriculture application will help them to access poultry services quickly (M = 1.82, SE = 0.10, SD = 0.97, V = 0.94). Furthermore, the results in table 3.4 shows that, using an m-agriculture application will improve the communication between the farmer and customers (M = 1.78, SE = 0.09, SD = 0.89, V = 0.80). Also, most customers would find the m-agriculture application very useful in their poultry activities (M = 1.77, SE = 0.09, SD = 0.90, V = 0.81). Lastly, using an m-agriculture application in poultry services would increase productivity (M = 1.76, SE = 0.09, SD = 0.93, V = 0.87).

Table 4. Inferential statistics of the PU of customer respondents

PERCEIVED USEFULNESS (PU)	TN	M	SE	SD	V
Using an m-agriculture application would help to access poultry services quickly.	100	1.82	0.10	0.97	0.94
Using an m-agriculture application would improve the communication between the farmer and customers.	100	1.78	0.09	0.89	0.80
Using an m-agriculture application in my poultry activities would increase my productivity.	100	1.76	0.09	0.93	0.87
Using an m-agriculture application would enhance my effectiveness in poultry activities.	100	1.83	0.10	0.96	0.93
Using an m-agriculture application in my poultry activities would enable me to accomplish tasks quickly.	100	1.84	0.09	0.90	0.80
I would find the m-agriculture very useful in my poultry activities	100	1.77	0.09	0.90	0.81

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4.3.5 Brief Research Discussion

Regarding the research analysis discussed above as shown in Tables 3 to 4, the respondents (customers) are willing to embrace and accept technology in poultry activities, thereby paving way for us to propose, develop and implement a mobile agriculture application for customers of Poms Poultry Farm.

5 Proposed M-Agriculture System for PPF

This section describes the process we utilized to develop the proposed m-agriculture system for PPF. The proposed system was developed and evaluated and the result corresponded with the expected output. Consequently, using the SDLC approach, the proposed system has been developed to ensure that the obligations of PPF as required are met. The software program used in designing the proposed system is based on the PHP-based, client/server type software model. The system is implemented using Bootstrap and MySQL as the backend.

5.1 System Requirements

The functional requirements of our proposed m-agriculture application system are:

- The system will enhance effective communication between customers and farmers.
- The system will help increase productivity in the poultry activities.
- The system will allow the Farmer to upload and update products.
- The system will keep records of orders.

In terms of non-functional requirements, our proposed m-agriculture application system successfully runs/operates on mobile devices/ smartphones. Furthermore, our proposed m-agriculture system will be reliable and shall be available within 24 hours every day and can be accessed by both the farmers and customer.

Using the above requirements as well as other features: ***Application Service*** (*messaging*), ***Utility Services*** (*authentication, user storage, logging and monitoring, application storage, interfacing, and search*), and ***Configuration Services*** (*group management, identity management, and application management*), an m-agriculture system shown in Figures 4 to 10 were developed to help both farmers and customers in farming activities and services respectively.

5.2 Use Case Diagram for Farmers and Customers

This Use Case Diagram is a graphic depiction of the interactions among the elements of an m-agriculture system. The main actors of this use case diagram are the Administrator/ Farmer and Customers.

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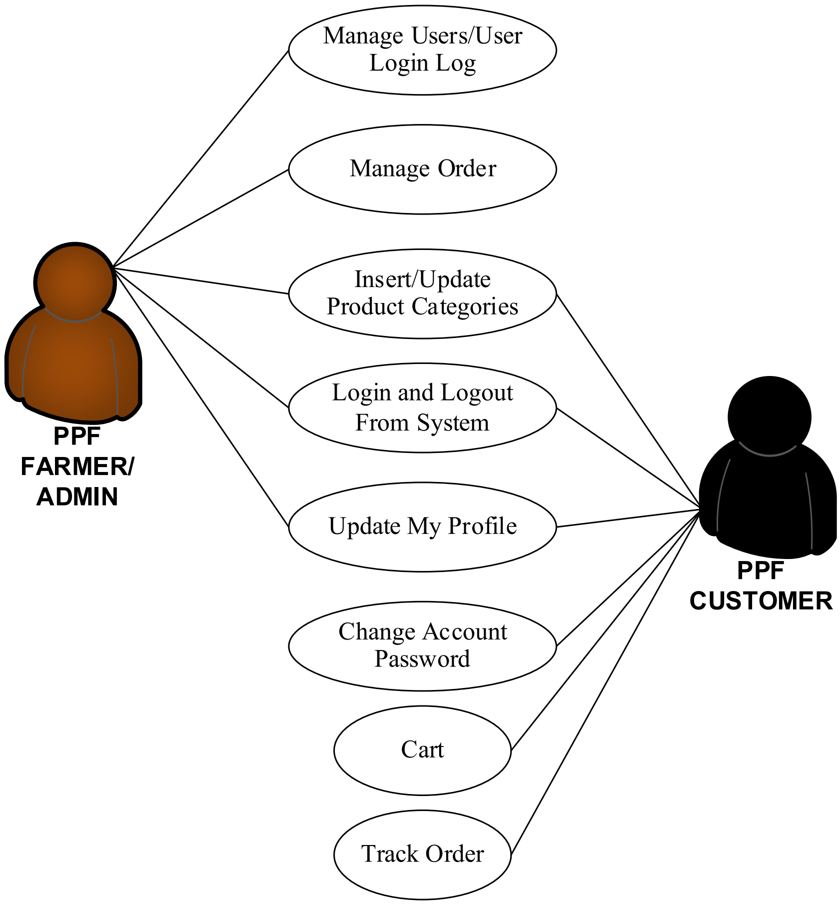

Fig. 3. Use Case diagram for our proposed system

5.2.1 Administrator/ Farmer

The administrator/ farmer's relationship among other actors are Manage users, Manage orders, Insert/Update Product Categories.

5.2.2 Customers

The customer's relationship among the actors are search product categories, add Products to Cart, Wish List, and Track orders.

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5.3 Discussion and Evaluation of the Proposed M-Agriculture Application

Globally, advancements in ICTs have paved the way for the proliferation and beneficial adoption of pedagogic methods in farming activities for both farmers and customers in agriculture. For example, the mobile agriculture application system proposed in this paper, cannot be implemented without both farmers and customers willing to accept and embrace technology as part of farming activities and services in Poms Poultry farm at Oyarifa. Initially, farmers and customers have to go through the normal face to face farming activities which bring about more problems in this process.

Based on the research conducted, the findings revealed that none of the farmers use technology to interact with customers concerning farming activities and products. Furthermore, the findings of the research also revealed that both farmer and customer respondents are strongly willing to embrace mobile agriculture applications and perceive technology as an important tool to improve their farming activities in terms of output quality, patronizing their products, social influence processes, and job significance.

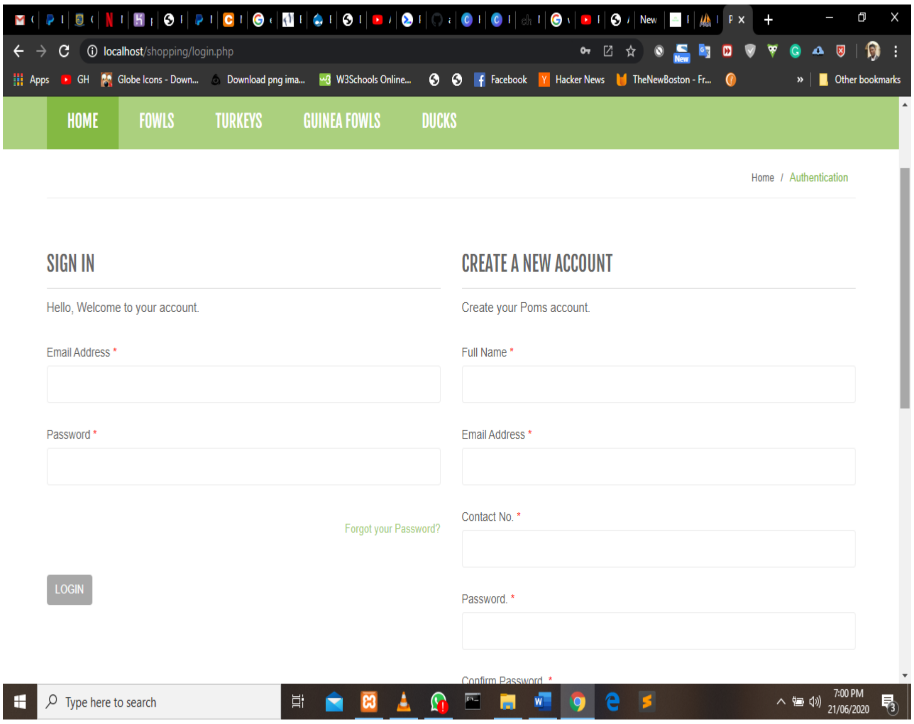

Fig. 4. User login screen

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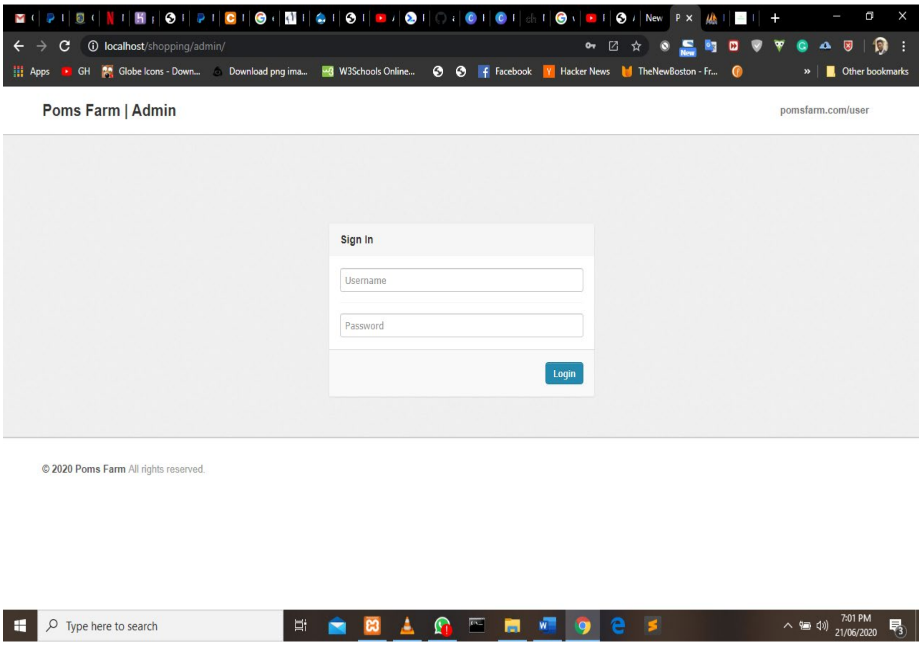

Fig. 5. Administrator/Farmer login screen

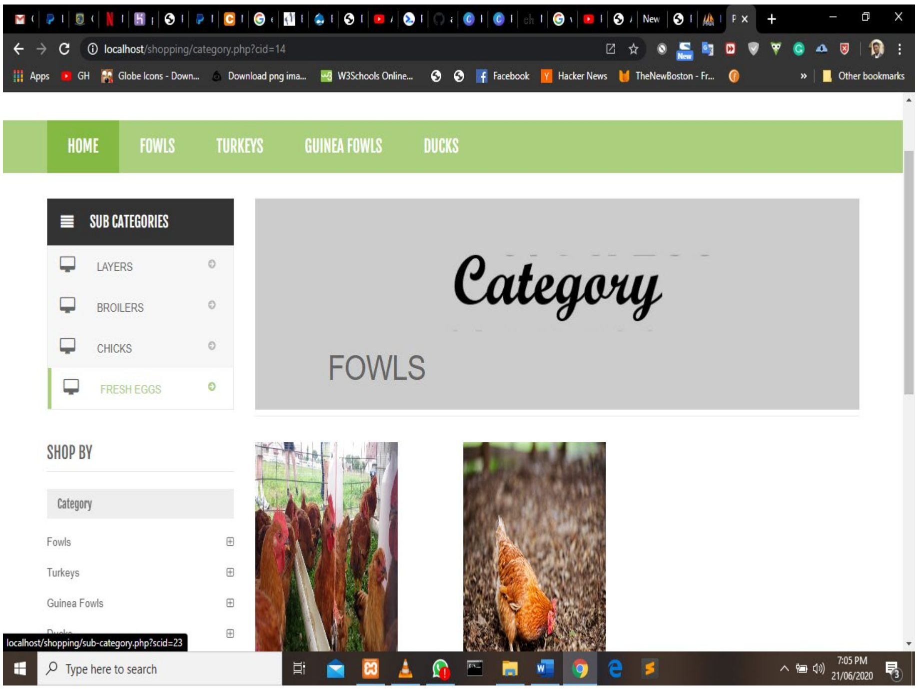

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Fig. 6. Product category

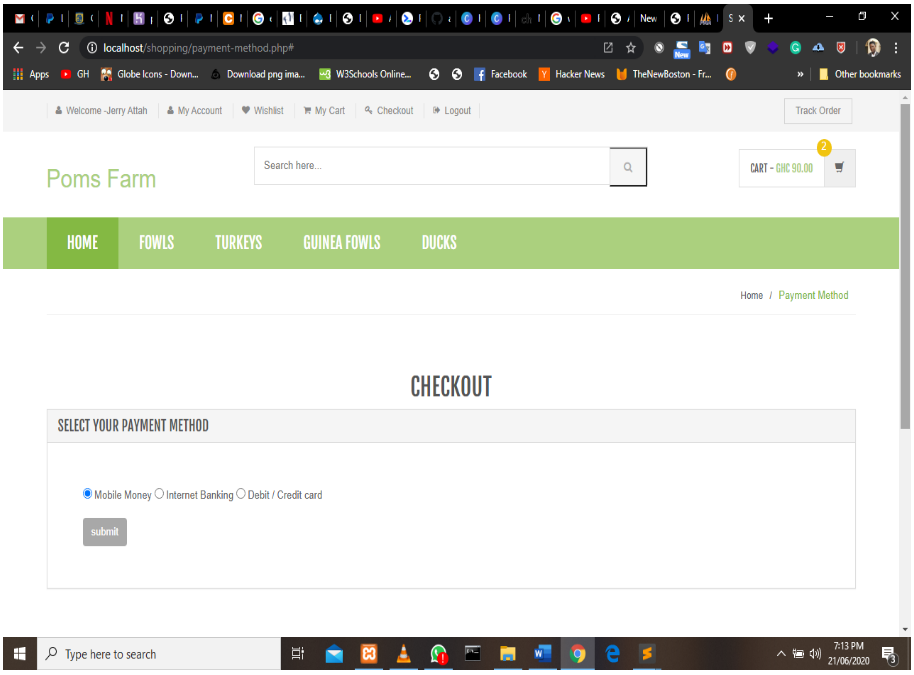

Fig. 7. Checkout page

To successfully develop and implement the m-agriculture application for PPF as proposed in this paper, it was very necessary to review our research questions and ascertain the readiness of farmers and customers in adopting technology as part of farming activities and services. Additionally, it was significant to consider vital variables or needed resources that influence both farmers and customers of PPF to encourage them to use ICT's for farming activities.

The number of farmers and customers used for evaluating our proposed m-agriculture system were five (5) and fifty (50) respectively. In the use of the m-agriculture application, both farmers and customers agreed that more training in technology usage was needed to effectively implement the proposed m-agriculture system. The proposed m-agriculture system enabled opinions of both farmers and customers to be taken into consideration for effective and successful implementation.

6 Concluding Remarks

The fast growth and proliferation of ICT in agriculture have paved the way for technology usage as a tool for farming. This proliferation has enabled agricultural sectors to employ other modes of farming involving ICT such as m-agriculture. To promote and inspire farmers and customers to adopt m-agriculture in PPF, this paper utilized a quantitative research methodology (questionnaire), the Technology Acceptance Model (TAM) theoretical framework, and Mobile Application Development Framework (MADF) to propose an m-agriculture system. The questionnaire for this research was developed using components of the TAM and MADF framework. The questionnaire was administered to one hundred and thirty (130) customers in PPF. The proposed m-agriculture system uses smartphone and laptop/notebook features that allow farming to take place anytime and anywhere by PPF farmers and customers through ICT in agriculture.

Similar to the results of previous studies stated in our related work, results of our study revealed that most of the farmer and customer respondents are willing to accept and embrace technology as part of farming in PPF. Additionally, the proposed m-agriculture system is suitable for integrating ICT in agriculture with the current Face-to-Face (F2F) farming mode in PPF. Furthermore, it is envisaged that judging by the global significance of m-agriculture in agricultural sectors, the proposed m-agriculture system in this paper can also be applied and implemented in other poultry farms in and outside Ghana to further corroborate national international relevance of ICT in agriculture.

A limitation of this research study is the population size concerning the number of customers in PPF as well as other poultry farms in Ghana. To further substantiate the proposed m-agriculture system in this paper, further research, evaluation, and implementation in many other poultry farms in Ghana is very necessary, vital, and relevant. Since this research work is limited to PPF, future work will focus on increasing the population size through the promotion of further research design, amplification, and development of a notebook for the proposed m-agriculture system so that many other poultry farms in Ghana can use it to encourage and motivate their farmers and customers to integrate ICT in agriculture.

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