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SUMMARY

RESEARCH ARTICLE   **OPEN ACCESS**

A PLC BASED CONTROL SYSTEM FOR LOAD FREQUENCY CONTROL IN AN ISOLATED SMALL HYDRO POWER PLANT

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ABSTRACT

Renewables provide 20 % of the power generation worldwide, being hydro power the cheapest and most sustainable way to generate power, representing almost a fifth of the generation worldwide. In Cuba, electrification in mountainous areas is through isolated small hydro power plants from the National Electroenergetic System. One of the most important components in hydro power plants is the frequency controller, due to the changing condition of the demand of power generated by users. The use of inefficient regulation systems with regulation techniques made from resistive load or ballast, provides the statement of frequency regulation through the management of the water flow as a viable technical solution. In the current work, the frequency regulation in the small hydro power plant "Hanabanilla" with a PID as a controller designed in Matlab Simulink and its implementation in a control system made from a PLC M241 by Schneider Electric is proposed.

I. INTRODUCTION

The generation of electric power through hydro power plants is one of the most efficient and safest ways to generate power. The beginning of its use dates back from the first Industrial Revolution in England, being the civil engineer John Smeaton its main promoter. Currently, it plays an essential role in the electrification of rural areas located far from the big networks of power distribution, especially in developing countries.

Normally, small hydro power plants, whose power ranges between 50 and 500 kW according to the Latin American Energy Organization (known in Spanish as OLADE) [1] are more profitable and cleaner for the environment than hydro power plants which have bigger power. There are two ways of operation in the small hydro power plants: isolated mode and that connected to an electric network. By working in both ways of operation, consumers require a continuous and quality service, being the frequency of the system one of the quality rates. Deviation of the instant frequency value is an inevitable fact due to the imbalance produced between generation and the charges connected to the system that vary randomly depending on the incorporation or desconnection of such charges. In order to maintain the instant frequency value of the system within the recommended ranges, it is necessary to implement a frequency regulation mechanism.

The problem of frequency control in small hydro power plants can be pictured as a rejection before disruption [2] and it is subject to variations of operation's conditions of the plant. The load-frequency control or automatic control of generation (known in Spanish as AGC) is focused on maintaining the frequency within the permissible limits and controlling the interchange of power between the different areas. In Cuba, out of the 107 small and micro hydro power plants currently working, only six of them have some frequency regulation mechanism, and since these systems are technologically obsolete and energetically inefficient due to the use of the load or regulation for ballast resistances, it is necessary the design of a frequency control in isolated systems which are adapted to the demands of quality in the generation of electric power and which are best used on the available water resource.

The small hydro power plant "Hanabanilla" ranks in the type of run-to-the-river small hydro power plant and consists of a

unit which generates 130 Kw of power with a Pelton turbine, and it is currently working connected to the National Electroenergetic System (known in Spanish as SEN), since it does not possess a frequency regulation system to work in an isolated mode. Since its beginnings, this small hydro power plant worked in an isolated mode with an electronic system of frequency regulation by resistive load, being its purpose to feed the plant service of the Hydro power Plant "Hanabanilla" with 43MWh and the Administrative Building of the entity. This regulation system broke down leaving the unity inoperative until it was decided to syncronize it to the National Electroenergetic System (known in Spanish as SEN).

The proposal to design a frequency regulation system for the small hydro power plant intends to get the unity which generates back to work in isolated operation, as it was originally conceived, working as a backup to the plant service of the Hydro power Plant "Hanabanilla" before eventualities such as cyclones or breakdowns in the Hanabanilla-La Moza-Santa Clara System, so as to perform a black start without having to depend on the SEN.

The main contribution of this work is the proposal of a frequency regulation system made from PLC in a small hydro power plant where the final action element is a servomotor which is controlled by a Lexium 32 servo control.

II. THEORETICAL REFERENCE

Two main ways to control the frequency in small hydro power plants are known: the control of the water flow which gets in the turbine and the adjustment of the generator load by using resistances banks for the adjustment of the frequency [3], though Peña's work [4] successfully combines both regulation methods so as to reach an optimus adjustment of the frequency-load control as the operation point of the plant varies. The first method consists of adjusting the controller to an operation point of the plant by regulating the quantity of water that flows into the turbine [5] and the second fixes the operation to a value of constant power, normally the maximum value, by balancing the loads of the users with a resistive loads system connected in parallel [6],[7].

From these two main ways to operate an isolated small hydro power unit, a wide variety of control methods in the scientific litterature has been implemented in order to solve the problem with the frequency regulation in this type of systems. Some of the most well-known methods are the Fuzzy Multimodel Control [8], the Intelligent Hybrid Control [9], the Multiple Flow Control [10], the Integral Control based on Neural Networks [11] and the Adaptive Control [12], [13]. A review [14] did some research on the new operation strategies and control for electric distribution networks connected to small hydro power plants.

A scheme of Sliding Mode and model order reduction has been recently implemented by Qian [15] for the solution of the problem concerning frequency-load control in small hydro power plants. In this project, how the system in the two ways of operation works is explained: isolated and connected to an electrical network. The system is modelled mathematically under both ways of operation, by obtaining the reduced model for its further analysis and, according to the order reduction model, a sliding control algorithm is applied. Since the control algorithm is applied to the original system, a sufficient condition about the stability of the system according to the theory of small earn in control systems is demostrated.

A combination of the diffuse logic and the adaptive control comes true in Weldcherkos's proposal [16], where he uses an adaptive inference system with diffuse logic (Adaptative Neuro-Fuzzy Inference System - ANFIS) and this result is compared with the responses of the system with a conventional PID control. By using ANFIS, a faster transitional response is achieved (5-second order), much more than using PID (60 seconds).

An adaptive controller with diffuse logic for small hydroelectric plants by Özbay and Gençoğlu is proposed [13], by using dynamic models of linear and non-linear turbine without taking into account the water hammer effect. It is interesting how faster settling times are achieved with the non-linear model than with the linear model by using this algorithm.

On the other hand, Asoh, Mbinkar, and Moutlen [17] propose a PI control with diffuse logic in a linear plant model and in another case with non-linear model. The obtained results in the simulations for the linear plant showed settling times of 95 seconds with a conventional PI, while with a PI control with diffuse logic the settling times were of 12 seconds, this with load variations of a 3% of the total value of the plant generation power.

A controller of variable structure is introduced by Kumar and Mathew [18] to show the significant improvement in the transient response with different step-typed reference inputs for changing loads. The authors explain the functioning of a plant working in isolated mode and the range of power losses. They also reduce the value of wasted power to a 50% of the power delivered by the plant, due to the variation in the water flow.

Another of the tendencies is the use of an electronic load controller, developed by Kapoor, Phunchok, Kumar and Rahi [19], which senses and regulates the frequency generated by a small hydro power plant. It is explained in the work that an electronic load controller is a solid state device, designed to regulate the output power of a small hydro power-typed generation system and keep to the closest possible constant load value in the turbine to generate stable voltage and frequency.

Kenzhaev [20] proposes the use of an automatic digital microprocessor control system, based on the analysis of the current use of digital frequency controllers as automatic ballast load controllers for small hydro power plants. At present, there are two practical circuit designs of this type of a controller: 1. Step ballast load connection to the generator output using a contactor-relay switching; and 2. The use of analog power semiconductor automation (analog ballast load). The advantage of this solution is more accurate automatic control. One of the most promising circuit designs for small hydro power plant ballast load controllers is a digital frequency controller. Digital measurement is widely used in modern circuitry, characterized by high accuracy and is well combined with a stepwise automatic ballast switched by thyristor contactors. The practice of using digital frequency controllers to stabilize the rotational speed of an off-grid small hydro power plant has shown that they provide adequate power plant dynamic indicators and stable plant operation with almost all types of hydraulic turbines.

While Marques and Molina [21] discuss in a detailed way the modelling and the proposal of a new control scheme of a three-phase electrical network connected to a small hydro power type of plant. They implement a new control scheme, which consists of a multi-level hierarchical structure and it adds a maximum power point tracker for a better use of the hydraulic power contributed to the system.

Karthikeyan, Menna Eligo and Dawit [22] also propose a control structure with a tuning method for a load-frequency controller in systems of PID type of power. The proposed scheme assures stability in the system during dynamic state conditions.

Saad's work [23] is based on the design of a PID control for an isolated small hydro power plant. The simulations of the plant with the PID varying the operation point of this, result in settling

times between 9 and 30 seconds for a variation of the load by disturb of 2% out of the total of the installed power.

A Digital PI control algorithm is proposed by Huerta [24] for the speed regulation in a synchronous Pelton-generator turbine system in a small hydro power plant. The developped scheme is waterfall-type with a proportional control in the internal bow and an integral-proportional control in the external bow, achieving a settling time response of 12 seconds before a unitary step input.

Peña, Fariñas and Domínguez [4] bring forward a proposal for the adjustment of a controller by looking for the optimum operation point of a small hydro power plant through the combination of both ways to regulate frequency: by resistive loads (ballast) and through the water flow control which goes into the turbine. Settling times up to 5 seconds for impulsive loads of 11% are obtained and in the range between 20 to 30 seconds for step type of input of 13%.

In Shashikant and Shaw's research [25], an interesting comparison as for the tuning of the PID type of control is made by using three different optimization methods: Lightning Search Algorithm (LSA), Particle Swarm Optimization (PSO) y Quasi Oppositional Based Lightning Search Algorithm (QOLSA). Finally, the optimized PID with the QOLSA method showed better voltage and power responses to the output of the unit than that with the other methods.

A PI controller has been used by Safaei [26] to reduce the peak of frequency deviation. The optimal gain of PI controller and integrator of dump load is obtained by genetic algorithm (GA) to achieve minimum frequency deviation. In this method, the peak of frequency deviation is reduced less than 1 Hz while in the conventional scheme, the peak of frequency deviation is 3 Hz. In other words, the positive or negative peak of frequency deviation has been reduced about 60%.

Gupta [27] proposed in his work the use of a Programmable Logic Controller (PLC) for control and automation of small hydro power (SHP) station, its advantages and cost effectiveness. Programmable logic controllers (PLC) can be used for control & automation of SHP station. The main reason for this is cost effectiveness. Various functions and controls can be achieved by programming the PLC. They can be used for full plant automation including governing of auto-operation includes speed control, load control, excitation control, and level control automatic start/stop sequencing, gate control, start/stop of auxiliary systems, and protection requirement etc. Functions other than control like continuous monitoring, data recording, instrumentation and protections can also be performed. For remote operation, communication with PLC can be performed. For continuous monitoring purpose, a personal computer can be interfaced with PLC and continuous data can be recorded regularly.

Alam and Chopra [28] paper present a project based on Proportional–Integral–Derivative (PID) for the implementation of load controller for three-phase synchronous generator. Electronic load controller is a device which is related to power electronics method of controlling, managing and monitoring frequency of a system. Mostly, in rural areas, we do not have access to grid for power. There pico- and micro-hydropower can be implemented to provide power. For persistent operation and control of a three-phase synchronous generator, an electronic load controller has been implemented rather than using speed controller governor which is much more expensive. With the help of the proposed device, load output can be controlled, and thus, frequency can be maintained constant which again reduces worst case of overloading on generator. Therefore, with the help of the proposed scheme, protection of both generator and user's load can be maintained. The proposed system can play a vital role in run-off-river type hydropower station because there is no point of saving water. Thus, the proposed system can be used to minimize the overall cost of installation of the hydropower plant up to a large extent in rural areas where we do not have access to grid connection for electricity.

Maina [29] paper investigates the performance of a single unit small hydropower plant in both grid-connected and islanded operation. The overexcitation and volt/hertz excitation limiters have been included in the study to compare their responses in both modes of operation. The plant is evaluated under different loading scenarios considering both resistive and inductive loads. A PI tertiary control for speed reference setting in islanded operation is introduced in the governor to enable regaining of 50 Hz frequency after load changes. The results obtained from the simulation study show the importance and difference of analysing different loading scenarios both in grid-connected and island modes. Also, the inclusion of PI control in governor aids in returning the frequency to its nominal value.

III. MATERIALS AND METHODS

The modelling of the turbine-generator system of the small hydro power plant "Hanabanilla" was performed by having into account the technical data of the plant and taking as reference the linear model stated by Kundur [30], where it is assumed that:

- The water resistance is significant.
- The water pipe is inelastic and the flow is incompressible.
- The water flow speed varies directly with the sluicegate's opening and with the square root of the net hydraulic load.
- The output of the unit's power is directly porportional to the product of the hydraulic load and volumetric water flow.

For the Pelton turbine model, 100 meters was taken as an average hydraulic load and an average water speed in the pipe of 6.5 m/2, staying as transferential function of the turbine:

$$G_t = \frac{-4s + 1}{2s + 1} \qquad (1)$$

While for the 200 kW synchronic generator, from the electrical data, the load-damping constant was calculated D=0.8 to find the $Kp = \frac{1}{\frac{\partial Pl}{\partial F}} = \frac{1}{D}$ of the generator and the time constant $Tp = \frac{2*2.88}{60*0.8} = 0.12\ s$, resulting in:

$$G_p = \frac{1.25}{0.12s + 1} \qquad (2)$$

As an element of final action a direct current servomotor fulfilling with high dynamic performances and being capable of developing a constant nominal torque of 33 Nm was chosen, given by the mechanical demands of the injector needles of the turbine. It is well-known that this type of drive gives stability to the system for being a first typical order, this in detriment of other electro-hydraulic type of actuators that are also mentioned in litterature [30], [31], but that present non-linear features in its behavior.

The transferential function which describes the dynamics of the direct current selected servomotor is given by [32]:

$$G_k = \frac{10}{0.0139s + 1} \qquad (3)$$
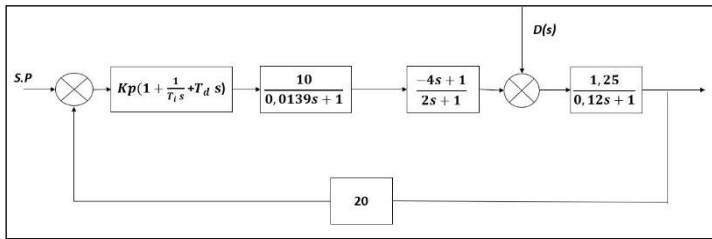
Figure 1: Control scheme of the small hydro power plant
"Hanabanilla".
Source: Authors, (2022).

The droop constant of the system was taken into account R=5%, thus, we have in the feeback 1/R=20, as it is stated by Kundur [30].

Due to the need of achieving a response from the system with zero error in stable state so as to achieve to keep the frequency in 60.00 Hz, it was decided to firstly tune a PI type of control before the value-step entry 30 for disturb, by making use of the Matlab-Simulink software and to assess its performance. The transitional response with the comprehensive proportional control, with Kp=0.015 and Ti=0.5s, is considered to be quick, with settling time of 7.3 seconds; however, it was decided to tune a PID control so as to improve the transitional response.

The tuned PID shows a response with settling times of 6.6 seconds, having as the following parameters: Kp= 0.016, Ti= 0.5 s, Td= 0.1 s.
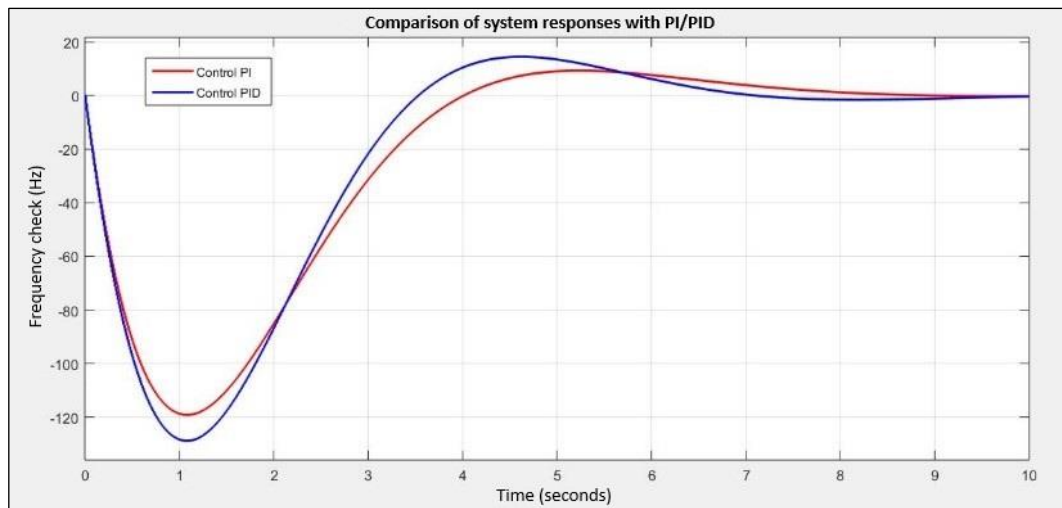
Figure 2: Variation of the frequency with controllers type PI and PID.
Source: Authors, (2022).

In the figure 2, the improvement of the response of the PID respect to a PI type of control is showed. In red color, the response of the PI and in blue, that of the PID. The improvement of the transitional response which introduces the derivative action in the PID, makes this to be the chosen one in detriment of the PI. It is evident the inverse response of the system given by the zero in 0.5 which introduces the transferential function of the hydraulic turbine, which brings stability problems and a slow response given that two physical phenomena with opposed dynamics are manifested in the process.

The frequency regulation proposal in the small hydro power plant "Hanabanilla" is based on a Control System made from PLC M241 by Electric Schneider. The reason for his choice is given by the robustness and demonstrated reliability which provide the control systems made from programmable logic controller (known in Spanish as PLC) and its high flexibility in the configuration of the software and the hardware, as well as the capacity they have to execute several tasks and operations in real time simultaneously.
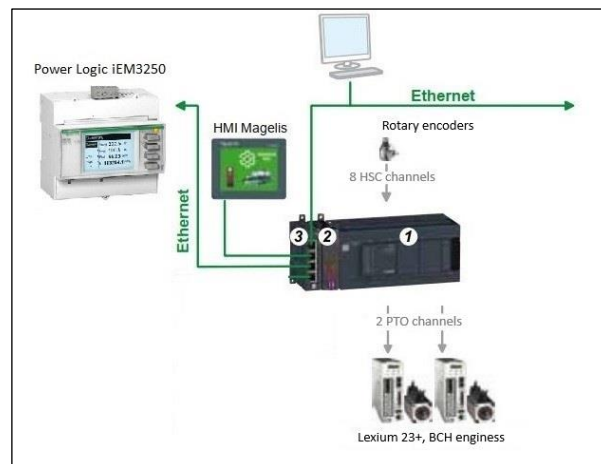
Figure 3: Control paltform based on PLC M241.
Source: Authors, (2022).

M241 has two Pulse Train Output (PTO), which will be necessary for the control of the position of the two CD servomotors, which will work on the needles of the injectors of the turbine through the Lexium 32 servo controllers (*servo drive*) of the own Schneider Electric manufacturer.

It is also fundamental the possibility of setting a PID function within the M241 programming logic, allowing to put into practice the design of a controller of this sort.

Automaton programming was performed with the software created by the own SoMachine v.4.3 manufacturer. Aside from tuning the PID controller, the electrical drive of the CD servomotors with the Lexium 32 module was set in the program, and all the boot sequence, the stop and the unit operation, as well as the alarms and plant's shots were programmed.

The design of the control system was performed by taking into account that the turbine has two injectors, therefore, it is necessary to use two servomotors for its drive. Schneider Electric M421 PLC only has two Pulse Train Output (PTO). When combined with the Lexium 32 servo drive, they only allow to control only one servo since it is necessary to change the direction of rotation of both motors to achieve the opening and closing operations of the injectors. It was then decided to control the first one with PID through the two Pulse Train Outputs for a fine adjustment of the system frequency and the other servomotor was controlled with a ON/OFF controller.

A Power Logic iEM3250 network analyzer is used as an element of the frequency measurement so as to communicate with the automaton by Modbus Serial IOScanner protocol and transfer the reading value of the system frequency, as well as the other electrical parameters such as active and reactive energy, power factor, voltages and phases currents for the setting of the alarms and plant's shots.

Figure 4 shows the frequency control loop according to the ISA S5.1-84 norm: the Lexium 32 (FC-2) servo controller and the Schneider Electric M241 PLC (PLC-1) constitute the controller, the servomotor of direct current (FZ-2) is the actuator, and the Power Logic iEM3250 network analyzer (ST-2) is the measurement element closing the control loop.
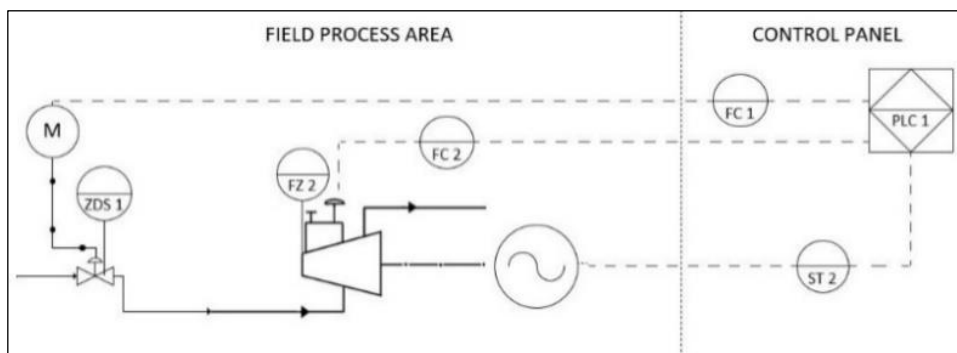
Figure 4: Frequency control loop scheme according to the ISA Norm.
Source: Authors, (2022).

The scheme also includes the motorized valve control which allows the water input to the turbine, which is operated with a frequency converter (FC-1) located in the control panel. This is an ON/OFF type of control and is covered by the boot sequence and stop of the plan.

IV. RESULTS AND DISCUSSIONS

The effect of varying the operation point of the plant (hydraulic load) with the PID controller in the control system of the Small Hydro power Plant "Hanabanilla" does not damage significantly the system response. Figure 5 and Table 1 reflect the behavior of the system response in each case.
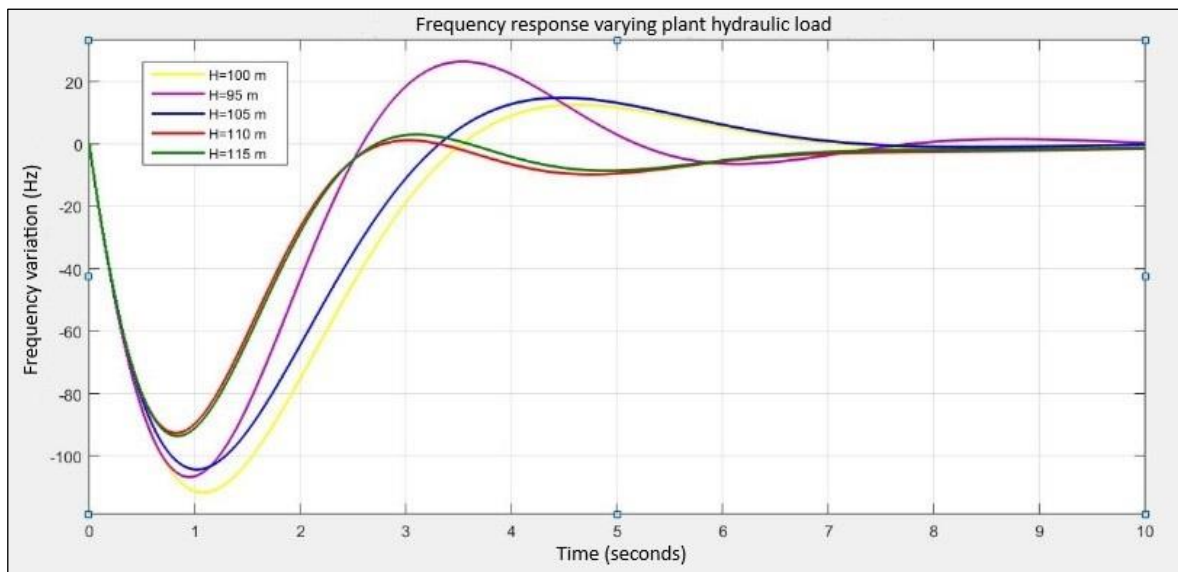
Figure 5: Variation of the plant response with the PID varying the hydraulic load.
Source: Authors, (2022).

As showed in the graphic of figure 5, settling times in the most critical cases never exceed the 10 seconds time despite the variation of the operation point of the plant with the change of the hydraulic load of the unit. Similar responses were obtained in the works presented by Padhan and Majhi [33], Tan [34] and Anwar and Pan [35], where from the PID controllers designed by frequency method [33], [35], and from IMC inner controller model, settling times of 4.4 seconds and 8.4 seconds respectively were obtained.

Table 1: System response with PID varying the hydraulic load.

Hidraulic load	Response	Maximum overshoot %Mp	Settling time-ts
95 m	Violet	32	9.5 seg
100 m	Yellow	16	6.6 seg
105 m	Blue	18	6.9 seg
110 m	Red	3	7.3 seg
115 m	Green	5	7.5 seg

Source: Authors, (2022).

A PID controller for the load-frequency control in a plant with similar features to that of the present article is tuned in the work of Saad and Chi [23]. For a turbine with response time of 4 seconds and with a droop feature of 5%, the tuned controller by Saad grants the turbine-generator system a much slower response (33.6 seconds) that those obtained in this work. The simulations performed by Saad were for variations of the demand of 2% of the total generation capacity of the generator whereas those performed in this work were of 25%. Once the adjustment of the PID control was obtained through the stated technical design requirements, all the control logic of the small hydro power plant "Hanabanilla" was programmed. The boot sequences and stop of the unit, the process and safety interlocks, the alarms and the shots of the plants were taken into account. The reading of all the electrical parameters of the generator, sensed by the Power Logic iEM3250 network analyzer, lead to the supervision and control of the plant's shots and to a safe operation.

The functioning of the program with the the same simulator of the SoMachine v4.3 software was simulated, by forcing all the conditions so as to check the correct functioning of the sequences automatically from the PLC.

The setting of the Lexium 32 servo drive was done through the features and dimensions of the Pelton turbine that the plant has and the servomotor of the direct current selected for the drive of the injector needles. The alarms and servo stops were taken into account to include it in the automaton logic.

V. CONCLUSIONS

The design of a PID controller, through the linear model of the plant is adjusted to the technical operation demands of a isolated small hydro power plant and the settling times of the response before variation of the hydraulic load are similar to those stated in litterature.

The choice for a direct current servomotor as an actuator element in the control loop gives stability to the system.

The use of the PLC M241-based control platform by Schneider Electric allows a flexibility both in the development of the control system and in the communication of this with supervision systems that can be added in higher levels of the automatization pyramid.

The use of the Lexium 32 servo controller integrated to the PLC-bsed control platform for the frequency regulation in a small hydro power plant constitutes a contribution to this work so as to give a technical solution to the state problematic, since this type of servo actioning are frequently used in applications of packing and packaging lines processes in the food-processing industry where the speed control of conveyor belt and the position control in different axes is necessary, given that the use in the control areas of the electrical power systems is not well stated in litterature.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Ing. Julio César Bravo Cortés, Dr. H.C. José Rafael Abreu García.
Methodology: Dr. H.C. José Rafael Abreu García.
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Writing – Original Draft: Ing. Julio César Bravo Cortés.
Writing – Review and Editing: Ing. Julio César Bravo Cortés, Dr. H.C. José Rafael Abreu García.
Supervision: Dr. H.C. José Rafael Abreu García.
Approval of the final text: Dr. H.C. José Rafael Abreu García.

VII. ACKNOWLEDGMENTS

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RESEARCH ARTICLE   **OPEN ACCESS**

AN EVALUATIVE ANALYSIS OF PARTICLE SWARM OPTIMIZATION FOR REINFORCEMENT LEARNING IN PENDULUM TASK

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ARTICLE INFO

ABSTRACT

Applying swarm intelligence algorithms to reinforcement learning of neural networks is practical because they do not rely on gradients. Particle swarm optimization (PSO) is a representatives of swarm algorithms. In this paper, the author experimentally evaluates the effectiveness of PSO in the reinforcement learning of multilayer perceptrons (MLPs), using a pendulum control task. Experimental results demonstrated the successful training of an MLP with 8 hidden units, enabling rapid uprighting of the pendulum. Notably, it was found that increasing the population size rather than the number of iterations allowed PSO to discover better solutions. In PSO, increasing the population size promotes global exploration in the early stages, while increasing the number of iterations enhances local exploitation in the later stages. Based on the results of this experiment, it is evident that in this learning task, early-stage global exploration is more important.

I. INTRODUCTION

In supervised learning, neural networks can be optimized using gradient-based methods with labeled training data. This involves computing the difference between neural network's outputs and their respective target values, and then adjusting connection weights and unit biases through backpropagation of errors. However, reinforcement learning tasks require the use of gradient-free training algorithms since labeled training data are not available. Applying swarm intelligence algorithms [1,2] to reinforcement learning of neural networks is practical because they do not rely on gradients. On the other hand, Q-learning [3,4] is a popular reinforcement learning method that selects subsequent actions based on the reward r(t) for action a(t) in state s(t) at each time step t. Unlike Q-learning, swarm algorithms do not require the calculation of r(t) at every step, but instead, evaluate the reward after the completion of an episode. This feature of swarm algorithms relieves the practitioner from the burden of designing appropriate rewards for every combination of states and actions. Particle swarm optimization (PSO) [5,6], ant colony optimization (ACO) [7,8], and artificial bee colony (ABC) [9,10]

are representative swarm algorithms. However, to effectively use these algorithms for training neural networks, it is essential to select appropriate variations and design their hyperparameters carefully, as they have a significant impact on performance. In this paper, the author experimentally evaluates the effectiveness of PSO in the reinforcement learning of multilayer perceptrons, using a pendulum control task.

II. PENDULUM TASK

As a reinforcement learning task, this study utilizes the pendulum task available in the OpenAI Gym[1,2]. The goal of the task is to maintain the pendulum in an upright position by applying torque. The system is depicted in Fig. 1, which shows a screenshot of the task, with the round arrow indicating the direction and magnitude of the torque applied by the controller. The study aims to provide insights into the performance of PSO on this task.

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1. https://www.gymlibrary.dev/environments/classic_control/pendulum/
2. https://github.com/openai/gym/blob/master/gym/envs/classic_control/pendulum.py

The author modified the system such that the task starts with the pendulum in a position opposite to the desired outcome, as shown in Fig. 2(a). The objective is to manipulate the pendulum to reach and maintain the state depicted in Fig. 2(b). Additionally, the author adjusts the system to begin the control task with zero angular velocity for the pendulum.
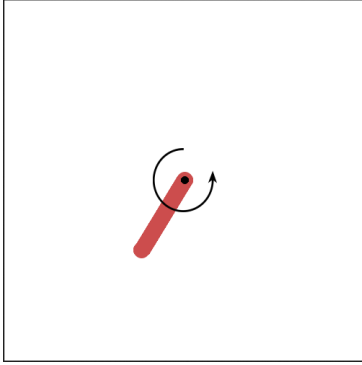
Figure 1: Pendulum system.
Source: OpenAI Gym, (2023).
https://www.gymlibrary.dev/_images/pendulum.gif

Figure 2: Initial and goal states.
Source: Author, (2023).

An episode in the simulation consists of 200 time steps, during which the controller observes the current state and determines the corresponding action. The state is characterized by three values: the cosine and sine of the angle (θ), and the angular velocity, which are within the ranges of -1.0 to 1.0 and -8.0 to 8.0, respectively. The action taken by the controller is the torque applied to the pendulum, within the range of -2.0 to 2.0. The constant torque of 2.0 (or -2.0) is not sufficient to bring the pendulum from its initial position to the goal position: the controller must actively swing the pendulum, leveraging gravity to increase the angular velocity and allow it to overcome the obstacle.

In this study, the author defines the fitness of a controller as follows:

$$\text{Fitness} = \frac{1}{200} \sum_{t=1}^{200} (1 - \text{Error}(t)), \qquad (1)$$

$$\text{Error}(t) = \frac{|\theta(t)|}{\pi}. \qquad (2)$$

θ(t) denotes the angular at time step t. Initially, the error is calculated as Error(t)=|±π|/π=1, indicating that the pendulum is in a position opposite to the desired goal state. As the pendulum moves towards the goal state, the error decreases. At the goal state, the error is 0/π=0, indicating that the pendulum is upright.

The fitness score rewards the controller more for achieving the desired goal state more quickly and maintaining it longer, i.e.,

a higher fitness score is obtained when the error is lower for more time steps.

III. MULTILAYER PERCEPTRON

This study adopts a multilayer perceptron (MLP) [11] as the pendulum controller. The MLP is a three-layered feedforward neural network. The topology is illustrated in Fig. 3, while the feedforward computations are shown in (3)-(7).

Input layer:

$$out_i^{(1)} = x_i, i = 1,2, \ldots, N \qquad (3)$$
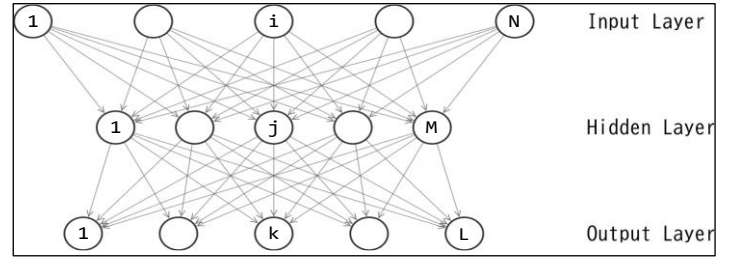
Figure 3: Topology of the MLP.
Source: Author, (2023).

Hidden layer:

$$in_j^{(2)} = \theta_j^{(2)} + \sum_i w_{i,j}^{(2)} out_i^{(1)}, j = 1,2, \ldots, M \qquad (4)$$

$$out_j^{(2)} = h(in_j^{(2)}), j = 1,2, \ldots, M \qquad (5)$$

Output layer:

$$in_k^{(3)} = \theta_k^{(3)} + \sum_j w_{j,k}^{(3)} out_j^{(2)}, k = 1,2, \ldots, L \qquad (6)$$

$$out_k^{(3)} = h(in_k^{(3)}), k = 1,2, \ldots, L \qquad (7)$$

The activation function denoted as h() is the hyperbolic tangent function whose shape is illustrated in Fig. 4. This activation function is a widely used in neural networks due to its ability to produce a smooth non-linear output that ranges from -1.0 to 1.0.
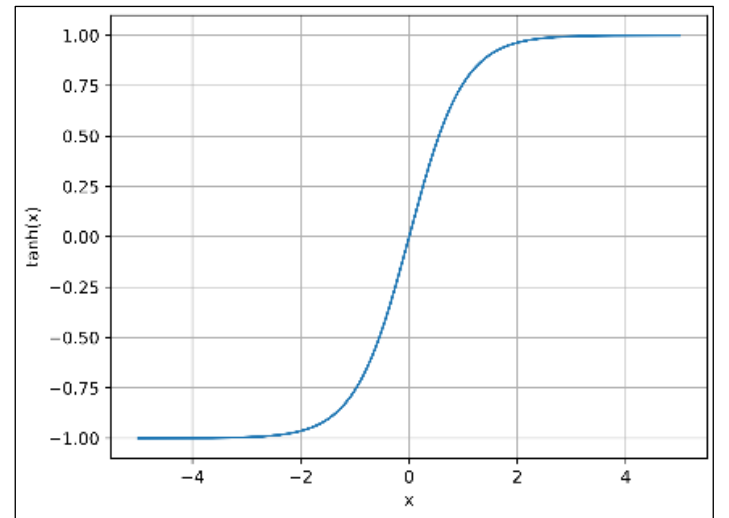
Figure 4: Hyperbolic tangent function.
Source: Author, (2023).

The MLP plays the role of a policy function where the action at time t is a function of the observation at time t, i.e., action(t) = F(observation(t)). The input layer of the MLP comprises three units that receive the values of cos(θ), sin(θ), and the angular velocity. To ensure that the input values are within the range of [-1.0, 1.0], the angular velocity is normalized by dividing it by 8.0. The output layer of the MLP consists of one unit, which outputs the torque applied to the pendulum. To ensure that the torque falls within the range of [-2.0, 2.0], the output value is scaled by multiplying it by 2.0.

IV. TRAINING OF MLPS USING PSO

The MLP illustrated in Fig. 3 comprises M + L units and NM + ML connections, giving a total of D = M + L + NM + ML parameters. To train the MLP, the author formulates the problem as the optimization of a D-dimensional real-valued vector, $\boldsymbol{x} = (x_1, x_2, \ldots, x_D)$, where each x_i corresponds to one of the D parameters in the MLP. The feedforward computation, as described in (3)-(7), involves applying the values of $\boldsymbol{x}$ to their corresponding connection weights or unit biases.

In this study, PSO is applied to optimize the D-dimensional vector $\boldsymbol{x}$. PSO represents one of the swarm intelligence algorithms, which are characterized by being population-based stochastic search algorithms. PSO utilize $\boldsymbol{x}$ as a particle position in the D-dimensional search space. Fig. 5 shows the process of training neural networks by PSO.

Step1:	Initialization
Step2:	Evaluation
Step3:	Conditional Termination
Step4:	Updates of Pbests and Gbest
Step5:	Updates of Particle Velocities
Step6:	Updates of Particle Positions
Step7:	Goto Step2

Figure 5: The process of particle swarm optimization.
Source: Author, (2023).

In Step 1, vectors $\boldsymbol{x}^1, \boldsymbol{x}^2, \ldots, \boldsymbol{x}^S$ are initialized randomly, where S represents the swarm size (the number of particles in the swarm). $\boldsymbol{x}^s$ denotes the position vector of the *s*-th particle in the D-dimensional search space, i.e., $\boldsymbol{x}^s = (x_1^s, x_2^s, \ldots, x_D^s), s = 1, 2, \ldots, S$. The swarm size is predetermined. In Step 2, the fitness of each particle is evaluated using (1). In Step 3, the loop of the swarm process is terminated when a specific termination condition is satisfied. In this study, the loop is terminated when the loop counter reaches a predetermined value. In Step 4, the personal best (Pbest) of each particle and the global best (Gbest) in the swarm are updated according to their fitness scores. The Pbest of a particle represents the position vector that has achieved the highest fitness score up to the current iteration for that specific particle. On the other hand, the Gbest represents the position vector with the highest fitness score among all the Pbests within the population. Let us denote each Pbest as $\boldsymbol{p}^s$ and the Gbest as $\boldsymbol{g}$, respectively. In Step 5, the velocity of each particle is updated. Let $v^s = (v_1^s, v_1^s, \ldots, v_D^s)$ represents the velocity for the *s*-th particle. The velocity v^s is updated by (8).

$$\boldsymbol{v}^s \leftarrow w\boldsymbol{v}^s + c_p r_p(\boldsymbol{p}^s - \boldsymbol{x}^s) + c_g r_g(\boldsymbol{g} - \boldsymbol{x}^s) \qquad (8)$$

w denotes the inertia weight, while c_p and c_g are coefficients. Additionally, r_p and r_g are uniformly distributed random values

within the interval [0,1]. In Step 6, each particle moves in the search space according to its velocity. The position vector $\boldsymbol{x}^s$ is updated by (9).

$$\boldsymbol{x}^s \leftarrow \boldsymbol{x}^s + \boldsymbol{v}^s \qquad (9)$$

V. EXPERIMENT

The MLP's capability to model nonlinear functions is influenced by the number of hidden units. Optimizing a smaller MLP using swarm algorithms is facilitated by a reduced number of variables (the shorter length of position vector $\boldsymbol{x}$). However, this reduction in hidden units may impede the MLP's capability to effectively control the pendulum. Conversely, a larger MLP is more capable of successfully controlling the pendulum, but optimizing it becomes more challenging due to the longer position vector $\boldsymbol{x}$. Moreover, implementing a larger MLP requires additional computational resources. Therefore, striking a balance between these trade-offs is essential for determining the optimal number of hidden units for the given task. This study explores three different configurations of hidden units: 8, 16, and 32. PSO hyperparameter values were determined through empirical analyses, as illustrated in Table 1. The number of iterations was set to 500 or 100, corresponding to swarm sizes of 10 and 50, respectively. Consequently, the total number of fitness evaluations remained constant at 50,000 (equal to the product of iteration and swarm size). It is important to choose an appropriate search space because the values in $\boldsymbol{x}^s$ are utilized as connection weights or unit biases in the neural network. The range should neither be excessively large nor small. In this experiment, the search space is $[-10.0, 10.0]^D$. The position vectors $\boldsymbol{x}^1, \boldsymbol{x}^2, \ldots, \boldsymbol{x}^S$ are randomly initialized within the space, and the velocities $\boldsymbol{v}^1, \boldsymbol{v}^2, \ldots, \boldsymbol{v}^S$ are initially zero vectors.

Table 1: PSO hyperparameters.

Hyperparameter	(a)	(b)
Swarm size	10	50
Iteration	500	100
Fitness Evaluations	50,000	50,000
Inertia weight w	0.9	0.9
Pbest coefficient c_p	1.0	1.0
Gbest coefficient c_g	1.0	1.0

Source: Author, (2023).

An MLP with 8, 16, or 32 hidden units was trained 11 times independently. Table 2 displays the best, worst, average, and median fitness scores achieved by the trained MLPs among the 11 trials. Each of the two hyperparameter configurations (a) and (b) was applied.

Table 2: Fitness Scores among 11 Runs.

		M=8	M=16	M=32
(a)	**Best**	0.810	0.831	0.832
	Worst	0.571	0.565	0.577
	Average	0.675	0.727	0.702
	Median	0.641	0.811	0.687
(b)	**Best**	0.832	0.833	0.833
	Worst	0.807	0.623	0.583
	Average	0.823	0.789	0.783
	Median	0.825	0.827	0.830

Source: Author, (2023).

Comparing the scores in Table 2 between configurations (a) and (b), it is observed that the values obtained using configuration (b) are higher than those obtained using configuration (a). This result indicates that configuration (b) is better than configuration (a). Wilcoxon signed rank test revealed that this difference is statistically significant (p=1.52e-5). Therefore, in this study, it is evident that increasing the swarm size rather than the number of iterations allowed PSO to discover better solutions. In PSO, increasing the swarm size promotes global exploration in the early stages, while increasing the number of iterations enhances local exploitation in the later stages. Based on the results of this experiment, it is evident that in this learning task, early-stage global exploration is more important.

Next, comparing the fitness scores obtained using configuration (a) among the three variations of M (the number of hidden units), it is observed that even for the smallest size, M=8, the scores are not inferior to those of M=16 or M=32. In fact, the average and worst values across the 11 trials indicate that M=8 is the most desirable. Increasing hidden units would typically enhance the MLP's nonlinear modeling capability and improve the performance of pendulum control. However, it can be seen that increasing hidden units to 16 and 32 does not improve the control performance and instead leads to a decrease in the learning performance through PSO. Wilcoxon rank sum test revealed that the difference between M=8 and M=16 (or 32) is not statistically significant (p=0.55 and p=0.42 respectively). As the number of hidden units increases, the dimensionality of the search space also increases, resulting in the increased difficulty in global exploration. Therefore, in the learning task of this study, the swarm size of 50 particles is sufficient for M=8 but insufficient for M=16 and M=32, indicating that the global exploration was not adequate in those cases.

Fig. 6 presents the learning curves of the best, median, and worst runs among the 11 trials, where M=8 and the configuration is (b). These learning curves indicate a slower progression of fitness scores within the ranges of [0.4, 0.5] and [0.6, 0.7]. Consequently, attaining a fitness score of 0.4 is relatively straightforward for PSO in training MLPs, while challenges arise in achieving higher scores for improved pendulum control. Remarkably, even in the most unfavorable trial out of the 11 conducted, PSO successfully trained the MLPs to reach a score of 0.807 (as shown in Table 2), demonstrating the robustness of PSO in effectively discovering desirable solutions.
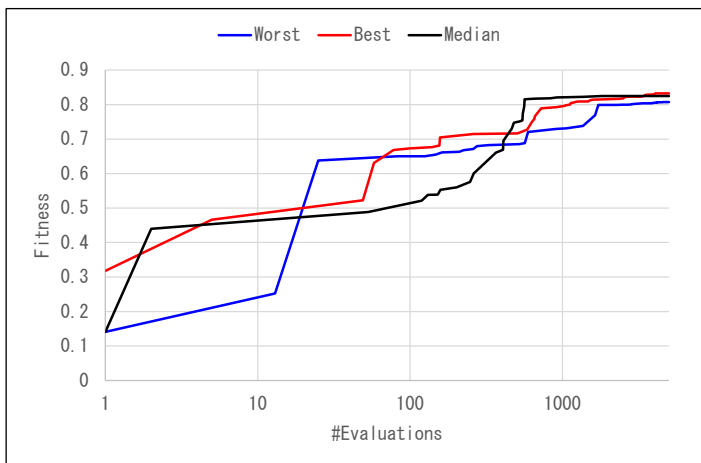
Figure 6: Learning curves.
Source: Author, (2023).

(i) Prior to training.
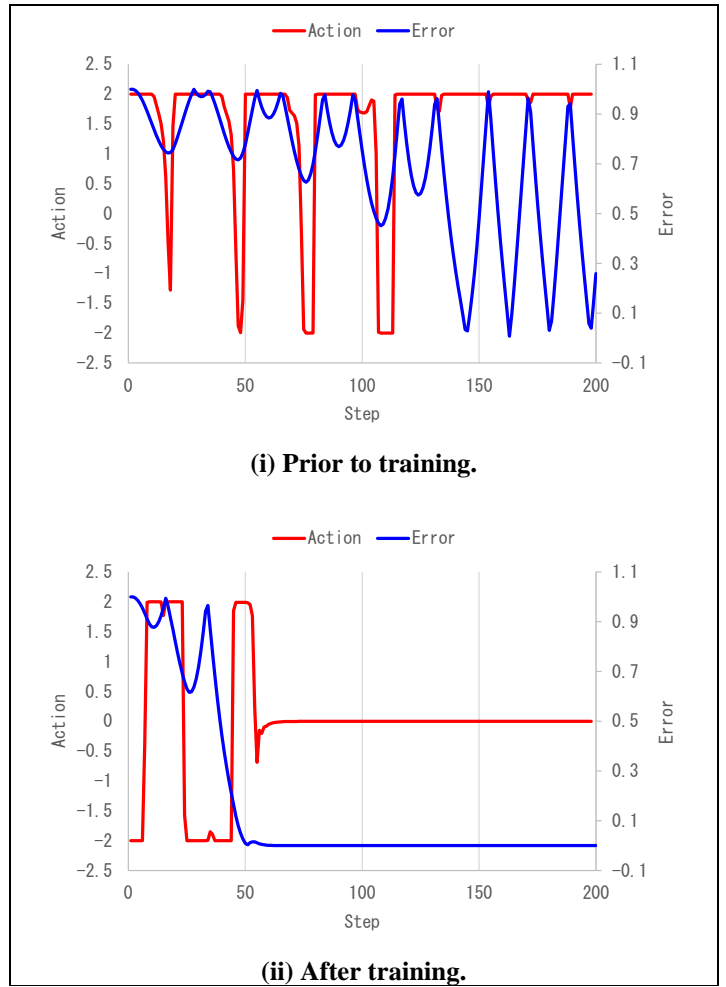
(ii) After training.

Figure 7: Actions and errors by the MLP.
Source: Author, (2023).

Fig. 7(i) illustrates the actions and errors of the MLP in the 200 steps prior to training, while Fig. 7(ii) displays the corresponding actions and errors after training. In this scenario, the MLP employed 8 hidden units, and the configuration (b) was utilized. Fig. 7(i) reveals that the MLP prior to training outputs significant variations in torque values ranging from 2.0 to -2.0 during the initial and mid-stages of the 200 steps, indicating an attempt to lift the pendulum. However, from the mid-stage to the end, the torque value remains approximately constant at 2.0, leading to pendulum rotation and substantial fluctuations in error. In contrast, Fig. 7(ii) reveals that the MLP after training successfully switches the polarity of torque appropriately within the first 50 steps, lifting the pendulum upward and rapidly reducing the error to nearly zero. Furthermore, it maintains the pendulum in the upward position with zero error by setting the torque value to 0 for the remaining steps, exerting no unnecessary force on the pendulum. Supplementary videos are provided which demonstrate the pendulum controlled by the MLPs[3,4].

VI. CONCLUSIONS

In this study, the neural network controller for the pendulum task was trained using Particle Swarm Optimization. The results demonstrated the successful training of an MLP with 8 hidden units, enabling rapid uprighting of the pendulum. Notably, it was found that a larger swarm size yielded greater effectiveness compared to increasing the number of iterations. In future work,

3. https://youtu.be/g7sqUhZnru4
4. https://youtu.be/o49by3OwT58

the author plans to evaluate additional evolutionary/swarm algorithms by implementing them on the same task as conducted in this study.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Hidehiko Okada.
Methodology: Hidehiko Okada.
Investigation: Hidehiko Okada.
Discussion of results: Hidehiko Okada.
Writing – Original Draft: Hidehiko Okada.
Writing – Review and Editing: Hidehiko Okada.
Resources: Hidehiko Okada.
Supervision: Hidehiko Okada.
Approval of the final text: Hidehiko Okada.

VIII. ACKNOWLEDGMENTS

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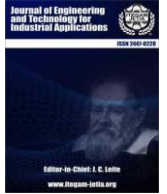
RESEARCH ARTICLE   **OPEN ACCESS**

ANGIOGENESIS STIMULATION IN BACTERIA-INFECTED ACUTE WOUND HEALING WITH HONEY TREATMENT IN BALB/C MICE

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ARTICLE INFO

ABSTRACT

The use of honey for wound healing has been carried out several times, but until now no one has compared the effectiveness of honey from various types of honey found in Indonesia for stimulating the formation of new blood vessels (*Angiogenesis*) in acute wounds infected with bacteria. The other side of wound healing that will be observed in this study is that wounds are often exacerbated by conditions of infection due to bacteria. The purpose of this study was to determine the level of stimulation of wound healing by treating honey in acute wounds infected with bacteria. This study was divided into 4 groups, namely the control group (K-MD), the first treatment group with Javanese Honey (MD-JW), the second treatment group with Kalimantan Forest Honey (MD-KLM) and the third treatment group with NTT Honey. (MD-NTT). In the results of the study, the highest VEGF levels were found in the MD-NTT group, followed by the MD-JW group, then the MD-KLM group and the lowest were in the K-MD group. The OneWay Anova test obtained $p > 0.05$ and the Post Hoc LSD test showed that the average VEGF levels in the MD-NTT, MD-JW and MD-KLM groups were significantly higher than the K-MD group ($p < 0.05$). In this study, it can be concluded that giving honey from NTT can increase Vascular Endothelial Growth Factor (VEGF) levels better than honey from Java and Kalimantan in healing acute wounds infected with bacteria in BABL/C mice.

I. INTRODUCTION

Wound healing is a physiological process that can occur naturally and dynamically in the body. The wound healing process includes 4 stages; hemostasis, inflammation, proliferation (granulation, contraction, and epithelialization), and remodeling [1]. Factors that determine success in the wound healing process are the adequacy of oxygen and nutrients that are needed by cells that play a role in the wound healing process. Availability of oxygen and nutrients is determined by the presence of vascular. In the wound process, some of the vessels are damaged, which is why it is necessary to form new vascularization or what is called neovascular [2].

Angiogenesis is the process of forming new blood vessels that already exist. This process occurs the growth of new capillaries that are connected to each other to form blood vessels that are consistent or fixed in the tissue with the wound. Cytokines and growth factors involved in this process of angiogenesis are basic *Fibroblast Growth Factor* (bFGF), Transforming Growth Factor (TGF-α, TGF-β), *Vascular Endothelial Growth Factor* (VEGF) and prostaglandins [2]. The surface of endothelial cells has growth factor receptors that play an active role in dissolving the extracellular matrix to facilitate the subsequent migration and proliferation of endothelial cells [3].

Honey is thought to be a good alternative in wound care because of its ability to be anti-bacterial, anti-inflammatory and immunostimulatory [4]. This ability is inseparable from hygroscopicity, sugar content and also contains hydrogen peroxide [5]. Previous studies stated that honey has a debridement effect for wounds [6], anti-bacterial activity [7], and the ability to reduce inflammation (Ghaderi et al, 2010) and wound areas [8]. Honey's

activity in wound healing is also influenced by the characteristics of the honey itself. This difference in activity can be caused by the species of honey-producing bees/wasps, geographical location, surrounding vegetation, and possibly also due to the process of making and storing it [9]. The extent and variety of vegetation in Indonesia is very likely to cause differences in the effectiveness of honey. This research will specifically use three types of honey in Indonesia, namely Central Java Forest Honey, Kalimantan Forest Honey, Flores NTT Forest Honey. Although there may be differences in its content, honey itself is generally composed of 40% glucose, 40% fructose, 20% water, amino acids, vitamins biotin, folic acid, pyridine, thiamine, the enzyme diastase invertase, glucose oxidase, catalase, minerals [10].

The results of this study will find out how fast each type of honey will help stimulate the formation of new blood vessels (Angiogenesis) in acute bacterial-infected wounds when compared to dressing treatment and no treatment, if it shows better ability than the comparison then it can be used to treat wounds that are more cost-effective for society and Health institutions.

II. MATERIALS AND METHODS

This research is an experimental study regarding the comparison of administration of three types of natural Indonesian honey to efforts to accelerate wound healing at VEGF levels. The research was carried out at the Laboratory of Sultan Agung University Semarang in June 2023 and has passed ethical eligibility from the Semarang Ministry of Healh Polytechnic with number 0479/EA/KEPK/2023.

The tools are Surgical tools, Bactec, Individual mouse cages, Gauze, Hydrocolloid dressing, plaster, 4 mm biopsy punch, micropipette, microtube, microtome, polypropylene sheet, 2.5 mL syringe, cotton swab sterile, computer/laptop. The Reagents are three types of honey, ketamine-xylazine, VEGF kit and NaCl.

There were 24 mice used in this study which were divided into four groups. All research samples were made by making 2 wounds on the skin of the back and given a suspension of 20 µl of S. aureus bacteria. The control group was treated for wounds by bandaging (K-MD), the first treatment group was treated for wounds by administering Central Java Forest Honey and bandages (MD-JW), the second treatment group was treated for wounds by administering Kalimantan Forest Honey (MD-KLM). and bandages, and the third treatment group was treated for wounds by administering Flores NTT Forest Honey and bandages (MD-NTT). All samples in the study group were treated for wounds every day, macroscopic wound condition monitoring was carried out for seven days and observation of infection and examination of VEGF levels was carried out on the 7th day.

The data collection carried out was primary data collection which was collected directly by the researchers by directly examining the blood specimen of the mice and the data was processed using SPSS version 26.0 to be tested One-Way Anova and Post Hoc LSD with value of significance is 95%.

III. RESULTS AND DISCUSSIONS

III.1 THE HONEY ORIGIN

In this study, honey was collected from three islands in Indonesia, namely Java, Kalimantan and East Nusa Tenggara (fig. 1). Each honey in each region has different characteristics. This is due to different weather, topography and different vegetation.
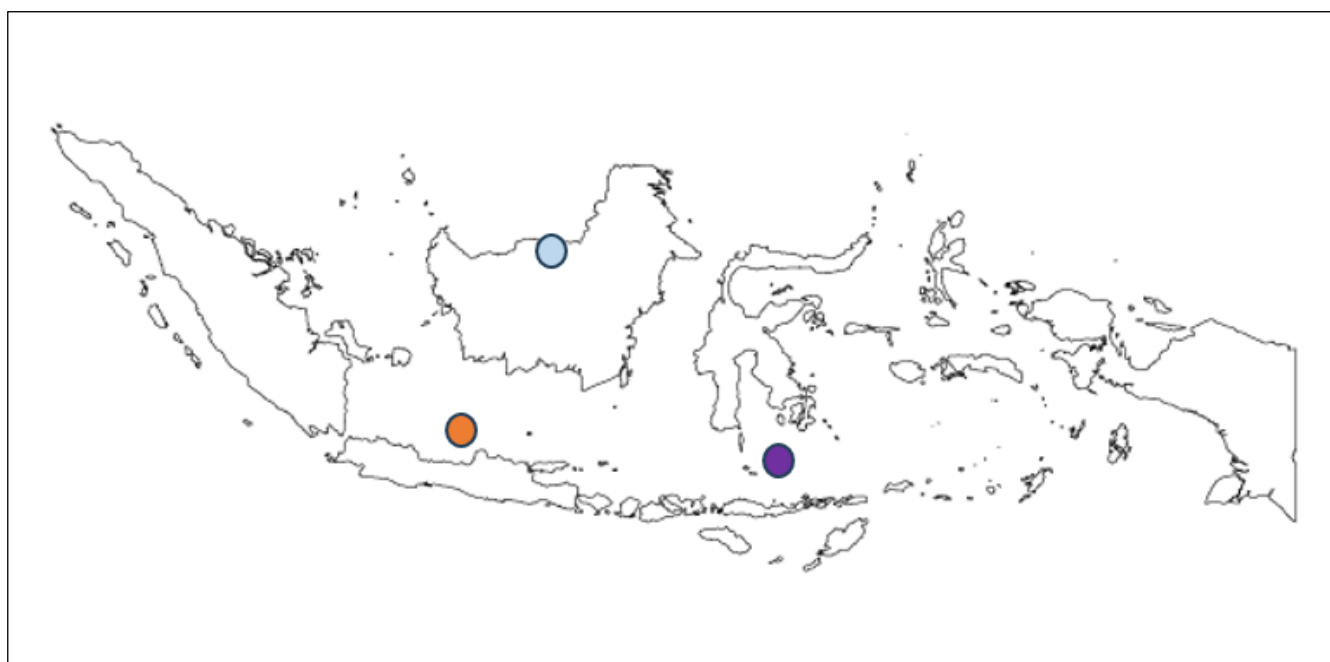
Figure 1: Map of Indonesia which consists of various islands and the origin of honey. The red color indicates the island of Java, the blue color is the island of Kalimantan, the purple color is the island of East Nusa Tenggara.
Source: Authors, (2023).

III.2 THE VEGF LEVELS

This study used 24 mice divided into 4 groups. The control group (K-MD), the first treatment group was treated for wounds by administering Central Java Forest Honey and bandages (MD-JW), the second treatment group was treated for wounds by administering Kalimantan Forest Honey (MD-KLM) and bandages, and the treatment group the third was wound care by administering Flores NTT Forest Honey and bandages (MD-NTT) then continued with blood sampling for examination of VEGF levels as a marker of angiogenesis. The results of VEGF levels are as shown in Table 1.

Table 1: Mean Results of VEGF levels.

Variable	K-MD	MD-JW	MD-KLM	MD-NTT	P-values (Anova)
	Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	
VEGF levels	68.24±19.94	103.49±27.65	94.32±25.19	118.7±29.01	0.043
Shapiro-Wilk	0.842	0.643 _	0.523 _	0.763 _	
Level Test	0.739				

Source: Authors, (2023).

Based on Table 1, it can be seen that the highest VEGF levels were found in the MD-NTT group, followed by the MD-JW group, then the MD-KLM group and the lowest was in the K-MD group. The normality test was carried out using the Shapiro Wilk and the homogeneity test using the Levene test showed that the data in this study were normally distributed and homogeneous ($p > 0.05$).

Based on these results, it was continued with the One Way Anova test and it turned out that there was a significant difference between groups, $p < 0.05$. To find out which group had a significant difference, an LSD Post Hoc test was carried out. These results are explained as follows:
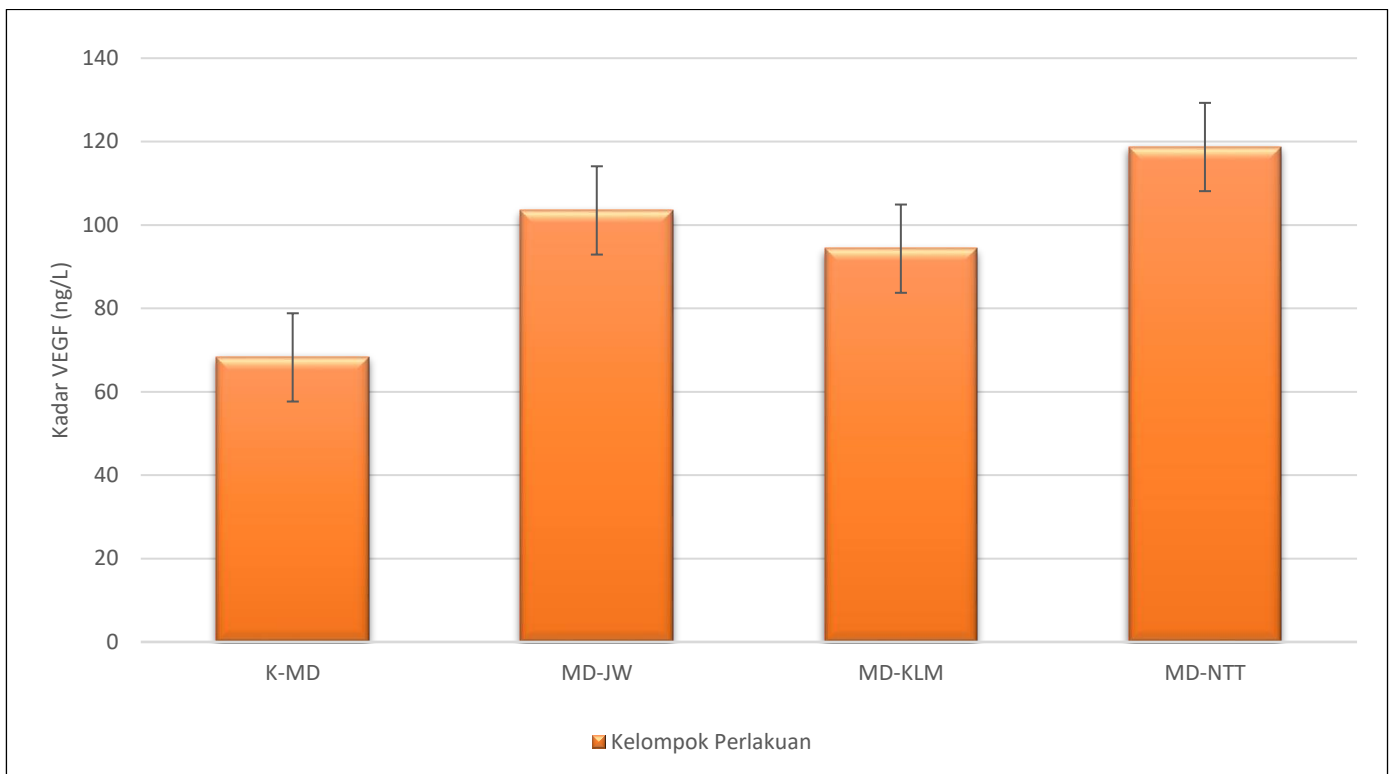
Figure 2: VEGF Levels.
Source: Authors, (2023).

The results of the LSD Post Hoc test showed that the average VEGF level in the MD-NTT, MD-JW and MD-KLM groups was significantly higher than the K-MD group, $p < 0.05$. Meanwhile, the average VEGF level in the MD-KLM group NTT was significantly higher than the MD-JW and MD-KLM groups, $p < 0.05$ (Fig. 2). And the mean VEGF level in the MD-JW group was significantly higher than in the MD-KLM group, $p < 0.05$. From the results of this analysis it can be concluded that giving 2 ml of NTT honey had a better effect on stimulating angiogenesis than giving Java honey and Kalimantan honey.

This study used an experimental research type and a cross-sectional approach with four treatment groups, each group consisting of 6 mice that were treated and then assessed by calculating the comparison of the size of the wound area measured every day with the initial size of the wound, microscopic observation for examination VEGF immunology from the wound, the calculation of the number of leukocytes in blood samples and

the calculation of the number of bacteria in the rat wound swab using the dilution method. Each treatment group was treated for wounds every day, macroscopic wound monitoring was carried out for seven days as well as observation of infection and examination of VEGF levels on the 7th day.

Honey is an alternative that can provide a faster effect on wound healing by stimulating tissue growth and the effect of epithelialization. The role of honey in wound healing is also supported by anti-inflammatory and antioxidant activities, and the ability to stimulate the removal of dead tissue [15] . Honey can inhibit the growth of bacteria around the wound, fungus is not susceptible to growing in honey. The spectrum in honey can inhibit the growth of gram-positive and gram-negative bacteria as well as aerobic and anaerobic bacteria [13].

Honey has a thick consistency and comes from flower nectar that has been processed by bees. The normal wound healing process is generally a chain process of coagulation, inflammation,

cell proliferation, and tissue remodeling [14]. Vascular Endothelial Growth Factor (VEGF) functions as a protein signal in the process of vasculogenesis and angiogenesis (new blood vessel formation). VEGF starts the regeneration process through the process of recruitment and differentiation of stem cells into endothelial cells that make up blood vessels [16].

In the initial phase of the inflammatory reaction, neutrophils and macrophages will enter the injured or injured tissue due to various chemotactic factors [11]. These cells will produce Reactive Oxygen Species (ROS) which can provide both beneficial and detrimental effects on the surrounding tissue. Apart from being produced by neutrophils, ROS which can provide a bactericidal effect are also produced by cells that are undergoing proliferation and have an important role in intracellular signaling in response to various extracellular stimuli, for example Hydrogen peroxide will be seen in limited quantities and induces Vascular Endothelial Growth Factor (VEGF) in the wound healing process which will be expressed in keratinocytes and also support the increase in angiogenesis. Conversely, excessive ROS production can cause tissue damage and interfere with the wound healing process [18]. The enzyme phosphotyrosine phosphatase and low molecular weight antioxidants such as glutathione play an important role in cellular redox regulation of cellular homeostasis which occurs because excessive ROS production can disrupt the function of communication between cells and ultimately affect the wound healing process [19]. The body itself has several antioxidant and redox systems to protect itself against damage caused by oxidative stress [12].

In this study the treatment group that provided optimal results for wound healing was in the K3 group (Flores Forest Honey, NTT), where the average healing rate was obtained (118.7 ± 29.01). This difference is suspected that the activity of honey in wound healing is also influenced by the characteristics of the honey itself and is caused by the species of honey-producing bees/wasps, geographical location, surrounding vegetation, and the process of making and storing it [9].

Based on Asroel's research, 2020 states that giving honey can increase VEGF in preecalmsia model rats [20]. The increase in VEGF expression in the administration of forest honey showed an increase in neovascularization compared to the control group. Forest honey is considered as one of the candidates among natural ingredients which according to data accelerates wound healing after palatoplasty surgery because of its high flavonoid content. Flavonoids are known to have anti-inflammatory and antioxidant properties and induce VEGF [17].

The results of all ANOVA test scores obtained p= 0.043 (p<0.05), which meant that there were significant differences in the results in the variable group, and continued with the Post Hoc LSD follow-up test and obtained p <0.05, which means that there were significant differences in each each variable group. From the results of the research conducted, all treatment groups had an influence on the stimulation of angiogenesis in mice wounds. Honey originating from NTT has a better effect than honey originating from Java and Kalimantan.

IV. CONCLUSIONS

Based on the results of the study concluded, that administering honey from NTT can increase *Vascular Endothelial Growth Factor Levels* (VEG) was better than honey from Java and Kalimantan in healing acute wounds infected with bacteria in BABL/C mice.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Eko Naning Sofyanita, Arya Iswara and Ahmad Riadi.
Methodology: Eko Naning Sofyanita and Arya Iswara.
Investigation: Eko Naning Sofyanita and Arya Iswara.
Discussion of results: Eko Naning Sofyanita, Arya Iswara and Ahmad Riadi.
Writing – Original Draft: Eko Naning Sofyanita
Writing – Review and Editing: Eko Naning Sofyanita and Arya Iswara.
Resources: Arya Iswara.
Supervision: Arya Iswara and Ahmad Riadi.
Approval of the final text: Eko Naning Sofyanita, Arya Iswara and Ahmad Riadi.

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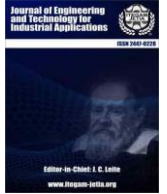
RESEARCH ARTICLE **OPEN ACCESS**

EFFECTS OF FINANCIAL INSTITUTIONS' MANAGEMENT EFFECTIVENESS ON FINANCIAL INCLUSION IN MBEYA CITY AND MBEYA RURAL DISTRICT

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ABSTRACT

This study evaluated the impact of financial institutions (FIs) management effectiveness on financial inclusion. This investigation was prompted because only a small portion, approximately 22%, of the Tanzanian population used banking services. To uncover the reasons behind the remaining 78% of individuals being excluded from the financial system, a positivistic research philosophy was adopted, and a causal-effect research design was employed. The study was conducted in both Mbeya City and Mbeya rural district. A sample of 210 respondents was selected from a population of 1,000 financial users and providers using a simple random sampling technique. Data was collected through the use of questionnaires. The collected data was carefully processed and underwent reliability and validity testing. Subsequently, the cleaned data were analyzed using structural equation modelling (SEM) with the assistance of SPSS AMOS version 26. The analysis revealed that FIs' management effectiveness, as measured by customer categorization, financial packaging, and digitization, had a positive and statistically significant impact on financial inclusion. Based on these findings, it is recommended that FIs' management take innovative actions under the central bank's regulation to address the concern that 78% of the Tanzanian population is unbanked.

I. INTRODUCTION

Financial inclusion has been a topic most development stakeholders worldwide are focused on in ensuring that different types of financial users have access to adequate and affordable financial services and products [1]. [2] revealed on FIs management is the initiator of causing financial users of different kinds with different needs and objectives to be financially included. By being able to categorize financial users based on the differences in their needs [3] inventing financial programs/products diversification [4], and inventing in financial digitization [5] are appropriate and innovative managerial practices towards sustaining financial inclusion.

Categorization of customers, as it was reported by [6] found to be an effective approach to different types of customers being universally accessed and used for financial services and products.

The clusters of customers said as it was put forward by [7], included men and women; informal and formal financial users; SMEs and large-scale firms. This categorization enables different types of customers to become financially included. Harmonization of this nature revealed increased specificity over access to different financial products, such as credits and savings, and access to their adequacy.

This [8] revealed that diversifying financial programs and products increased access to adequate and quality financial products of the need. This was explicitly said by that differentiating financial programs into, say, provision of credits, savings, marketing and training consultancies increase accessibility by different categories of customer. Moreover [9] stipulated that financial credits diversification based on different customer clusters, such as SMEs credit and large-scale enterprise credits, men and women, reveal to enhance accessibility to specific

financial credits the need. Diversified insurance products such as climate change insurance; heavy rainfall and floods insurance, crop insurance, fire outbreaks are revealed to sustain the returns from different investments and businesses such as agriculture. The certainty over the return on investments ensures sustainable access to financial credits and other financial services, given the perpetual trust in financial institutions pear to the needy group [10].

Financial digitization uses sosphiscated electronic systems to transact financial services [11]. As it was commented by [12] use of mobile banking, internet banking, and e-money payment creates affordable financial products. Adoption and use of digital systems lead to customer service centricity in which this tiresome behavior is overcome instead of customers traveling long distances to towns visiting the counters. Financial digitization was revealed by [13] to reduce the cost of transacting by 78%, increasing household savings to such a level. Use of mobile financial services in Nigeria as reported by [14] found to increase savings by 46%, which was used to feed families of five children per day.

1.5 billion Asian and African population users revealed by [15] to be financially excluded was reported to be caused by most of this population users are at disadvantageous remote areas where digital financial systems are not enabled. Moreover, the 4% of population users in Columbia being banked was reported by [16] to be caused by most of them being low-income earners. In this situation where financial services providers are risk averse, offering them credits becomes challenging. The reluctance of most financial institutions to categorize customers based on their needs and offering over homogeneous financial products revealed by [17] in Tanzania to be the cause of the majority of population users being financially excluded.

The [12] in Pakistan connoted that women in the area were financially included due to management's influence in inventing on their specific needs. This study revealed that since women were at a disadvantageous side compared to men, identifying them in a specific manner helped them become financially included. The level of financial inclusion with women increased from 21% as it was before to 80% following innovation over customers' categorization. The study by [12] used descriptive design and thematic data analysis methods.

Financial packaging was revealed as an innovative financial institution's managerial practice enabling different types of customers to be financially included in Nigeria [18]. Microenterprises being a group focus revealed that for special needs /objectives to be achieved, diversifying financial products such as over SMEs and large scale firm's credits; consumer and business loans; formal and informal users' credits; men and women credits. The study conducted by [18] was exploratory in nature. It employed a judgmental sampling technique to collect and process data, which was subsequently analyzed using the content analysis method.

As it was reported by [19] in Kenya over, rural population users to access financial products, it was a revelation that rural areas of Kenya were enabled with internet supporting infrastructures for adult rural financial users being easy access to financial products. The facts by [19] were consistent with that by [20] in Tanzania in which it was reported that about 81% of financial accessibility and usability was met, especially with urban users, which is about 34% of the Tanzanian population. These results by [20] indicated that inventions and the use of digital systems in Tanzania overwhelmed users with financial access to such a large extent. The study by [20] was descriptive in that the data analysis tool was also descriptive, where simple frequency tables and graphs were used to present the analysis data.

In contrast to the previous theoretical and empirical reviews mentioned, the primary objective of this study is to comprehensively evaluate the impact of financial institution (FI) management effectiveness and innovation on financial inclusion. Unlike earlier studies that did not consider financial inclusion as an integrated and holistic approach, this research acknowledges the inadequacy of categorizing financial users based on their specific needs. Instead, it emphasizes the importance of financial packaging and financial digitization.

The study draws upon the Traditional Economic Theory proposed by [21] to address this knowledge gap. According to this theory, financial users (customers) can be classified into various clusters: savers and users, small and large-scale firms, rural and urban users, formal and informal users, and financially literate and illiterate individuals. This categorization enables a more effective response to their specific needs and objectives.

Overall, this study highlights the significance of customer categorization in meeting the diverse requirements of different financial users.

However, it is important to note that customer categorization alone is insufficient for achieving financial inclusion, as [22] emphasized. Financial inclusion cannot be attained without the implementation of financial packaging. Similarly, for categorized customers to access affordable financial products/programs, the promotion of financial digitization is necessary [13]. These factors require financial institutions' management innovation and effectiveness, which were the focus of this study.

While the constructs revealed under the Traditional Economic Theory are relevant, the theory does not explicitly address financial inclusion as an integrated and holistic economic perspective. Achieving financial inclusion necessitates interacting and integrating the three main players: the central bank (government), financial institutions, and users. In this context, while FI management effectiveness focuses on inclusive financial programs/products and financial digital systems for financial users, the central bank or government must ensure the sustainability of infrastructures such as strong enforcement of rules and regulations, an enabling internet environment, telecommunication network infrastructure, and a steady supply of electrical energy.

Another point of distinction between those as mentioned above theoretical and empirical background reviews and the present study is the geographical scope. While the study under examination was conducted in Mbeya City and Mbeya rural districts in Tanzania, other studies were conducted in Pakistan, Nigeria, Kenya, and Tanzania. Furthermore, while the reviewed studies were descriptive and exploratory, this study was analytical, utilizing Structural Equation Modeling (SEM) as the data analysis method. Additionally, the study formulated three specific objectives to address the identified research gap. These objectives included assessing the effects of customer categorization and FIs' managerial practices on financial inclusion, analyzing the effects of financial program/product diversification and FIs' management innovation on financial inclusion, and evaluating the contributions of inventing financial digital systems and FIs' managerial practices on financial inclusion.

The relationship between concepts, items, and variables was depicted through a conceptual framework presented in Figure 1. The model considered customer categorization, financial packaging, and financial digitization managerial effective practices as independent variables, while financial inclusion was the dependent variable.
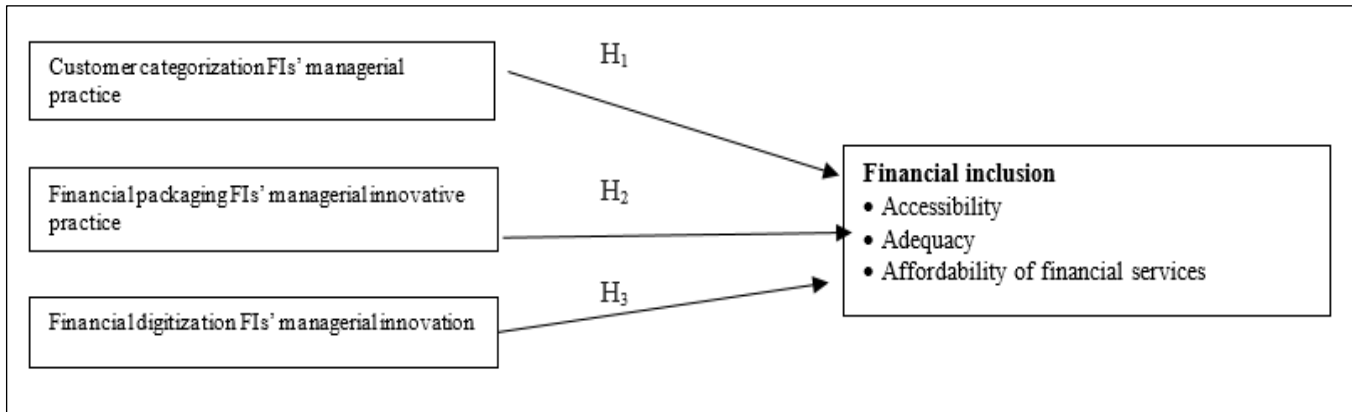
Figure1: Conceptual framework of the effects of financial institutions' management effectiveness on financial inclusion.
Source: [21] [22] and [13].

II. METHODOLOGY

The research was conducted in Mbeya City and Mbeya Rural District, selected based on various media and electronic publications highlighting the high percentage of unbanked individuals in Tanzania, estimated to be around 78%. These areas were representative of other regions in Tanzania facing a similar issue. The study employed a causal research design.

A sample size of 210 participants, consisting of financial users and financial service providers, was obtained from a population of 1,000. Financial users included farmers, service providers such as BodaBoda and Mama Lishe, and traders like Machinga, who had accounts with the targeted financial institutions. Financial service providers encompassed banks such as CRDB and NMB, non-banks like Britam Insurance Company, and microfinance institutions. The key informants, financial services providers and customers with accounts in those financial institutions were selected using a simple random sampling technique.

The Cochran formula was used to determine the sample size, with the margin of error (α) set at 0.1 and the population (N) set at 1,000. Applying the formula, a sample size 210 was obtained (refer to Table 1).

Table 1: Derivation of sample.

	Population size	Sample
Financial users	700	150
Financial service providers	300	60
Total	1,000	210

Source: Authors, (2021).

Primary data were obtained through the use of questionnaires. Additionally, secondary data were collected through a review of financial institutions' publications, examination of reading postures, access to e-platforms, and analysis of websites belonging to the surveyed financial institutions. The questionnaire was piloted with a sample size of 10 financial users and providers in Mbeya city and Mbeya rural district. The decision to use this sample size was based on [23] recommendation.

Following the completion of the pilot study, exploratory factor analysis was conducted to assess the construct validity and reliability of the questionnaire. The results of the pilot study indicated that Cronbach's alpha reliability values for the following constructs were acceptable, as they exceeded 0.5: customer categorization FI's managerial practice (0.720), financial programs/products FI's managerial innovation (0.730), financial digitization FI's managerial practice (0.820), and financial inclusion (0.891). Subsequently, the items related to financial inclusion were reviewed to improve their reliability before data collection.

The collected data through questionnaires were subjected to processing before analysis. Data processing involved data screening from which missing values, outliers and normality testing were dealt with. From a dataset, 8 sets were deleted by applying list-wise data deletion. The missing values deleted occupied only 2%, which was insignificant not to cause biased and immaterial analysis data. The 10 extreme cases were screened by computing for Mahalanobis distance values. From this data cleaning, the responses retained were 200. Moreover, normality testing used the coefficient of skewness and kurtosis with the value of +/-2 of spreading.

Data analysis used a quantitative approach through which structural equation modeling (SEM) with the aid of SPSS AMOS 26 was applied while its assumptions were tested. As stipulated above, before actual data analysis, data were cleaned by checking for missing values, extreme data and normality testing. Furthermore, data analysis involved linearity, multi-co linearity and homoscedastic testing. The structural equation model guided the analysis was:

$$FI = \beta_0 + \beta_1 \sum Me_1 + \beta_2 \sum Me_2 + \beta_3 \sum Me_3 + \epsilon \ (1)$$

Where Me_1 = categorization of customers; Me_2 = Financial programs/products diversification; $Me_{3=}$ = Financial digitization.

III. RESULTS AND DISCUSSION

III.1 MODEL DEVELOPMENT AND FACTOR ANALYSIS

The initial factor loadings in Table 2 show all the variables with their loadings. Indicators with low loadings below 0.5, which is the acceptable level of coefficients, were removed, and only loadings greater than 0.5 were retained for measurement. From the analysis, the Keiser-Meyer–Oklin (KMO) measure of sampling adequacy is notably 0.5 low and 0.9 high. Similarly, the bar lets' test of sphericity is highly significant (p<0.05) [24]. From the rotated component matrix (See Table 2) since the KMO values (factor loadings) were greater than 0.5 given p=000<0.05. This either indicated that measures suggest that factor analysis was an adequate instrument to use. The cumulative variance explained was 57.29%. The results were generally satisfactory.

Table 2: Rotated Component Matrix.

Constructs	Indicators	1	2	3	4
Me$_1$	SU	0.772			
	MW	0.810			
	SLF	0.791			
	RU	0.811			
	LIU	0.745			
	FIU	0.743			
Me$_2$	FC		0.649		
	FS		0.814		
	Fl		0.842		
	FM		0.746		
	FCs		0.698		
Me$_3$	MFS			0.794	
	EB			0.841	
	WP			0.867	
FI	AC				0.819
	AD				0.764
	AF				0.821
Eigen values		4.364	3.067	2.041	1.985
Variance explained		21.820	15.335	10.205	9.925
Total variance		57.29			
Reliability of factors		0.720	0.730	0.820	0.891
Reliability of the survey		0.79			

Source: Authors, (2023).

III.2 RELIABILITY AND VALIDITY TESTING

Reliability testing is aimed at determining the consistency of measurement, while validity is motivated to reveal the measurement instrument's accuracy [25]. Reliability used both Cronbach's alpha (α) and composite reliability. The acceptable level for α is ≥0.7, while that of composite reliability is ≥0.8 [26].

Validity testing employed convergent (using average variance extracted (AVE)) and discriminant validity. To reveal that AVE is adequate or accurate in measurement, then AVE≥0.5 (acceptable level) and 0.8 (perfect level) [27]. In assessing discriminant validity, the average variance extracted from the constructs was compared with the square root of the correlations between the constructs. It is recommended that AVE values should be higher than the squared correlation estimates and that the value of correlations between the constructs should be 1 [28]. Discriminant validity is assessed in two ways: 1) square root of AVE and 2) loadings and cross-loadings matrix. Table 3 presents the results of the calculated square root of AVE, which all fall under the threshold of 0.7, meaning that the discriminant validity was found. Similar results with AVE were 0.504 (low) to 0.632 (high).

Reliability testing results revealed the adequacy in measuring the consistency of the measurement tool since α values were between 0.720 and 0.891 as it was with composite reliability with its results between 0.808 to 0.884 (See Table 3).

Table 3: Factor loadings, Reliability and Validity testing results (N=200).

Constructs	Indicators	Loadings	Reliability testing		Validity testing		
			Composite reliability	Cronbach's alpha (α)	Convergent validity (**AVE**)	Discriminant validity (Factor loadings) √CR	Errorvariance
Me$_1$	SU	0.772	0.838	0.720	0.624	0.779	0.162
	MW	0.810					
	SLF	0.791					
	RU	0.811					
	LIU	0.745					
	FIU	0.743					
Me$_2$	FC	0.649	0.808	0.730	0.576	0.750	0.192
	FS	0.814					
	FI	0.842					
	FM	0.746					
	FCs	0.698					
Me$_3$	MFS	0.794	0.884	0.820	0.632	0.834	0.116
	EB	0.841					
	WP	0.867					
FI	AC	0.819	0.811	0.891	0.504	0.801	0.189
	AD	0.764					
	AF	0.821					

Source: Authors, (2023).

III.3 TESTING THROUGH STRUCTURAL EQUATION MODELING

With this subtitle, the study was motivated to assess the strength of the relationship between FI's management effectiveness and financial inclusion. In this assessment, the FI management effectiveness is revealed through variables in measurement which were the ability to categorize customers based on their specific needs, invention over financial programs/products differentiation, and invention on financial digitization. To reveal the goodness of fit of these variables on creating sound financial inclusion, the goodness of fit indices (GFI); Tuller Lewis Fit Index (TLI); Comparative fit index (CFI) and Root Mean Square Estimated Approximation (RMSEA) were applied. The results from the field were as presented in Table 4.

Table 4: Fit Indices Matrix.

Goodness of fit indices	Perfect	Acceptable	Values in the model	Results
Cminf/df	≤2	≤3	3	Acceptable
GFI	≥0.95	≥0.90	0.94	Acceptable
TLI	≥0.95	≥0.90	0.92	Acceptable
CFI	≥0.97	≥0.95	0.95	Acceptable
RMSEA	<0.05	<0.08	0.06	Acceptable

Source: Authors, (2023).

Thus with GFI =0.94 at cminf/df= 3 (greater than the acceptable range of 0.90 (See Table 4) showed the variable FI management effectiveness measured by customer categorization (Me1); financial packaging, (Me$_2$) ; and financial digitization (Me$_3$) fit the model. Consistent results were shown over TLI=0.92>0.90; CFI 0.97>0.95 and RMSEA = 0.06<0.08, the facts which were proposed the same by [29]. More other results about the strength of the relationship between variables (i.e. observed and unobserved variables) were shown in structural model of regression weights in Figure 2.

III.3.1 Customers categorization FIs' managerial practice and financial inclusion

Here, the study aimed to determine the effects of customers' categorization managerial practice in sustaining financial inclusion. The latent constructs in association included the savers and users (SU), men and women (MW), SMEs (such that small holders' farmers, Bodaboda, MamaLishe and Machinga) and large scale users (SLF), rural and urban areas customers (as it was with financial users in Umalila, and Inyala in Mbeya rural district (RU); and Mbeya City respectively), formal and informal users (FIU), financial literate and illiterate users (LIU). It is through this division or simply categorization in which it was revealed that customer categorization for financial inclusion was enhanced given the following positivistic results of standardized regression weights (SU=0.78; MW=0.69; SLF=0.65; RU=0.74; LIU=0.76; and FIU=0.74). Moreover the positivistic results over S.R.W = 0.76 at p = 0.010 (insignificant); (chi-square= 602, df =200 (acceptable) (See Figure 2 and Table 4) validated that the managerial practice of categorizing customers based on their needs and objectives was an effective approach towards attaining sound financial inclusion. Moreover, categorizing financial users helped increase access to financial services /products of the specialization (AC= 0.74). Furthermore, meeting the specific needs of different type of customers revealed to help being accessed to quality and adequate (AD = 0.75) (See Figure 2) and affordable financial services (AF = 0.80). The fostered indicators of accessibility, adequacy, and affordability showed effective and sound financial inclusion to be attained (See Figure 2).

III.3.2 Financial packaging FIs' managerial innovation and financial inclusion

With this subtitle, the study aimed to assess the effects of financial packaging FIs' managerial innovation on financial inclusion. The financial packaging or simply financial programs/products diversification was measured through the constructs diversified credits provision (FC), diversified savings(FS) and insurance financial products(FI), financial marketing(FM) and other consultancy services (FCs). Financial differentiation found to have a positivistic relationship with financial inclusion. The results over S.R.W=0.80 at p= 0.000 (non-significant); (chi-square= 602, df =200 (acceptable)) (See Figure 2 and Table 4) showed financial packaging such that over the provision of diversified financial credits (such as short term and long term credits; women and men credits; SMEs and large scale firms credits; informal and formal business credits; financial literate and illiterate credits showed to have positivistic impacts in creating sound financial inclusion given FC=0.75. The same results was shown over increasing access (AC= 0.74) to adequate (AD=0.75); and affordable financial services and products (AF=0.54). This is either a fact that the diversified insurance products such as that over climatic change, crop, drought, fire-outbreak, motor, life and health insurance enhanced financial inclusion (FI=0.81). This is from the truth that in case of uncertainties such as drought, fire-outbreak return on investments is sustained by sustainably being accessed to financial products.

The increase in accessibility (AC=0.74) through financial marketing was because financial institutions might be offering many services unknown to the needy group, thus through marketing (in-acted by executing promotion tools in currently e-bill boards, websites, mobile phones and blogs may be used), then customers became aware and therefore created high demand (FM=0.79). That means the accessibility said to be boosted was due to increased demand after being known to the products of the need marketed.

The enabled access to affordable financial products (AF=0.80) positivistic results show that the financial training consultancy services the financial institutions might provide are innovative in creating financial literacy behavior. The financial management skills customers acquired through training revealed positive effects over efficient allocation of financial credits and others to reveal the expected results (FCs= 0.78). These results were consistent with what [30] said on the effect of financial training, skills in using financial products to realize expected returns and financial adequacy.

III.3.3 Financial digitization FIs' managerial practice and financial inclusion

With the objective of assessing the impact of managerial innovation in financial institutions (FIs) on financial inclusion, this study aimed to examine the effects of financial packaging on various aspects of financial inclusion. The study measured financial packaging through constructs such as diversified credits provision (FC), diversified savings (FS), insurance financial products (FI), financial marketing (FM), and other consultancy services (FCs). The findings indicated a positive relationship between financial differentiation and financial inclusion. The statistical results, with S.R.W = 0.80 at p = 0.000 (non-significant) and chi-square = 602, df = 200 (acceptable), demonstrated that financial packaging, particularly the provision of diversified financial credits, had a positive impact on promoting financial inclusion (FC = 0.75). The study also revealed positive effects on increasing access (AC = 0.74) to adequate (AD = 0.75) and affordable financial services and products (AF = 0.54). Furthermore, the study found that diversified insurance products, such as those related to climatic change, crop, drought, fire-outbreak, motor, life, and health insurance, contributed to enhanced financial inclusion (FI = 0.81). These insurance products provided a safety net for investments in times of uncertainties, such as drought or fire-outbreak, thereby ensuring sustainable access to financial products.

The study highlighted that increased accessibility (AC = 0.74) through financial marketing was driven by financial institutions offering previously unknown services to the target group. Customers became aware of these services by employing marketing strategies through platforms such as e-billboards, websites, mobile phones, and blogs, resulting in a higher demand

(FM = 0.79). Therefore, the enhanced accessibility was attributed to increased demand after customers became acquainted with the marketed products.

The study also found that the facilitated access to affordable financial products (AF = 0.80) was influenced by financial institutions' innovative financial training and consultancy services. The financial management skills acquired through training were shown to positively impact the efficient allocation of financial credits and other resources (FCs = 0.78). These findings were consistent with the assertions made by [29] regarding the effect of financial training and skills on the appropriate use of financial products and achieving financial adequacy.

Under the subtitle "Financial Digitization FIs' Managerial Practice and Financial Inclusion," the study examined the effects of financial institutions' adoption of digital technologies on financial inclusion. The constructs used to measure financial digitization included mobile financial services (MFS), internet financial transactions (EB), and wire payment (WP). The results showed a significant positive association between these constructs and financial inclusion, with an aggregated S.R.W = 0.65 at p = 0.020 and chi-square = 602, df = 200 (acceptable). These findings indicated that the adoption of sophisticated electronic systems sustained financial inclusion.

The study revealed that using mobile financial services, such as sim banking and mobile banking platforms (MFS = 0.66), reduced transaction costs associated with traveling. [31] also noted that mobile banking reduced transportation costs by eliminating the need for customers to travel long distances to access financial services in urban areas. Additionally, the study found that mobile financial services simplified the process of depositing and withdrawing money, allowing customers to perform these transactions from the comfort of their homes without the need to visit physical bank branches. The use of mobile financial services or banking increased financial customer centricity in areas like Umalila and Isyonje in Mbeya rural area, enabling transactions without needing to visit counters in Mbeya City and Mbalizi town.

Moreover, the study revealed that internet banking and financial transactions improved accessibility (AC=0.74) to affordable financial products (AF = 0.80). Adopting e-registration systems reduced the paperwork required to open accounts (EB = 0.64). The study found that customers could scan and send documents as attachments through email, eliminating the need for physical document submission. The adoption and invention of e-submission systems also reduced the reliance on manual processes, considered burdensome and a barrier to banking access for unbanked customers.

However, despite the positive results regarding financial digitization and inclusion, the study identified that most customers in the research areas, specifically in Mbeya rural areas such as Inyala, Ndaga, Umalalila, and Swaya, remained unbanked. This highlighted the lack of effective internet connectivity, telecommunication networks, and other necessary infrastructure to provide mobile financial services and e-banking in those areas. Consequently, the study emphasized the importance of an integrative and holistic approach to financial inclusion, requiring government intervention to ensure the availability of necessary infrastructures, including internet access, telecommunication networks, roads, and electricity supply. These factors were crucial for sustaining financial inclusion (AD = 0.75) and increasing access to adequate financial products through innovations in mobile apps, downloadable financial services from app stores, and wire payments (WP = 0.63). Although not the main focus of this study, the issue of safety in using e-float was also mentioned, as discussed by [32].
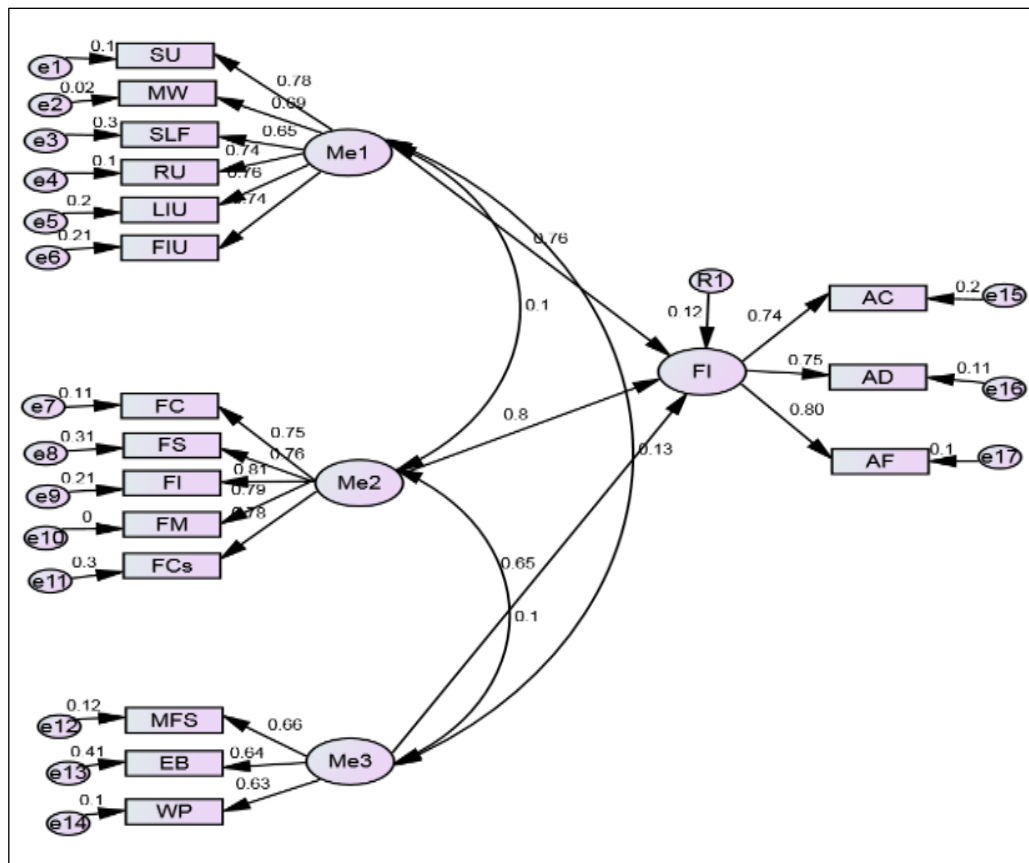

Figure 2: Structural Model.
Source: Authors, (2023).

III.4 HYPOTHESIS TESTING

The hypothesis testing was motivated to determine the strength of positivism and the significant effect between variables. In this study, the standardized path coefficient was used to reveal the extent of determination. With this standardized path coefficient ($\gamma > 0.2$), critical ratio (C.R>1.96) and its significance, $p<0.05$[33] were applied to determine such strength of association between variables. The results in Table 5 stipulate the reality.

Table 5: Variables in relationships.

Hypothesis	Relationships	Estimate	S.E	C.R	S.R.W	p	Results
H$_1$	FI <- - - -Me$_1$	0.76	-0.01	1.99	0.21	0.01	Supported
H$_2$	FI <- - - - Me$_2$	0.80	0.02	2.00	0.24	***	Supported
H$_3$	FI <- - - -.Me$_3$	0.65	0.01	1.97	0.30	0.02	Supported

Source: Authors, (2023).

With $\gamma=0.21>0.2$, C.R$=1.99>1.96$; $p=0.01<0.05$ indicated that FIs management (Me1) effectiveness in categorizing financially needy customers indicated to have a positive and significant effect on financial inclusion. These results were consistent with that over FIs management effectiveness (Me2) in financial programs/products diversification about financial inclusion given $\gamma = 0.24$, C.R$=2.00$ at $p=0.08$. Moreover, $\gamma =0.30$ (C.R$=1.97$ at $p=0.02$) showed that FI management effectiveness (Me3) over financial digitization had a most positive and significant effect on financial inclusion.

IV CONCLUSION AND RECOMMENDATIONS

Financial inclusion refers to the accessibility and usability of financial resources and products. Previous research has identified several factors that significantly contribute to financial inclusion, including financial literacy, accessible financial infrastructures, and formalization of business firms. However, this study highlights the crucial role played by innovative management practices in financial institutions. Specifically, effective customer categorization, financial packaging/diversification, and financial digitization managerial practices were found to have positive and significant effects on financial inclusion.

Based on this study's positive and significant results, several recommendations are put forth for action. Firstly, the government should enforce policies that are fair and economically balanced. These policies should not discourage liberation but should also prevent financial customers from being exploited by service providers. Additionally, financial institutions should adopt innovative and effective practices by embracing the principles of customer categorization, financial packaging, and digital financial systems. These measures will enhance financial inclusion and ensure financial resources are accessible to a wider population.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Kaula Stephen and Gwahula Raphael.
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Investigation: Eko Naning Sofyanita and Arya Iswara.
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RESEARCH ARTICLE **OPEN ACCESS**

MONITORING OF ANNUAL EFFECTIVE DOSE (AED) IN SURFACE SOILS OF AHERO RICE FIELDS, KENYA

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ARTICLE INFO	ABSTRACT
	The annual effective doses (AED) both AED (in) and AED (out) in the surface soils of Ahero rice fields, Kenya were investigated. The associated health risk of the soils from the four fields Field 1, Field 2, Field 3 and Field 4 was measured using gamma ray spectrometric technique employing Sodium Iodide Thallium doped detector. Five surface soil samples were collected at a depth of 15 – 20 cm from the Field 1, Field 2, Field 3 and two samples from Field 4. The average AED (in) of 0.30 ± 0.01 mSv/y and an average AED (out) of 0.20 ± 0.01 mSv/y for field 1, an average AED (in) of 0.19 ± 0.01 mSv/y, an average AED (out) of 0.20 ± 0.01 mSv/y for field 2, an average AED (in) of 0.28 ± 0.01 mSv/y and an average AED (out) of 0.18 ± 0.01 mSv/y for field 3 and an average AED (in) of 0.34 ± 0.01 mSv/y and an average AED (out) of 0.23 ± 0.01 mSv/y for field 4. All the AED values both in and out from the four fields were below the recommended level of 1mSv/y. The values indicate that there is no health hazard associated with the surface soils of the study area to the farmers and the general population.

I. INTRODUCTION

The concentration of natural radionuclides of ^{238}U, ^{232}Th and singly occurring ^{40}K in the soils have a direct bearing on the terrestrial radiatiation [1]. The three radionuclides are found in significant concentrations in the soils [2]. It is worth noting that natural radioactivity depends on the geological formations of the place [3]. Anthropogenic activities especially Agricultural based ones in an attempt to replenish the soils with nutrients using inorganic fertilizers adds to the radioactivity levels to the soils [4]. The hazards of exposure due to the radionuclides has formed a basis of major concern in the recent times [5]. The associated effects of exposure to the varying levels of radiations from ^{238}U, ^{232}Th and ^{40}K have been broadly discussed in various literature [6]. The Ahero rice fields are part of the larger Nyando wetlands region. This region is characterized by a Precambrian system of granodiorites that are granitic in nature [7]. The granitic rocks have higher concentrations of ^{238}U [8]. It is estimated that every year there are 40000 new cancer cases and over 27000 deaths in Kenya [9]. ^{238}U and ^{232}Th are highly radiotoxic. Individuals exposed to high amounts of ^{232}Th have an increased risk of bone cancer while

ingestion of large concentrations of ^{238}U can cause lung cancer and kidney damage [10]. ^{40}K on the other hand is a mineral required by the human body muscles to work efficiently. It helps in the functioning of the nerves and muscle contraction. However, too much of ^{40}K in the body can affect the working of the muscles of the heart; an irregular heart beat which may result in to heart attack and in worst cases death.

The farmers and the general public are in direct contact with the soil, fertilizers and untreated water from river Nyando [11]. They inhale the dust particles of the soils which find their way in to the body through the respiratory system [12]. The radionuclides of ^{238}U, ^{232}Th and ^{40}K have very long half-lives [1]. Farming in Ahero fields is not void of use of inorganic fertilizers especially phosphatic ones. These phosphatic fertilizers originate from rocks that are highly rich in ^{238}U [13]. The addition and hence accumulation of natural radionuclides in the top soils is potentially hazardous to the human health and environment [12]. According to a study by [14], there were cases of reported skin burns when the study was conducted at four health care providers. The skin burns can be attributed to the direct irradiation from the radionuclides.

This study of monitoring annual effective doses (AED) both AED (in) and AED (out) in the surface soils of Ahero rice fields was therefore undertaken to assess the radiological risk associated with the interaction of the soils by the farmers and the general public since no similar study had been done at the study area.

II. MATERIALS AND METHODS

II.1 STUDY AREA

The present study was conducted at the Ahero rice fields (Ahero Irrigation Scheme - AIS). The study area is located on latitude on latitude $00°9´´S$ and longitude $34°56´´E$ and at an altitude of 1160m above sea level [7]. Ahero fields is found in Muhoroni Sub County that has a population of 151799 [15]. These fields are characterized by vertisols just like other National Irrigation Schemes [16]. The soils are suitable for irrigation of rice due to their low percolation rates. The source of water for irrigation in the Ahero fields is river Nyando whose river bed is also characterized by rocks of granitic nature [7]. Map showing Ahero Irrigation Scheme where the study was done is as shown in figure 1 below.
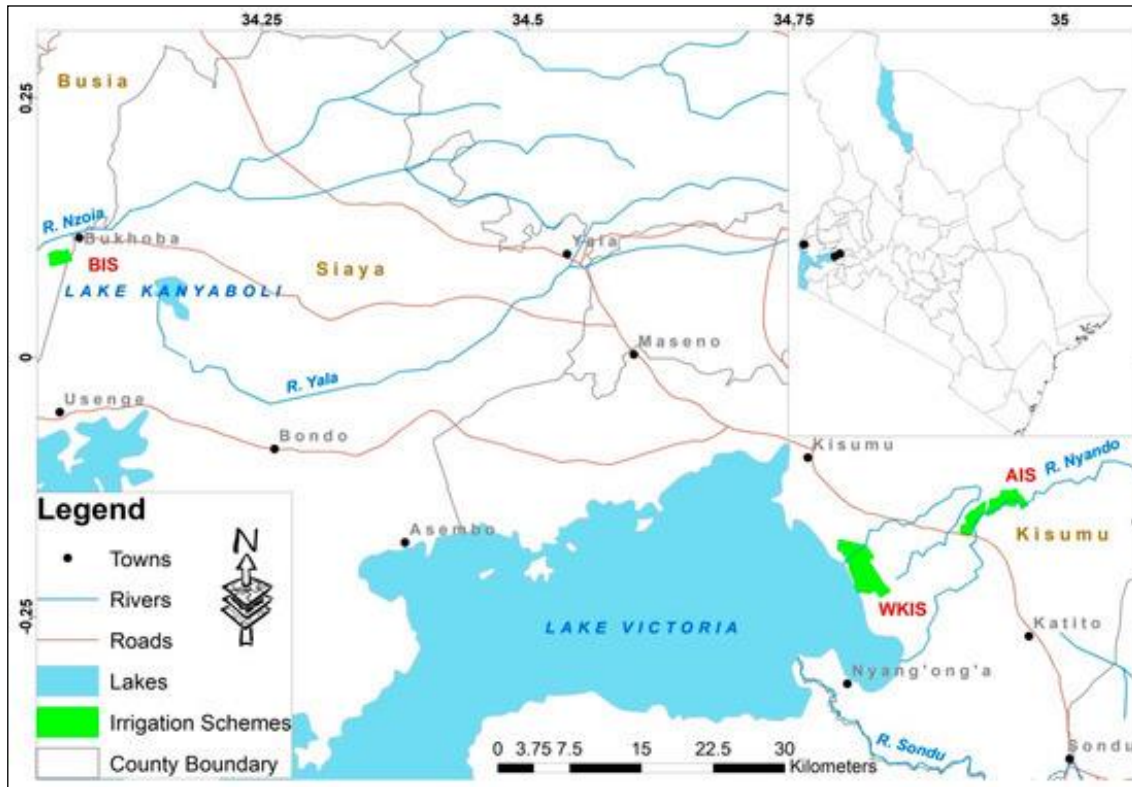

Figure 1: Map of Ahero irrigation scheme (google map).
Source: Authors, (2023).

II.2 SAMPLE COLLECTION AND PREPARATION

A total of 17 surface samples at the depths of 15 – 20 cm were collected. Samples S_1 to S_5 were from a field where rice was already transplanted (field 1), S_6 to S_{10} samples were collected from a field where transplanting was being done (field 2), S_{11} to S_{15} samples were collected from a field where rice had already been harvested and cultivation done (field 3), S_{16} and S_{17} samples were collected from a field that had not been cultivated for 2 years. The samples were properly labelled and spread on mats in the laboratory to dry for two weeks (14 days) to dry. They were then crushed using mortar and pestle then sieved through a 2.00 mm sieve (< 2.00 mm particles were used).

170 g of each sample from the fields was weighed in to cylindrical plastic containers of uniform geometry. The containers were properly labeled and hermetically sealed. The samples were then kept for 30 days to allow for ^{232}Th and ^{238}U and their short lived progenies to reach secular equilibrium before counting [17, 18].

II.3 GAMMA RAY SPECTROSCOPIC ANALYSIS

NaI (Ti) gamma ray spectrometer was used in the spectral acquisition and analysis [11]. The spectrometry system consisted of 76 mm by 76 mm single crystal of Thallium activated Sodium Iodide. Spectrum acquisition and processing was made possible by coupling the detector output to a multichannel Analyzer (MCA). The energy calibration of the detector was done using the energy peaks of The energy calibration of the gamma ray spectrometer was done using the energy peaks of 662 KeV of ^{137}Cs, 1170 KeV and 1330 KeV of ^{60}Co [19]. The masses used were 1.2g for ^{137}Cs and 6.7g for ^{60}Co.

Gamma rays from the soil sample strikes the NaI (Ti) crystal emitting photons that dislodge electrons from the photocathode. The photoelectrons produced are collected by the pre – amplifier and shaped into voltage pulses. The pulses are multiplied in the photomultiplier by a series of dynodes. Finally, the MCA digitizes the pulses and the output is displayed through personal computer

III. RADIATION LEVEL MEASUREMENTS

III.1 ABSORBED DOSE RATE (ADR)

The ADR values shown in table 1 below used in the determination of AED were got from the study by [11] at the same study area.

Table 1: Absorbed Dose Rate of samples collected.

	Sample	Absorbed Dose Rate (nGy/h)
Field 1	S_1	98.35 ± 4.91
	S_2	67.73 ± 3.38
	S_3	130.84 ± 6.54
	S_4	53.40 ± 2.67
	S_5	57.18 ± 2.85
	Average ADR	**81.50 ± 4.07**
Field 2	S_6	62.68 ± 3.12
	S_7	44.55 ± 2.22
	S_8	47.81 ± 2.39
	S_9	61.12 ± 3.05
	S_{10}	$46.97.18 \pm 2.34$
	Average ADR	**52.59 ± 2.62**
Field 3	S_{11}	80.78 ± 4.03
	S_{12}	53.97 ± 2.69
	S_{13}	47.14 ± 2.35
	S_{14}	56.23 ± 2.81
	S_{15}	135.28 ± 6.76
	Average ADR	**74.68 ± 3.73**
Field 4	S_{16}	109.47 ± 5.47
	S_{17}	74.10 ± 3.70
	Average ADR	**91.79 ± 4.59**

Source: [11].

III.2 ANNUAL EFFECTIVE DOSE (AED)

In determining the outdoor AED to the population, the occupancy factor was put into consideration [20]. The annual effective dose AED(in) and AED (out) were determined using equations 1 and 2 respectively [21].

$$AED \text{ (in)} = ADR \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \qquad (1)$$

$$AED \text{ (out)} = ADR \times 8760 \times 0.4 \times 0.7 \times 10^{-6} \qquad (2)$$

Where AED (in) and AED (out) are Annual Effective Doses for indoor and outdoor environments respectively, ADR is the absorbed dose rate in air in nGy/h, 0.7 (SvGy) is the conversion factor for absorbed dose rate in air to an effective dose, 0.8 is the indoor occupancy factor while 0.4 is the outdoor occupancy factor. The units of AED are milliSierverts per year (mSv/y).

IV. RESULTS AND DISCUSSIONS

IV.1 DETERMINATION OF ANNUAL EFFECTIVE DOSE

The AED (in) and AED (out) were determined and the results tabulated in table 2. The results were also represented in figure 2.

Table 2: A summary of indoor and Outdoor Annual Effective Dose Rates for all the samples in this study.

	Sample	AED (in) mSv/y	AED (out) mSv/y
Field 1	S_1	0.36 ± 0.01	0.24 ± 0.01
	S_2	0.25 ± 0.01	0.17 ± 0.01
	S_3	0.48 ± 0.01	0.32 ± 0.01
	S_4	0.20 ± 0.01	0.13 ± 0.01
	S_5	0.21 ± 0.01	0.14 ± 0.01
	Average AED	**0.30 ± 0.01**	**0.20 ± 0.01**
Field 2	S_6	0.23 ± 0.01	0.15 ± 0.01
	S_7	0.16 ± 0.01	0.11 ± 0.01
	S_8	0.18 ± 0.01	0.12 ± 0.01
	S_9	0.22 ± 0.01	0.15 ± 0.01
	S_{10}	0.17 ± 0.01	0.12 ± 0.01
	Average AED	**0.19 ± 0.01**	**0.13 ± 0.01**
Field 3	S_{11}	0.30 ± 0.01	0.20 ± 0.01
	S_{12}	0.20 ± 0.01	0.13 ± 0.01
	S_{13}	0.17 ± 0.01	0.12 ± 0.01
	S_{14}	0.21 ± 0.01	0.14 ± 0.01
	S_{15}	0.50 ± 0.01	0.33 ± 0.01
	Average AED	**0.28 ± 0.01**	**0.18 ± 0.01**
Field 4	S_{16}	0.40 ± 0.01	0.27 ± 0.01
	S_{17}	0.27 ± 0.01	0.18 ± 0.01
	Average AED	**0.34 ± 0.02**	**0.23 ± 0.01**

Source: Authors, (2023).

From the Table 2, soil samples from field 1 had an average AED (in) of 0.30 ± 0.01 mSv/y and an average AED (out) of 0.20 ± 0.01 mSv/y, an average AED (in) of 0.19 ± 0.01 mSv/y, an average AED (out) of 0.20 ± 0.01 mSv/y for field 2, an average AED (in) of 0.28 ± 0.01 mSv/y and an average AED (out) of 0.18 ± 0.01 mSv/y for field 3 and an average AED (in) of 0.34 ± 0.01 mSv/y and an average AED (out) of 0.23 ± 0.01 mSv/y for field 4. The average AED (in) and average AED (out) for field 4 were higher, this is because although the field had not been used for 2 years, accumulation of the radionuclides had taken place due to continuous use of inorganic fertilizers.
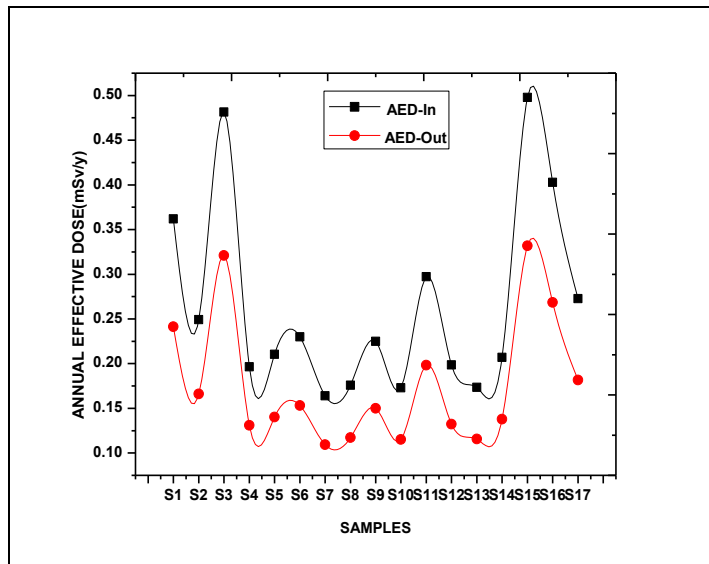
Figure 2: Indoor and Outdoor Annual Effective Doses for the collected samples.
Source: Authors, (2023).

It can be noticed from the results that all the fields had their AED (in) and AED (out) above the world value of 0.07 mSv/y [2]. Although all samples had high AED (in) and AED (out) than the world levels, their values were below the world permissible value of 1 mSv/y.

V. CONCLUSIONS

An investiagation of annual effective dose in the surface soils of Ahero rice fields, Kenya has been done using gamma ray spectroscopy. The average AED (in) and AED (out) values from all the four fields were below the permissible level of 1mSv/y [22]. Thus the interaction of the population with the soils does not pose a health hazard. However, a study needs to be done to assess the AED (in) and AED (out) in the rice components and other crops cultivated at the study area for example Soy beans, maize and water melons to provide a comprehensive data base information on radiation safety.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Mukanda Kere Wanyama, Michael Nakitare Waswa and Linda Ouma.
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VII. ACKNOWLEDGMENTS

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RESEARCH ARTICLE   **OPEN ACCESS**

SOIL LOSS ESTIMATION USING RUSLE MODEL AND GEO-SPATIAL TECHNOLOGY IN THE BASEMENT COMPLEX OF AKURE, SOUTHWESTERN NIGERIA

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ARTICLE INFO	ABSTRACT
	Soil loss estimation has been carried out using the revised universal soil loss equation (RUSLE) model and geo-spatial technology in the basement complex of Akure, Southwestern Nigeria. The objectives are to predict average annual rate of soil erosion and address the menace of erosion in the area. Geologically, the area is underlain by the basement complex rocks of Southwestern Nigeria. Meteorological data, soil information, remote sensing data and digital elevation model (DEM) formed the data base. Three Landsat images of the study area covering 1987, 1997 and 2017, with 30 m spatial resolution were deployed using ArcGIS spatial analyst tool. The RUSLE parameters; Rainfall Erosivity Factor, Slope Length and Steepness Factor, Soil Erodibility Factor, Cover and Management Factor and Support Practice Factor were assessed in a GIS (Geographic Information System) environment. The soil loss was classified into low, moderate, high and very high level of severity. The results showed that soil erosion has moderately increased due to anthropogenic effects over the years.

I. INTRODUCTION

Soil erosion, the displacement or transportation of the upper layer of soil is an important phenomenon with several consequences. Soil erosion involves detachment and transport of soil particles from top soil layers. It is the systematic removal of soil, including plant nutrients from the land surface by various agents of denudation. The loss of the upper layer of soil due to the effects of forces such as water, wind and agricultural practices is profound. Soil erosion has been recognized as a major issue around the world [1 - 3].

Large amount of precipitation and associated runoff processes, wet and saturated soil including sand and silt, the characteristics of land cover and management such as removal of vegetation cover and deforestation, topography of land, poor drainage system account for erosion. Some human interventions can significantly increase erosion rates [1, 4, 5]. Its possible effects include devastating landscape alterations, river and reservoir siltation, water quality degradation, nutrient loss, and decreases in soil productivity [6, 7].

Advances in geospatial technology have assisted in the process of modeling soil loss with enhanced accuracy [2, 3, 8]. Soil erosion can be mapped using models such as USLE, RUSLE etc. The Universal Soil Loss Equation (USLE) is a widely used soil erosion prediction model, where rainfall-runoff erosivity is the prominent factor responsible for erosion. The Revised Universal Soil Loss Equation (RUSLE), a modification of the USLE model has been acknowledged to produce high-accuracy results. It is a product of an extensive review of the USLE and its data base, analysis of data not previously included in the USLE, and the theory describing fundamental hydrologic and erosion processes. The RUSLE Model provides a quantitative and consistent approach to estimate soil erosion under a wide range of conditions [9 - 11].

The study area is located between latitudes 7°7′30″N and 7°21′0″N; longitudes 5°1′30″E and 5°24′0″E. It falls within the

central senatorial district of Ondo State, Nigeria (Fig. 1). The major rock types in the study area are charnockite and granite rocks. The three principal petrographic varieties are the fine-grained biotite granite, medium to coarse grained, non-porphyritic biotite – hornblende granite and coarse – porphyritic biotite- hornblende granite.
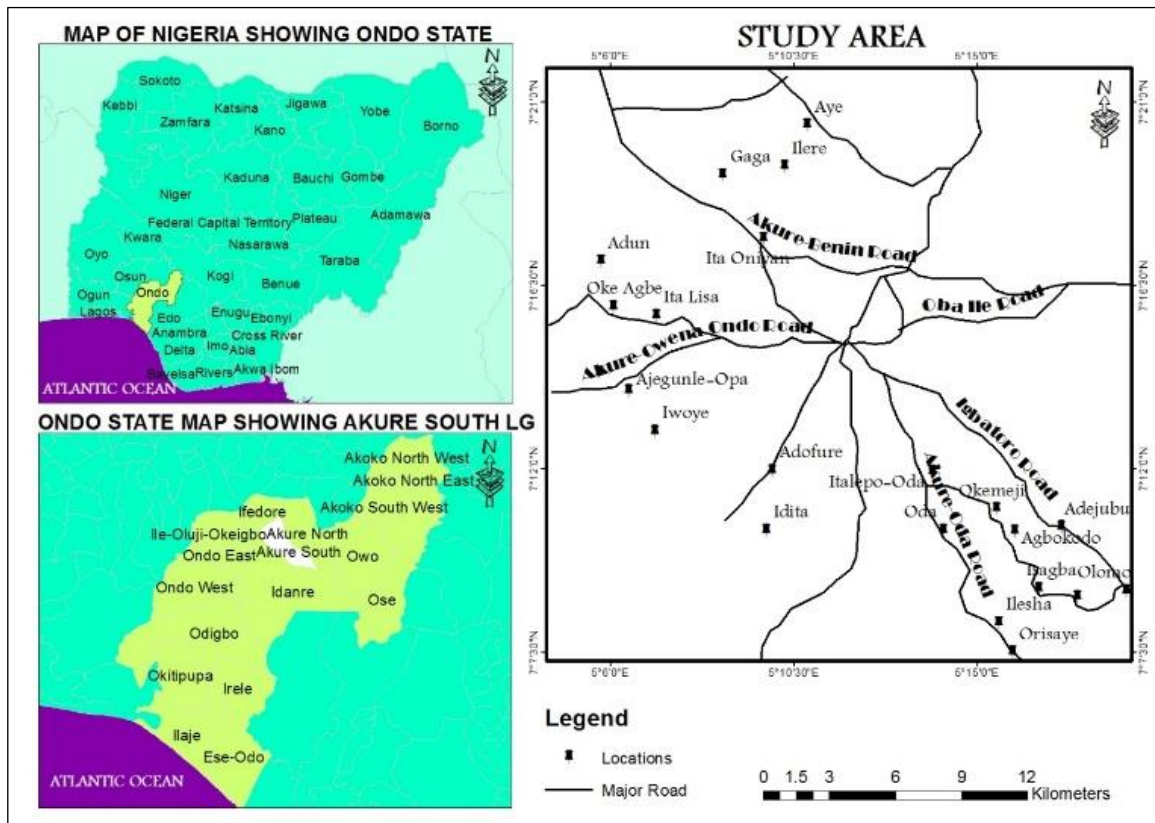

Figure 1: Map of the study area.
Source: Authors, (2023).

The study area is composed of lowlands and rugged hills with granitic outcrops in several places. Some of the more prominent hills rise above 250 m above sea level. The most outstanding characteristics of the drainage systems over the areas of Basement Complex rocks is the proliferation of many small river channels. The channels of the smaller streams are dry for many months, especially from November to May. The mean annual temperature is 27.3°C with the annual total rainfall of 1805.9 mm [12, 13].

The works of [6], [9], [10], [11] and similar authors demonstrated the importance of GIS and remote sensing, Multi-criteria Evaluation and RUSLE model in soil loss estimation. The combined use of the RUSLE model, remote sensing and GIS techniques in the assessment and quantification of the soil loss in the basement complex of Akure, Southwestern Nigeria is presented in this paper.

II. THEORETICAL REFERENCE

The RUSLE model and the input parameters have been presented in literature [3, 8, 11, 14, 15]. The predicted average annual soil loss, **A**, according to the Revised Universal Soil Loss Equation (RUSLE) is expressed as:

$$A = R * K * LS * C * P$$

R is the Rainfall-Runoff Erosivity Factor. It is an index showing erosive force on surface soils. The rainfall intensity and erosive duration are requisite inputs in the computation of the R factor:

$$R = 38.5 + 0.35 * Pr$$

where Pr = Annual average rainfall (mm/yr).

K, Soil Erodibility Factor indicates vulnerability of soil to rainfall and runoff detachment and transport based on soil texture, grain size, permeability and organic matter content.

LS, Slope Length and Steepness Factor, accounts for the effect of slope length (L) and the slope steepness (S) on erosion. The factor L and factor S are generally considered together.

C, Cover-Management Factor, is an index that indicates how crop management and land cover affect soil erodibility.

The P-factor, **Support Practice factor,** refers to the level of erosion control practices such as contour planting, terracing and strip cropping.

III. MATERIALS AND METHODS

Temporal changes of soil erosion risk were assessed from 1987 to 2017. The parameters of RUSLE model were estimated using remote sensing data in a GIS environment. The study utilized 30 m Landsat imagery (Landsat 5, 7 and 8), 30 m SRTM Digital Elevation Data, Tropical Rainfall Measuring Mission (TRMM) Rainfall Data, Soil Map of the area and base map. Three (3) study periods were considered. Table 1(a & b) shows the attribute of the remotely sensed data.

The major input parameters used in the study included Rainfall Erosivity Factor (R), Slope Length and Steepness Factor (LS), Soil Erodibility Factor (K), Cover and Management Factor (C) and Support Practice Factor (P) as documented in [2 - 4, 8, 10].

ArcGIS 10.2 was used to run the model. The Flowchart of the methodology is presented in Fig. 2.

Table 1(a): Remotely sensed data attribute - Landsat Data.

Landsat Data			
Path	Row	Sensor	Resolution
190	55	Landsat5 TM	30m
190	55	Landsat7 ETM	30m
190	55	Landsat8 OLI_TIRS	30m

Source: Authors, (2023).

Table 1(b): Remotely sensed data attribute - DEM Data.

DEM Data		
Date	Sensor	Resolution
2017	Aster	30m
2007	Aster	30m
1997	SRTM	90m

Source: Authors, (2023).
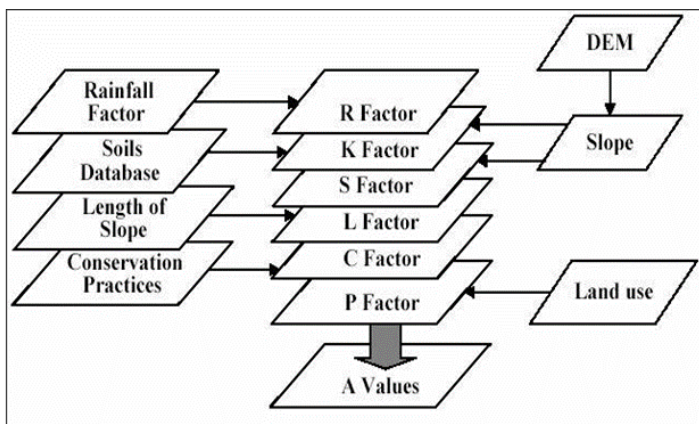
Figure 2: Procedures of RUSLE implementation in GIS.
Source: Authors, (2023).

IV. RESULTS AND DISCUSSIONS

The components of RUSLE model are presented as maps.

IV.1 RAINFALL AND RUNOFF EROSIVITY FACTOR (R)

(Figs. 3 - 5) show the variation of the runoff erosivity factor over the study cycle.

Figure 3: R factor map of 1997.
Source: Authors, (2023).
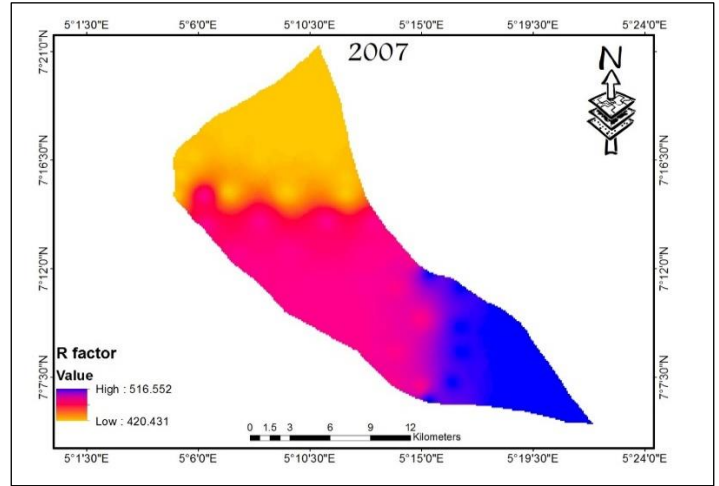
Figure 4: R factor map of 2007.
Source: Authors, (2023).
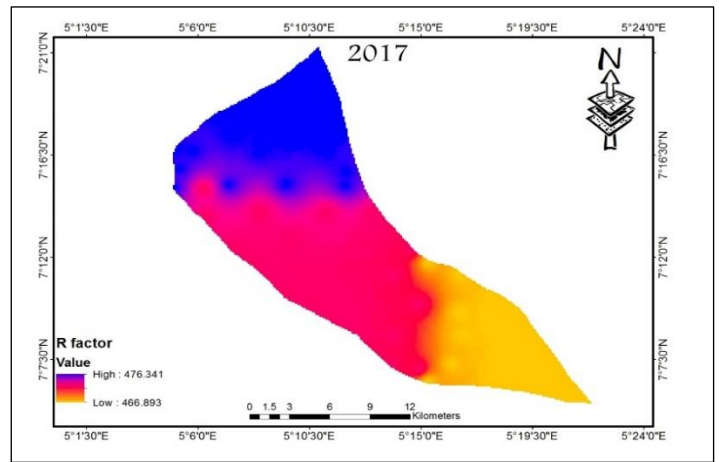
Figure 5: R factor map in 2017.
Source: Authors, (2023).

IV.2 ERODIBILITY FACTOR (K)

Fig. 6 shows the soil types in the area. The soil erodibility is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff [1, 15]. A high K value implies more vulnerability to soil erosion whereas, low k values indicate less vulnerability to soil erosion. Presence of organic matter in soil decreases erodibility since it reduces soil vulnerability to loosening. Soil erodibility factor proposed by [16] cited in [1] was adopted [2, 3, 10].
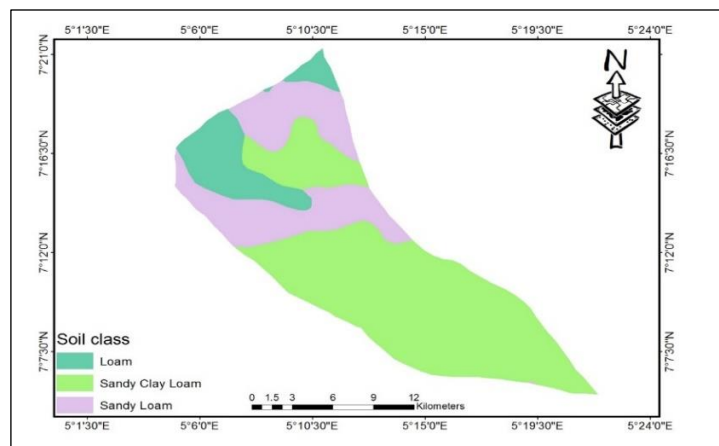
Figure 6: Soil map of the área.
Source: Authors, (2023).

IV.3 SLOPE LENGTH FACTOR (L) AND SLOPE STEEPNESS FACTOR (S)

The slope length factor, indicates the effect of the slope length on erosion (Figs. 7 - 9). S is the steepness of the slope signifies the effect of the slope on erosion. The relationship between the loss of soil and the gradient is influenced by the density of the vegetation cover and the size of the soil particles [1, 3, 6].

IV.4 COVER MANAGEMENT FACTOR (C)

The C factor map (Figs. 10 - 12) reveal the effect of crops and management practices on erosion rates. It indicates how the conservation plan will affect the average annual land loss and how this potential loss of soil will be distributed in time during construction activities, crop rotations or other management schemes. Four landcover classes namely Forest, Vegetation, Bare land, and Built environment were mapped out [4, 5, 15].

Figure 7: LS factor map of 1997.
Source: Authors, (2023).
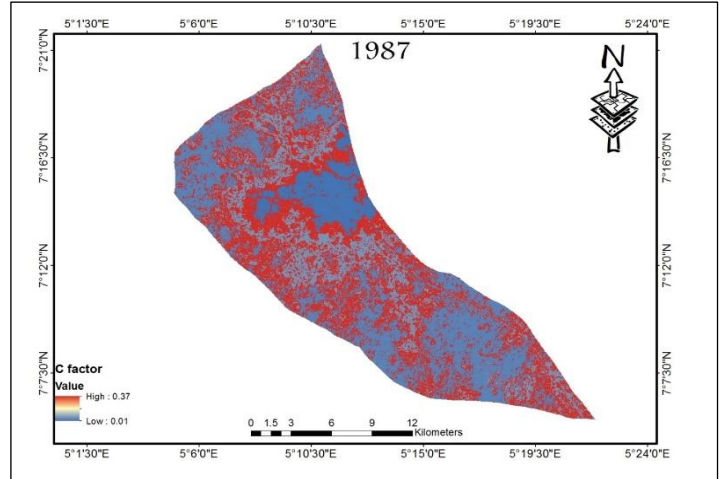
Figure 10: C factor map of 1987.
Source: Authors, (2023).

Figure 8: LS factor map of 2007.
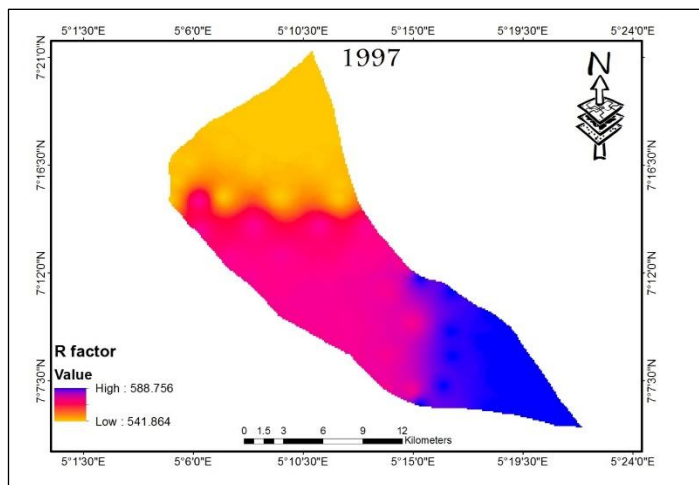Source: Authors, (2023).
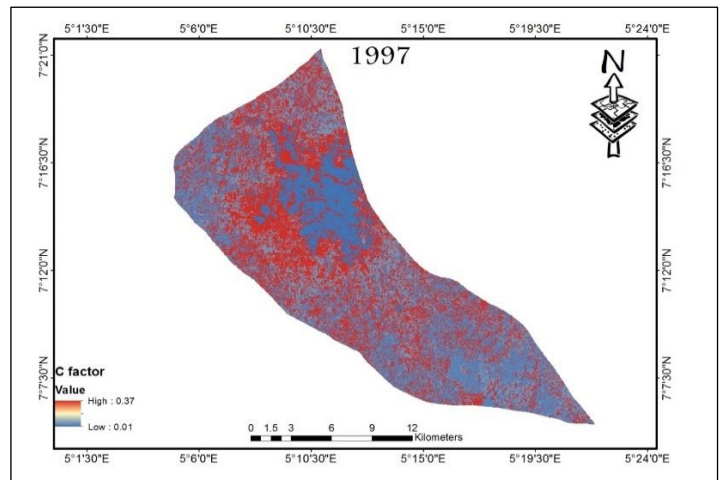
Figure 11: C factor map of 1997.
Source: Authors, (2023).

Figure 9: LS factor map of 2017.
Source: Authors, (2023).
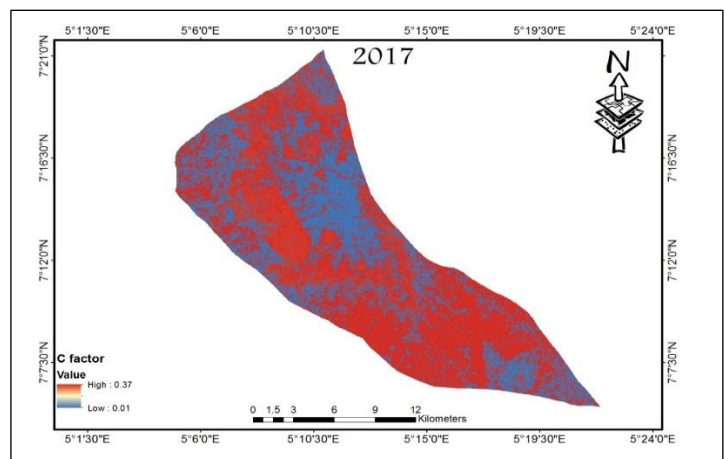
Figure 12: C factor map of 2017.
Source: Authors, (2023).

IV.5 CONSERVATION PRACTICE FACTOR (P)

The P factor reveals the impact of support practices on the rate of erosion (Fig. 13 - 15). It reflects practices that reduce the rate. P factor map was developed in ArcGIS using landuse/landcover map of the study area [1, 4, 5].

IV.6 LAND USE /LAND COVER CLASSIFICATIONS

Mapping of the study area in 1997, 2007 and 2017 showed four basic land use/land cover classes namely forest, vegetation, built environment and bare land as shown in (Figs. 16 - 18), respectively. Table 2 shows the area extent of each class.

Figure 13: P factor map of 1997.
Source: Authors, (2023).

Figure 16: Landcover map of 1987.
Source: Authors, (2023).

Figure 14: P factor map of 2007.
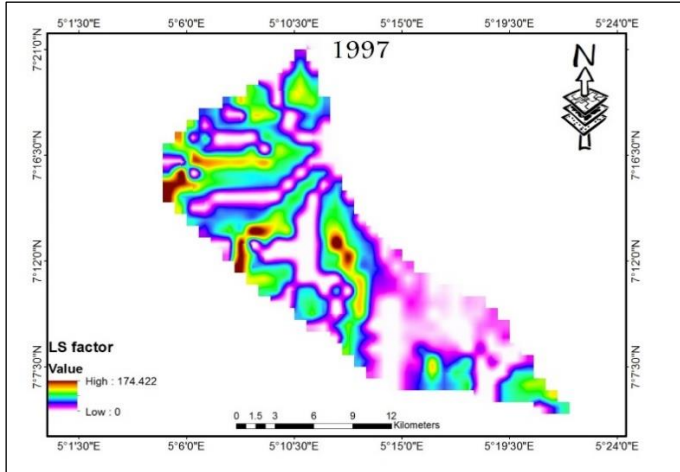Source: Authors, (2023).

Figure 17: Landcover map of 1997.
Source: Authors, (2023).

Figure 15: P factor map of 2017.
Source: Authors, (2023).

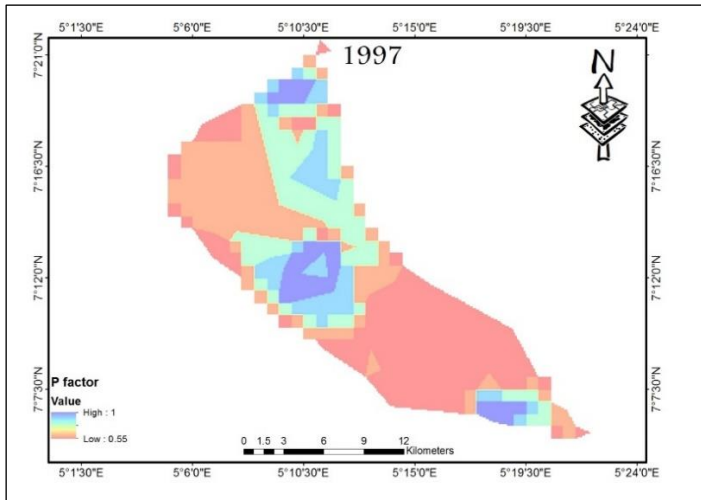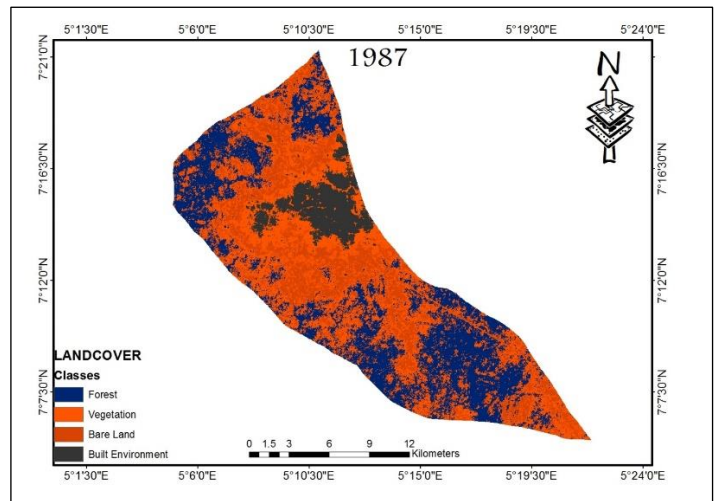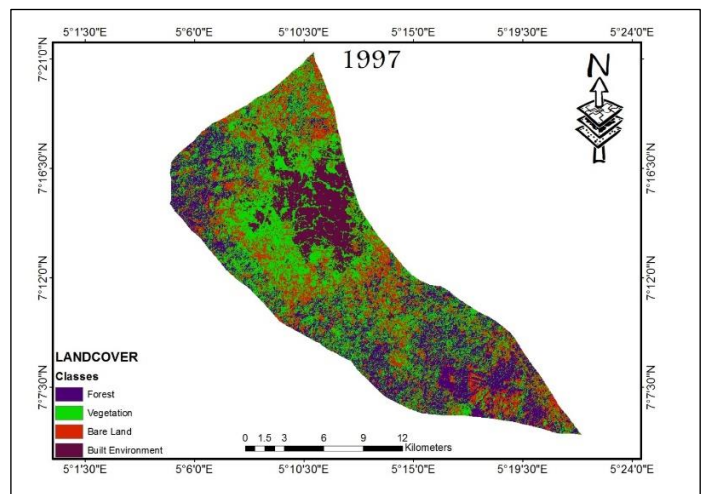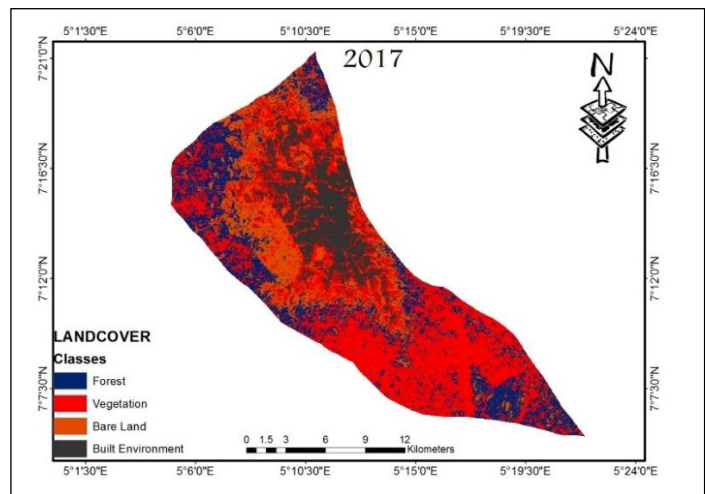Figure 18: Landcover map of 2017.
Source: Authors, (2023).

Table 2: Area extent of Landcover classes.

Classes	1987 Area (in sq km)	1997 Area (in sq km)	2017 Area (in sq km)
Bare Land	57.25	70.31	58.79
Built Environment	26.01	37.87	49.54
Forest	109.69	89.57	75.82
Vegetation	137.79	133.00	146.59

Source: Authors, (2023).

Vegetation dominated the landcover all through the study cycle. The second major landuse/land cover type was forest. Built environment increased across the years while the forest cover indicated decline. Land use/land cover information is essential for the selection, planning and implementations of land use schemes to meet the increasing demands of basic human needs and welfare [6, 7, 17].

IV.7 ESTIMATION OF SOIL LOSS

The annual soil loss rate was obtained by integrating the respective RUSLE factors; erosivity (R), erodibility (K), topographic (LS), cover management factor (C), and conservation support practice (P) layer values using ArcGIS 10.2 [3, 11, 14]. The study showed four classes (Table 3). The high and very high erosion prone areas constitute the erosion hotspots. These areas require urgent remediation measures. Low soil erosion risk dominates the area in the moderate forest class. However, it increases by approximately 17% across the years. Areas with steeper slopes have been identified as highly vulnerable to erosion. Generally, it can be seen that the average rate of soil loss and the contribution to the total soil loss from steeper slope is higher compared with that of gentle slope. [3, 11, 14].

Table 3: Area under various soil loss zones of the study area (Soil loss trend).

Classes	1997 Area (in sq km)	Area (in %)	2007 Area (in sq km)	Area (in %)	2017 Area (in sq km)	Area (in %)
LOW	247.36	75.92	313.90	90.00	300.1	92.00
MODERATE	30.98	9.510	12.50	4.50	25.10	7.00
HIGH	21.13	6.50	1.40	0.40	2.60	0.80
VERY HIGH	26.34	8.10	0.30	0.10	0.70	0.20

Source: Authors, (2023).

V. CONCLUSIONS

The RUSLE model combined with GIS has proven to be effective for evaluating erosion vulnerability. Implementation of suitable measures in the erosion hotspot is important. Effective management practices would protect key infrastructures such as roads and properties. Enhanced spatial resolutions and accuracies of the digital elevation models are desirable to check possible limitations of the study.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele and Omosekeji.
Methodology: Oyedele and Omosekeji.
Investigation: Oyedele, Omosekeji and Olaseeni.
Discussion of results: Oyedele, Omosekeji and Olaseeni.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Omosekeji and Olaseeni.
Resources: Oyedele, Omosekeji and Olaseeni.
Supervision: Oyedele and Olaseeni.
Approval of the final text: Oyedele, Omosekeji and Olaseeni.

VII. ACKNOWLEDGMENTS

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RESEARCH ARTICLE   **OPEN ACCESS**

PROPOSAL OF A PROGRAMMABLE LOGIC CONTROLLER BASED ON OPEN HARDWARE

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ABSTRACT

Industrial automation is dominated by solutions that are implemented with distributed controllers, such as programmable logic controllers. Currently, companies such as Industrial Shields, Norvi, Controllino, or Arduino offer industrial controller solutions that are based on open hardware. These, although they do not have the capacity to work in applications that require high safety integrity levels, represent a low-cost alternative to traditional solutions. This study is the result of the collaboration between Universidad Central Marta Abreu de Las Villas and company CEDAI UEB Villa Clara. The objective of this article is to make a proposal for a programmable controller based on open hardware that is an economical and flexible alternative for industrial automation. The MCI-VC v1.0 is intended to be a compact, low-cost, STM32 microcontroller-based controller that complies with parts of the IEC 61131 standard. The controller will have digital and analog inputs, digital outputs, and RS485, Ethernet, USB, and SPI communication for expansion modules. The proposal is conceptually cheaper than its counterparts, which should allow obtaining a competitive product. The design meets the defined technical requirements and has higher performance than several commercialized controllers.

I. INTRODUCTION

Industrial automation is the application of different technologies to control and monitor a process. It is currently dominated by solutions that are implemented with distributed controllers, such as Programmable Logic Controllers (PLC) [1]. Unlike general-purpose computers, a PLC is designed with multiple input/output channels, extended temperature ranges, electrical noise immunity, vibration and shock resistance, real-time operation capability, and compliance with established international standards [2], [3].

The use of programmable controllers in industry has improved efficiency in the use of time, which translates into a reduction in production costs [4]. However, its implementation generally requires significant capital investments, a fact that prevents many companies to start the process of updating their control systems [5].

The evolution of open hardware and single-board embedded minicomputers has grown exponentially in the last decade due to the accelerated decrease in their manufacturing cost [6]. As a result, these platforms have been used in a myriad of applications ranging from amateur electronics to advanced robotics and industrial control [6]. Currently, several foreign companies and enterprises offer certified industrial controller solutions based on open hardware. They represent a low-cost commercial alternative to traditional approaches [7], [8].

In Cuba, companies such as Empresa de Tecnología de la Información y la Automática (ATI) and Empresa de Automatización Integral (CEDAI) stand out in the field of automation. The last one after a study determined that there is a

need in the country for simple controllers for applications of small and medium complexity. From the determination of this need, the company CEDAI made an express request to the Department of Automatic Control of Universidad Central "Marta Abreu" de Las Villas to conduct a joint project aimed at designing a controller of this type. In this way, CEDAI established technical requirements and provided experience in working with several of the required hardware elements.

This study is the result of the collaboration between the Universidad Central "Marta Abreu" de Las Villas and the company CEDAI UEB Villa Clara. It shows an analysis of current trends in the development of industrial controllers based on open hardware worldwide. As part of the analysis, an approach to the devices of this type designed in Cuba is made. Finally, the objective of this article is to make a proposal for a programmable controller based on open hardware that is an economical and flexible alternative for industrial automation.

II. THEORETICAL REFERENCE

The International Electrotechnical Commission (IEC) is a worldwide standardization organization whose objective is the alignment of positions and the creation of standards in the fields of electronics and electricity [9]. Due to the need to normalize perceptions in the field of programmable controllers, the IEC created IEC 61131. This standard defines a programmable controller as: "An electronic system with digital operation, designed for use in an industrial environment, using a programmable memory for the internal storage of user-oriented instructions for the implementation of specific logical, sequential, timing, counting and arithmetic functions to control, by means of analog or digital inputs and outputs, different types of machines or processes" [10].

The IEC 61131 standard in its parts establishes the requirements to be met by a PLC, while clearly defining the tests and verifications to be performed on them. Therefore, the development of the proposed design and the prototyping of the same must be ruled by these regulations [11]. It is based on proven techniques, which are currently used in several forms and in many control products. Therefore, it integrally defines the entire design process for PLC including programming languages, implementation, communication, and technical documentation [12].

II.1 CURRENT TRENDS IN OPEN HARDWARE

The statement of principles of open hardware defines it as: "Hardware whose design is made available to the public so that anyone can study, modify, distribute, make and sell the design or hardware that is based on that design [13]. Among the open hardware platforms employed are Arduino, Raspberry, and STM32, which have gained popularity for their flexibility and low cost.

Arduino is an open-source prototyping platform based on flexible and easy-to-use hardware and software. Its most popular variants are the Arduino Nano, the Arduino Uno shown in Fig. 1a, and the Arduino Mega. These are development boards based primarily on ATMEL microcontrollers that make it possible for anyone to make use of this tool, even people with no experience in electronics or programming [14], [15]. One of its greatest advantages is its worldwide support; a large number of users develop their projects and share their results and experiences, thus facilitating learning [16]. Its main applications range from prototyping, small projects or educational robotics to more advanced purposes such as home automation or the Internet of Things (IoT) [17].

Working with Arduino allows designers and developers to quickly prototype interactive electronic projects and test their functionality before integrating them into the final product. This involves conceptualizing and building a sample product, which is then tested and refined through several stages before deployment. These steps are usually independent of the application domain and can be applied to a wide range of projects [18].

Raspberry Pi is a low-cost embedded minicomputer, like the one shown in Fig. 1b, which was created with the purpose of introducing programming to the educational environment [19]. It has a power comparable to most cell phones and can perform tasks such as multimedia player management, programming, or servers without problems of technical limitations. Among its potential applications is an auxiliary controller in low-cost systems, taking advantage of its high processing capacity [20]. Given their hardware performance, operating systems can be installed on them, similar to computers [21].

The achievable performance, hence the user's perception, depends fundamentally on the available hardware platform. Embedded system development must take into account hardware characteristics; timing, memory usage, power consumption, and physical failures [22]. Although the platforms described above have been used in industry, their design is considered not robust enough to withstand an aggressive industrial environment with high electromagnetic noise and harsh environmental conditions [23]. There are studies that determine that, although in recent years they are moving from being simply experimental platforms to entering the world of industry, they are not the best option for critical applications [22].

It is important to note that, in Cuba, the environment is hostile to technologies, especially in areas close to the sea. Tropicalization is a common problem on the island, which results in a high rate of degradation of PCB coatings due to high temperature, relative humidity, intense solar radiation, and corrosion of welds due to high salinity in the air [24]. In addition, adverse operating conditions, such as oscillation and regular power outages, must also be faced.

In this situation, the use of STM32 microcontrollers has emerged as an alternative, an industrial platform that offers greater performance where Arduino and Raspberry have some weaknesses. STM32 is a family of 32-bit microcontroller integrated Circuits (IC) from ST Microelectronics [23]. These IC are grouped in series, based on a 32-bit ARM processor core. The STM32 family of microcontrollers provides a basis for designing a wide range of embedded systems, from simple projects to complex real-time systems [25]. It includes dozens of different configurations that provide a wide variety of options in memory sizes, available peripherals, performance, and power and offer development boards such as the Evaluation board, Discovery, or Nucleo shown in Fig. 1c. According to [26] they are comparable in cost to the parts used for Arduino boards but offer significantly higher performance and more powerful peripherals.

Figure 1: Open Hardware platforms.
Source: Authors, (2020).

Development for the STM32 family has an extensive range of documentation and software libraries focused primarily on professionals [23]. In contrast, the Arduino platform offers a simple application library and a single toolchain that is accessible to relatively inexperienced programmers. For many simple systems, this offers a fast path to prototyping; however, simplicity has its costs.

The Automatic Control Department of the UCLV has a proven track record in the development of concept prototypes for embedded applications. PCB development, system assembly, and subsequent implementation in real operating environments are tasks commonly faced by its researchers. This work has been recognized and published in prestigious academic journals [27]–[29].

II.2 CONTROLLERS BASED ON OPEN HARDWARE

The progress and performance of open hardware devices led PLC manufacturers to install development boards of these platforms in their logic controllers [30], [31]. This idea opens the way to a new world of industrial automation and motivates professionals in this field to develop new systems under the philosophy of open hardware and software. Also, under this conception, it is possible to migrate the systems currently installed and increase the functionalities already obtained, with the advantages of programming on open platforms.

This type of initiative and project is well received by the automation sector. It is visible the lack of tools and elements that allow an improvement in the optimization of resources and processes of small and medium industries, that fit the needs of companies, and in turn, encourage the development of innovation and entrepreneurship projects [30]. However, several projects have tried to integrate open hardware platforms into industrial controls with the objective of their implementation in factories or for educational purposes.

In [32], the author discusses a model of a small-scale industrial system, which performs sequential operations using relays. The system shuts down automatically once it detects high levels of water or temperature, which are dangerous for industrial operations. This model is implemented using an Arduino microcontroller, which, according to the author, proves to be the most viable alternative.

The work presented in [33] shows a data acquisition system based on open hardware and software that is designed to be used as a teaching tool in the Science and Engineering Laboratories of the Universidad Nacional General Sarmiento. The system is composed of a hardware device, based on an Arduino Due and a set of sensors or signal adapters that transform the physical values of interest into the appropriate electrical signals. Computer software communicates with the device to configure it and obtain readings, whose values it displays and stores.

The author of [6] develops a PLC based on the Atmega328p microcontroller. Its programming was carried out in the integrated development environment (IDE) of Arduino and validation tests were performed where it showed a correct operation controlling loads of high and medium consumption. The main objective was to be used by various sectors of the municipal and regional industry in the town of Santander and additionally collaborate with learning in careers related to industrial electronics, automation, and control.

The project developed by [34] aims to design, build and implement a learning module oriented to physical and virtual instrumentation through Arduino PLC, applied in a dosing and mixing process. The system includes the monitoring of the entire process through a human-machine interface (HMI), to give students the facility to learn more industrial use designs with Arduino.

Currently, there are several companies developing logic controllers for industrial use. They are based on Arduino and other open platforms and their products are available in the market. It is necessary to point out that all the devices presented in this work are designed to be used in applications of small and medium complexity and according to their manufacturers, these products are not endorsed for use in processes that require critical safety. The following is an analysis of several alternatives that stand out for their quality, performance, and cost.

a) Industrial Shields b) Norvi c) Controllino d) Opta Arduino.
Figure 2: Controllers of the different companies.
Source: Authors, (2020).

The Spanish company Industrial Shields is dedicated to the design, production, and marketing of certified devices based on open hardware. Its products include PLC based on Arduino devices, which use the Arduino IDE as a programming platform. They can also incorporate HMI screens based on Raspberry Pi that the company itself markets and support USB, serial RS232 and RS485, and I2C communication protocols [9], [30].

The company has a basic controller product and two PLC ranges [35], the PLC 20 I/O (ARDBOX 20 I/O relay variant and analog variant) and the Ethernet PLC (M-Duino) [36], [37]. Industrial Shields aims to generate a wide range of products at a reasonable price and comparable in terms of requirements with traditional options. These are products with the capabilities to work in an industrial environment and are therefore very suitable solutions for small and medium-sized installations. This equipment complies with the EN 61010 standard associated with the safety requirements for electrical equipment for measurement, control, and laboratory use [38].

Norvi, a Sri Lankan company, is another leading developer of controllers for the industry based on open technologies. Its main products are the industrial controllers Norvi IIOT, Norvi CEMA, and Norvi ARITA. The devices developed by Norvi are certified to comply with EN 61010-1 and EN 61010-2-201 standards related to safety requirements for electrical equipment for measurement, control, and laboratory use, as well as IEC 61131-2, which specifies requirements and technical tests for programmable controllers and their associated peripherals [39].

In these PLC variants, there are two that employ other hardware than Arduino devices. According to [40] in the case of the Norvi IIOT it uses an ESP32-WROOM device as the central processing unit. ESP32 are low-cost devices similar to Arduino but have higher speed, memory, and communication interfaces such as Wi-Fi and Bluetooth and dual-core architecture [41], [42]. The Norvi Arita, in its high-efficiency industrial alternative, uses an STM32 microcontroller which presents an architecture suitable for its exploitation in industrial environments [40].

Controllino is a German company, dedicated to the manufacture of industrial PLC based on the Arduino platform,

using different environments such as the Arduino IDE, Programino, LabView, or ATMEL Studio as programming software [30]. There are three types of these controllers currently available on the market the Controllino MINI, MAXI, and MEGA, all with different technical characteristics [43]. Their products use the Atmega 328p microcontroller in its most compact versions and the Atmega 2560 in the MAXI and MEGA variants. The latter is the most representative due to its large number of inputs and outputs and the possibility of using Ethernet communication interfaces [36].

The company's controllers are manufactured in compliance with industrial and safety standards such as EN 61010-1, EN 61010-2-201, and IEC 61131-1, which validate the product along with the rest of its potential [44].

The Opta PLC is the first micro-PLC with industrial IoT capabilities designed by the Arduino company in cooperation with the Finder company. According to the manufacturer, it was designed to be used by PLC engineers as well as Arduino enthusiasts. It can operate in diverse areas such as industrial IoT, building automation, electrical load management, and industrial automation. It employs the STM32H747XI dual-core Cortex M7 + M4 MCU as its processing core [45].

Additionally, it supports the 5 traditional programming languages defined in the IEC 61131/3 functionalities while allowing flexibility and easy deployment of the Arduino platform using Arduino IDE. The device is available in 3 variants Opta Lite, Opta RS485, and Opta Wi-Fi. The RS485 model has the same capabilities as the Lite but adds an RS485 communication interface. The Wi-Fi variant adds Bluetooth and Wi-Fi communications [46].

Table 1: Characteristics of controllers based on open hardware.

	Ardbox 20 E/S	**Norvi Arita**	**Controllino Maxi**	**Opta Wi-Fi**
Company	Industrial Shield	Norvi	Controllino	Arduino
CPU	Atmega 328	STM32 F103	Atmega 2560	STM32H747XI
Power	12-24 VDC	12-24 VDC	12-24 VDC	12-24 VDC
Working Memory	2 Kb	48 Kb	8 Kb	1 MB
Flash Memory	32 Kb	256 Kb	256 Kb	2 MB
Digitial Inputs	10 multi mode	14 DI a 24 VDC	12 multi mode	8 multi mode
Digital outputs	5 (24 VDC)	12 (10 relay)	12 (10 relay)	4 (relay)
Analog Inputs	10 multi mode	4 multi mode	12 multi mode	8 multi mode
Analog Outputs	10 (PWM)	No	No	No
Commu-nication	USB, RS-485, I2C, SPI	Ethernet, RS-485	Ethernet, RS-485, UART, I2C, SPI	Ethernet, RS-485, Wi-Fi, Bluetooth
IDE	Arduino IDE	Arduino IDE	Arduino IDE	Arduino IDE

Source: Authors, (2023).

The controllers marketed by Industrial Shields, Norvi, Controllino, and Arduino, mentioned above, are capable of meeting the requirements of small and medium-scale processes. Their technical characteristics are shown in Table 1, they are suitable for such applications and have, for the most part, sufficient communication interfaces to be integrated into current industries. However, they do not have the capacity to work in applications that require high levels of safety, they are not programmable according to the 5 languages established by the IEC 61131-3 standard and, despite having industrial certifications, only the Norvi and Controllino controllers comply with the requirements of the 61131-2 standard.

II.3 CONTROLLERS DEVELOPED IN CUBA

From the experiences in the use of PLCs in the sugarcane process, it was decided at the time to manufacture a controller suitable for the needs of the sugar industry in Cuba. In this sense, three specific products were developed and marketed for several years: the PLC Nova, the EROS, and the EROS mPLC. These devices are programmable using the 5 languages of the IEC 61131-3 standard, for which they use the EROS PG software [47].

The Nova and EROS controllers are medium-sized devices with a large number of analog and digital inputs and outputs, as well as RS232/RS485 serial communication interfaces. In addition to these intrinsic features, there is the possibility of connecting expansion modules, which allows them to expand their potential and achieve scalability. The EROS mPLC was designed for process or manufacturing control, with the possibility of operating as an HMI using its integrated keyboard and display for supervision and control from the field. Additionally, it can function as a weighing and batching system, as well as for machine tool automation [48].

These devices had a high memory compared to similar devices of the time. Their design is highly immune to noise and can be operated under adverse temperature and vibration conditions. Over time, revisions were made to improve its performance; however, no recent updates or improvements in its features are reported [47], [49]. Although its appearance in the domestic market was a breakthrough for several sectors of the industry, currently its features and availability place it below the controllers that are available in the market.

III. MATERIALS AND METHODS

Design decisions influence the sensitivity of a product to variations in raw materials and working conditions, which in turn affects manufacturing costs [50]. Since a trade-off between performance and safety is necessary to ensure reliable and safe control, five fundamental requirements are identified: real-time performance, reliability, sustainability, survivability, and critical safety.

• Real-time performance: In the case of considering real-time requirements during PLC operation, critical parameters must be considered for the correct work of the system such as timing parameters, whose non-compliance will result in one of the

system's timing errors or not emitting a control signal at a given time [50].

- Reliability was defined by [8] as quality over time.
- Sustainability: "that development which is capable of meeting the needs of the present without compromising the ability of future generations to meet their own needs" [8].
- Survivability can be defined as "the ability of a system to fulfill its mission and, therefore, to cope with malicious, deliberate or accidental failures in a timely manner" [4].
- Safety critical: those systems that can potentially lead to serious catastrophic consequences due to the existence of unplanned events, which could result in human death or injury [50].

Proper controller design can improve system performance. In order to meet the demands of complex applications, the architecture of controllers must be universal, open, modular, and easily expandable. The application of standards allows systems that are developed according to their specifications to have important characteristics in terms of efficiency, quality, and above all, safety [10]. From the commercial point of view, although compliance with various standards is not mandatory, having the certification of organizations such as the IEC guarantees the devices created, makes the product more competitive in the market, and reduces installation and commissioning costs.

In Cuba, the CEDAI company, also in line with national science and innovation policies, is aware of the need for a low-cost, locally produced controller to boost the competitiveness of Cuban companies. Therefore, this work is part of a project in which the Central University "Marta Abreu" of Las Villas and the Integral Automation Company CEDAI UEB VC collaborate. The aim of this project is to implement a line of research in low-cost industrial controllers that meet the needs of industry in applications of small and medium complexity.

The MCI-VC v1.0, the name given to the design, is intended to be a compact, low-cost, STM32 microcontroller-based automaton that complies with the IEC 61131 standard. The aim is to achieve, in principle, a minimum unit to be used in small and medium-complexity tasks that do not require critical safety. From the analysis of each of the PLCs with open technologies shown above and according to the specifications that are considered of greater importance in industrial processes, the technical and functional requirements of the programmable controller to be designed can be defined. Requirements and technical characteristics established for the controller:

- Power supply: 100 - 240 VAC
- 12 digital inputs, 4 of them fast inputs
- 8 digital relay outputs 240 V/5 A, coil at 24 V
- 4 transistor outputs
- 6 analog inputs, range 0/4 - 20 mA or 0 - 10 V
- RS485 communication (via DB9 connector)
- Ethernet connection
- USB connection
- Real-time clock
- Data storage module via SD memory
- Expansion bus
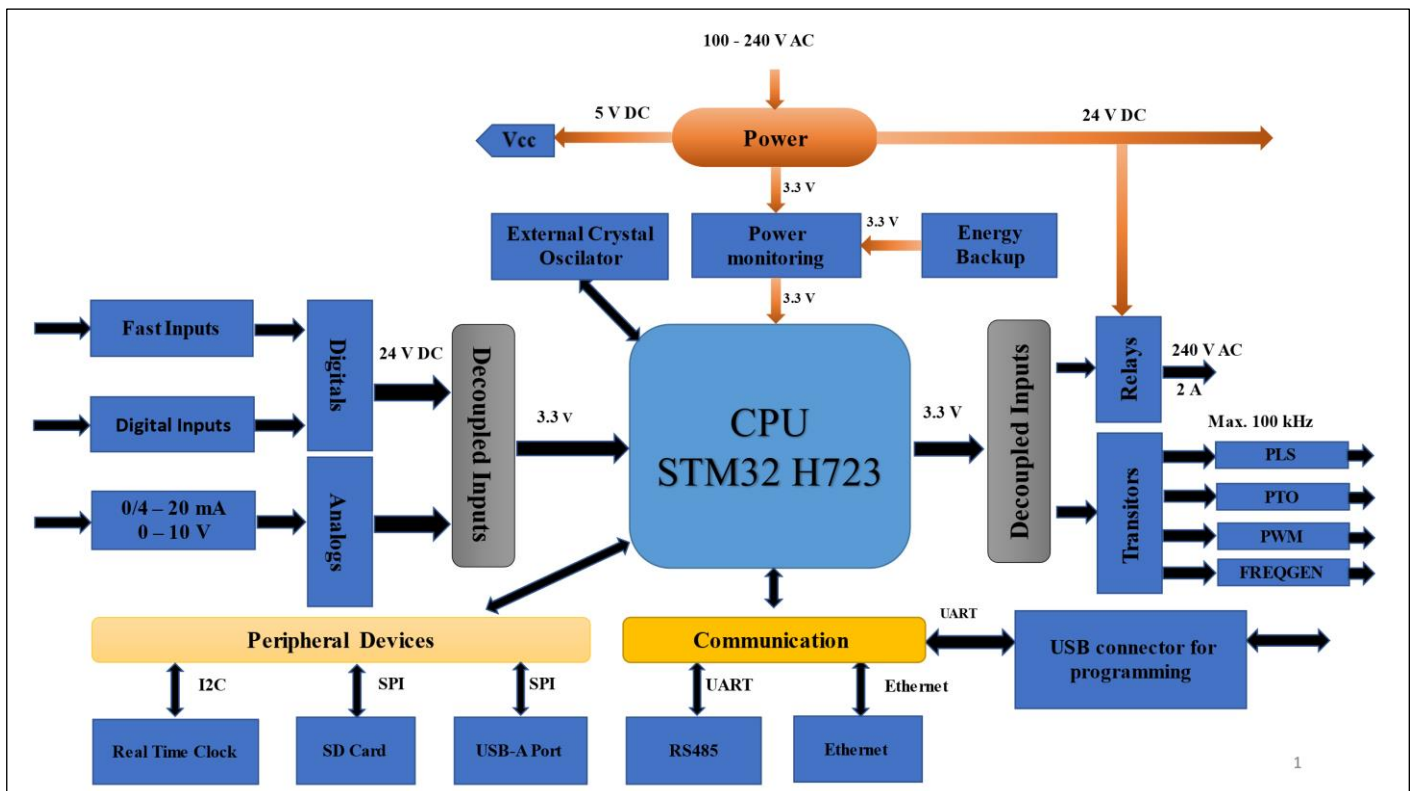
Figure 3: Hardware architecture scheme.
Source: Authors, (2023).

IV. CONTROLLER ARCHITECTURE

In accordance with the technical characteristics defined for the programmable controller, it is necessary to specify its structure. Fig. 3 shows the general hardware scheme to be used in the design.

This architecture constitutes the conceptual basis for the design of the controller. It defines its main functional characteristics and the relationship between the fundamental elements that make it up.

V. PHYSICAL DISTRIBUTION OF THE CONTROLLER

A modular implementation has been proposed for the industrial controller under development, according to the hardware model defined in the standards. The internal power supply units, the central processing and communications unit, and the input/output unit must be distributed independently.

The CPU module must be placed on top of the rest of the boards. It contains the communication interfaces of the controller and storage, as well as the STM32 microcontroller unit with its respective conditioning. It also contains connectors for the signals coming from the input/output board and for the connection of the external programming and debugging device ST-Link.

The input-output board must contain the 8 conventional 24 V digital inputs and the 4 fast inputs, the 6 configurable analog inputs, and the relay and transistor digital outputs, as well as their respective conditioning. It receives the 24 V and 9 V signals from the power supply and the ground references of the digital and analog circuits separately. The states of the input interfaces and the 9 V from the internal power supply are sent from this unit to the CPU board. Commands for handling the outputs and the analog selector are also received. Communication between the two units is via a 38-pin connector.

The controller shall have connectors for input and output interfaces and two 24 V terminals for powering external devices. The inputs shall be located at the bottom of the controller and the outputs shall be positioned at the top. The external connectors for RS-485 communication via DB9 female, Ethernet via RJ45 and USB as well as storage via SD card will be included on the front. On the sides, only the expansion bus connector shall be located on the right side of the equipment so that each module located in the rack is in this direction. Additionally, the connector for the external 100-240 VAC power supply must be located at the bottom.

The commercial destination for these devices may be initially focused on the domestic market, especially the industrial sector. It can also be used in the control of various auxiliary services for the tourism sector, health, management, and residential buildings. The estimated cost of a unit should be close to 200 USD, which makes the product competitive in the Cuban market. This price is below all the aforementioned equipment, which costs between 200 and 500 USD.

VI. CONCLUSIONS

After the analysis carried out in relation to programmable controllers for industry and the role played by open hardware for the implementation of the same today, the following conclusions are established.

The current development of open hardware technologies positions is an emerging and at the same time indispensable part in the conception of the programmable automaton for modern industry. STM32 microcontrollers represent a strong alternative to solve the shortcomings in terms of performance and robustness that can present, especially in industrial environments, other hardware platforms such as Arduino, Raspberry Pi, or the Z80 used in Cuban controllers.

The proposed design meets the technical requirements defined and has similar technical characteristics to controllers that are currently marketed while achieving a reduction in costs. It's modular conception and physical distribution allow an adequate insertion in industrial environments. In addition, the design allows the scalability of a higher-performance model and the expansion of its functionalities.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: David Kairuz-Cabrera, Delvis Garcia-Garcia, and Jorge Lemus Ramos.
Methodology: David Kairuz-Cabrera and Alain Martinez Laguardia.
Investigation: David Kairuz-Cabrera, Delvis Garcia-Garcia, and Jorge Lemus Ramos.
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Resources: Delvis Garcia-Garcia and Arley Bosh Quirós.
Supervision: Delvis Garcia-Garcia and Arley Bosh Quirós.
Approval of the final text: David Kairuz-Cabrera, Delvis Garcia-Garcia, Arley Bosh Quirós, Jorge Lemus Ramos and Alain Martinez Laguardia.

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RESEARCH ARTICLE   **OPEN ACCESS**

GOLD REMOVAL FROM GOLD-BEARING ORE USING ALPHA-CYCLODEXTRIN: RESPONSE SURFACE METHODOLOGY AND ARTIFICIAL NEURAL ANALYSIS NETWORK OPTIMIZATIONS

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ARTICLE INFO

ABSTRACT

This paper explores the use of alpha cyclodextrin (α-CD) for gold extraction from gold-bearing ore in the Democratic Republic of Congo (D.R.C). The research aims to identify the optimal gold removal conditions using Response Surface Methodology (RSM) and Artificial Neural Networks (ANN). Initially, ore samples were collected and processed to enhance leachability by reducing particle size. The leaching process employed a modified aqua regia with hydrobromic acid due to the strong molecular recognition between gold bromide ion and α-CD. Various leaching parameters, such as time, HBr concentration, pH, and stirring speed, were adjusted during experimentation. RSM yielded optimal values of 7.27 hours, 50 g/L, 1, and 200 rpm, resulting in 98.54% gold removal, while ANN produced slightly lower values of 7.5 hours, 50 g/L, 1, and 200 rpm, with 97.16% gold removal. For α-CD gold recovery, RSM and ANN optimization resulted in 40 minutes, 11.61 g/L, and pH 5, achieving 98.87% and 39.8 minutes, 10.71 g/L, and pH 5, with 99.98% gold removal, respectively. Validation tests supported these findings, indicating that RSM and ANN are successful methods for optimizing gold recovery from gold-bearing ore in the D.R.C.

I. INTRODUCTION

The concentration of the metal being extracted is a determining factor in the profitability of mining a specific ore, while the physical and chemical characteristics of gold affect the methods used for its processing. In the Democratic Republic of the Congo (D.R.C.), the basement is rich in many minerals which contain many metals in different proportions [1-2]. Gold is mainly found in the South Kivu and Ituri provinces, where artisanal mining is prevalent. Child labor is common in the industry and the D.R.C. government has ratified the International Labour Organization's Convention on the Worst Forms of Child Labour, and more needs to be done to eliminate child labor in the mining industry [3-4].

Gold mining is a complex process that involves exploration, processing, development, and extraction, among other steps. According to [5], gold is typically found in concentrated deposits, which makes mining more viable. The authors also note that there are three main methods of gold mining: open-pit mining, underground mining, and artisanal mining. Open-pit mining is used when the ore deposit extends deep into the ground, and it involves the removal of layers of overburden and ore. Underground mining, on the other hand, is used for deeper deposits and may involve the use of supports. As noted by [6], artisanal mining typically involves manual

extraction and concentration of minerals, including gold, often using traditional methods. Mechanized artisanal mining, on the other hand, involves the use of machines like hand tools, motorized water pumps, and crushers, among others [7]. Once the gold has been extracted, it needs to be processed and refined. Other methods of concentrations are used to concentrate minerals which contain metals for further processes [8]. According to [9], the methods of gold concentration from the ore can include gravimetric methods, such as sluices, shaking tables, and centrifuges, which rely on the high density of gold to separate it from other minerals in the ore.

Gold mining has a significant impact on the global economy, and according to [10], the global gold mining industry produces about 2,500-3,000 tons of gold per year, with the largest producing countries being China, Australia, Russia, and the United States. This industry is a major contributor to the economy of many countries and the methods of mining gold have evolved over time, as noted by Wang and Forssberg [11]. However, gold mining also has both positive and negative impacts on the environment and society. On one hand, it can create jobs and economic growth, especially in developing countries [12]. On the other hand, it can lead to environmental degradation, including deforestation, pollution of water sources, and destruction of habitats [13]. Additionally, the social impacts of gold mining can be significant. Reports of human rights abuses, labor exploitation, and child labor in some mining communities have been documented [14], so that efforts are being made to address these issues through international regulations and corporate social responsibility initiatives, as noted by Murillo-Sánchez and Reyes-Santacruz [15].

According to a study by [16], gold extraction involves several stages, including leaching, extraction, refining, and electrolysis. The commonly used method for gold extraction is the cyanide leaching process, where a cyanide solution is used to dissolve the gold from the ore in tanks or heaps [17]. Gold is then recovered from the saturated leaching solution by adsorption onto activated carbon or resins [18]. The two main methods used for the recovery of gold from the cyanide solution are precipitation on zinc powder (cementation) and adsorption on activated carbon [18]. Cementation on zinc powder involves the precipitation of gold from the enriched cyanide solution onto zinc powder. The complete process involves solid-liquid separation after cyanidation, clarification of the gold solution, partial deaeration of the solution, addition of zinc powder and lead salt to improve gold precipitation, and recovery of the precipitated gold [17]. Adsorption on activated carbon is based on the property of activated carbon to absorb the gold in the cyanide solution. The carbon is prepared from natural hard carbon (fruit kernels, coconut shells) treated to develop its adsorption capacity and porosity. The gold solution is pumped to the adsorption columns, where activated carbon is added to adsorb the gold-cyanide complex [18]. After gold recovery, the refining stage is carried out to obtain the highest practical purity of gold. The process begins with washing the carbon to remove organic impurities, and then the gold adsorbed on the carbon is recovered by elution using a hot, caustic, aqueous cyanide solution. Impurities are removed by filtration through a bed of activated carbon. The regenerated carbon is returned to the adsorption circuit, where gold is recovered either by cementation on zinc or by electrowinning, which is the final stage of the gold extraction process involving the deposition of gold on the cathode after taking an electron to become metallic gold. The cathode is made

of steel wool, and the anode is made of lead to facilitate oxygen release with minimal over potential [17].

Some authors have studied the thiourea process as an alternative to cyanide for the extraction of gold due to its environmental and health benefits, but the significant consumption of the reagent related to its oxidation in the solution is a disadvantage. To reduce this consumption, other authors investigated the mixture of thiourea with thiocyanate and iron sulfate [19-20]. However, recent developments aim to improve the process's cost-effectiveness and efficiency by reducing reagent consumption [21].

The [22] investigated the use of the chitosan and the manipuera processes, respectively. They have shown that chitosan can form complexes with gold after chlorination as shown in equation 1.

$$2Au + 2KClO_3 + 8HCl \rightarrow 2AuCl_4 + 2KCl + 4H_2O + O_2 \quad (1)$$

Aqua regia (AR) process consists of a mixture of hydrochloric acid (HCl) and nitric acid (HNO$_3$) in a 3/1 ratio that can dissolve gold in a matter of hours (equation 2). However, this process is highly corrosive and unstable and is not widely used at an industrial scale, limited to small and medium-sized processes, such as electrolytes in gold refining or recovering gold from electronic waste. Aqua regia can also dissolve other noble metals such as platinum and rhodium [23-24].

$$Au + HNO_3 + 4HCl \rightarrow HAuCl_4 + NO + 2H_2O \quad (2)$$

It should be noted that for the purpose of dissolving gold, hydrobromic acid (HBr) is used instead of HCl in this paper to create a modified aqua regia (MAR). The equation 3 becomes equation 4 as follows:

$$Au + HNO_3 + 4\,HBr \rightarrow HAuBr_4 + NO + 2H_2O \quad (3)$$

Efforts have been made in recent years to replace mercury and cyanide with less toxic reagents, and advancements in technology have led to the development of more efficient and environmentally friendly methods. Out of the various alternatives, the cyclodextrin (CD) process has emerged as a noteworthy contender. As reported by [25], this process utilizes a cyclic sugar molecule known as α-CD, which demonstrates selectivity in extracting gold from the ore. Moreover, α-CD is a cyclic oligosaccharide that has been shown to be effective in gold recovery [26], it is biodegradable, non-toxic, and has a high affinity for gold ions, making it an attractive alternative to conventional gold recovery methods [27]. The efficiency of α-CD in gold recovery has been investigated in electronic waste [28], low-grade gold ores [29], and even in refractory gold ores [30]. Moreover, that α-CD efficiency in gold recovery is attributed to its ability to form inclusion complexes with gold ions [31]. The formation of inclusion complexes is based on the hydrophobic effect and the van der Waals forces between α-CD and gold ions [29]. This complexation process can lead to the removal of gold ions from the ore, resulting in high gold recovery rates. So that α-CD was found to be an effective extractant for gold recovery, and it offers several advantages over conventional extractants, such as cyanide.

To date, a number of studies have been carried out on the use of α-CD in gold recovery. For example, Yen et al. [32] investigated the effect of various factors, such as temperature, pH, and α-CD concentration, on the recovery of gold from electronic

waste. They found that α-CD could effectively recover gold under a range of conditions. Similarly, Lee et al. [33] used α-CD to recover gold from waste printed circuit boards, and they reported a recovery rate of 98.5%. Despite its potential advantages, the use of α-CD in gold recovery is still in the early stages of development. Further research is needed to optimize the gold recovery process using α-CD and to understand the underlying mechanisms involved in the process.

The aim of this study is to investigate the efficiency of α-CD in modified aqua regia (MAR) gold recovery from gold-bearing ore and optimize the process using the simulation, optimization and prediction methods including Response Surface Methodology (RSM) and Artificial Neural Network (ANN), and then compare the results to find the optimum conditions. The ore will be characterized and series of experiments will be carried out. The significant parameters for leaching, neutralization and gold recovery processes such as time, pH, HBr and KOH concentrations ([HBr] and [KOH]), and α-CD concentration [α-CD], and their interactions will be also explored to determine the optimum conditions. After the experiments, the results will be analyses and the efficiency of the gold recovery process will then be evaluated by measuring the percentage of gold recovered from the ore. The findings of this study may have significant implications for the gold mining industry, particularly in the D.R.C., where the recovery of gold from low-grade ores is an important economic activity. Also, the use of α-CD as a lixiviant aims to reduce the environmental impact of gold mining and promote the application of green chemistry principles in the mining industry.

II. MATERIALS AND METHODS

II.1 MATERIAL COLLECTION

In this study, concentrated HBr and HNO_3 were used to form MAR (3/1 ratio) for gold leaching. α-CD at 99% was used as gold the extracting agent. Potassium hydroxide (KOH) was used for pH adjustment, and analytical-grade nitric acid (HNO_3) was used for gold analysis.

II.2 SAMPLE PREPARATION

Fifty (50) kg of gold-bearing ore was collected from 2 quarries located in South-Kivu province of the D.R.C. The homogenization of the sample was carried out using the cone and quartering method, and then divided into four representative parts using the quartering technique. A number of fragmentation operations were performed: primary and secondary crushing, a mineralogical analysis using transmitted and reflected light microscopy, and a chemical analysis using atomic adsorption spectroscopy/inductively coupled plasma (AAS/ICP). Moreover, 1 kg was used for AAS/ICP, and the remaining 49 kg gold ore sample was used for secondary crushing during 19.57 minutes in to get 80% passing 75 μm sieves.

III. GOLD RECOVERY STUDY

II.1 LEACHING PROCESS (LP)

The purpose of the process was to extract gold from a homogenized sample and 400 g of the sample was weighed and placed into a 1 L beaker for 5 min of contact time. Deionized water was added to the beaker to homogenize the pulp, and mechanical agitation was used to facilitate the process. HBr and HNO_3 were gradually added to the pulp while the pH and

potential were adjusted as needed. The solid and liquid phases were then separated by filtration, and a certain amount of the filtrate was taken for chemical analysis. The cake was washed to eliminate any remaining leaching agent before being dried in an oven at a temperature of 105°C for 24 hours. To ensure the precision in results, the leaching tests were duplicated and the average values were considered. Four factors were studied: time (x_1), HBr concentration (x_2), pH (x_3) and stirring speed (x_4), and a total of 47 tests were carried out by simultaneously varying the levels of each factor. Time, HBr concentration [HBr], pH, and stirring speed were varied in range of 1-7.5 hours, 50-200 g/L, 1-2, and 50-200 rpm, respectively.

II.2 NEUTRALIZATION PROCESS (NP)

The experimental procedure used for neutralization tests involved placing 50 mL of homogenized leachate in a 500 mL beaker, gradually adding a solution of KOH (0.1 M) to maintain the pH at required pH, stopping stirring once the set time was reached, separating the solid and liquid components through filtration, and finally analyzing 20 mL of the resulting filtrate to measure its chemical composition. The tests were triplicated and the average values were considered. Moreover, the following three factors with appropriate combination were studied: time (x_1), KOH concentration (x_2), and pH (x_3). Time, KOH concentration, and pH were varied in range of 1-10 hours, 84-224 g/L, and 5-6, respectively.

II.3 GOLD RECOVERY PROCESS USING α-CD (GP)

During the precipitation tests at room temperature (25°C), the process started with an amount of 50 mL of the filtrate which was taken into a 2 L beaker after ensuring the pH was at the desired level using KOH. α-CD was then gradually added while mechanically agitating the solution. Once the set time was reached, the recovered gold as well as the co-precipitates were removed by filtration, after what sodium bisulfite ($Na_2S_2O_5$) solution was used to disperse and reduce the complex α-Br in order isolate and precipitate the recovered gold metal. The liquid-liquid separation was carried out by decantation and a certain amount of the filtrate was collected for chemical analysis. Each recovery test was duplicated and the average value was considered. Time, α-CD concentration [α-CD], and pH were varied in range of 10-40 minutes, 5-20 g/L, and 5-6, respectively.

II.4 METHODS USED FOR PREDICTION, MODELING AND OPTIMIZATION OF STUDIED PARAMETERS

II.4.1 RSM METHOD

RSM known as full factorial method, was utilized to generate the experimental runs (using Minitab software and the analysis of variance (ANOVA)) varying the studied parameters [34-35]. In addition, the statistical technique of regression analysis was highlighted to determine a mathematical formula between the parameters and the response as shown in equation 4 [36-37].

$$y = f(x_1, x_2, x_3, x_4, \dots, x_n) \qquad (4)$$

where y is the dependent variable (response) and x_i the independent variables (parameters).

As demonstrated by Murthy et al. [38], for a good fitness of the model, the coefficient of determination R^2 should be at

least 0.80. The best precision of comparison of treatments was done by a value called coefficient of variation (CV) which should be low to minimize the dispersion around the mean value.

As a statistical indicator, the Fisher's F-test ANOVA was used to outline the significance of the studied model after assessing the effects of the parameters as well as their interactions. [36] and [39] have shown that for a highly significant model, variable or interaction, the P-value must be lower than greater than 0.0001 in a 95% confidence intervals. Also, the significance was associated to a P-value between 0.0001 and 0.05, while the non-significance was associated to a P-value higher than 0.05.

The experimental design matrix for leaching process (LP) and gold recovery process using α-CD (GP) tests are presented in Table 1, while the corresponding matrix for neutralization process (NP) is shown in Table 2.

Table 1: Design matrix for LP and GR.

Run N°	LP				GP		
	Time, x_1 (h)	[HBr], x_2 (g/L)	pH, x_3	Speed, x_4 (rpm)	Time, x_1 (min)	[α-CD], x_2 (g/L)	pH, x_3
1	1.0	50	1	200	10	5	5.0
2	1.0	200	2	50	10	5	5.5
3	1.0	100	1	50	10	5	6.0
4	1.0	150	1	50	10	10	5.0
5	1.0	100	1	150	10	10	5.5
6	1.0	150	1	150	10	10	6.0
7	1.0	100	2	150	10	15	5.0
8	1.0	150	2	150	10	15	5.5
9	1.0	100	2	100	10	15	6.0
10	1.0	150	2	100	10	20	5.0
11	2.5	100	1	100	10	20	5.5
12	2.5	150	1	100	10	20	6.0
13	2.5	200	1	150	20	5	5.0
14	2.5	50	1	150	20	5	5.5
15	2.5	200	1	150	20	5	6.0
16	2.5	100	1	150	20	10	5.0
17	2.5	150	1	150	20	10	5.5
18	2.5	200	1	100	20	10	6.0
19	2.5	100	2	150	20	15	5.0
20	2.5	150	2	150	20	15	5.5
21	2.5	200	2	100	20	15	6.0
22	2.5	100	2	100	20	20	5.0
23	2.5	150	2	100	20	20	5.5
24	2.5	50	2	50	20	20	6.0
25	2.5	100	2	50	30	5	5.0
26	2.5	150	2	50	30	5	5.5
27	2.5	200	2	50	30	5	6.0
28	5.0	50	1	150	30	10	5.0
29	5.0	100	1	150	30	10	5.5
30	5.0	150	1	150	30	10	6.0
31	5.0	200	1	150	30	15	5.0
32	5.0	200	1	100	30	15	5.5
33	5.0	50	2	100	30	15	6.0
34	5.0	100	2	100	30	20	5.0
35	5.0	150	2	100	30	20	5.5
36	5.0	200	2	100	30	20	6.0
37	5.0	50	2	50	40	5	5.0
38	7.5	50	1	150	40	5	5.5
39	7.5	100	1	150	40	5	6.0
40	7.5	200	1	150	40	10	5.0
41	7.5	100	1	200	40	10	5.5
42	7.5	150	1	200	40	10	6.0
43	7.5	100	2	100	40	15	5.0
44	7.5	150	2	100	40	15	5.5
45	*7.5*	*150*	*1*	*150*	40	15	6.0
46	7.5	100	2	50	40	20	5.0
47	7.5	150	2	50	40	20	5.5
48	-	-	-	-	40	20	6.0

Source: Authors, (2023).

Table 2: Design matrix for NP.

Run N°	Time, x_1 (h)	[KOH], x_2 (g/L)	pH, x_3
1	1.0	84	5.0
2	1.0	84	5.5
3	1.0	84	6.0
4	1.0	112	5.0
5	1.0	112	5.5
6	1.0	112	6.0
7	1.0	168	5.0
8	1.0	168	6.0
9	2.5	84	5.0
10	2.5	84	5.5
11	2.5	84	6.0
12	2.5	112	5.0
13	2.5	112	5.5
14	2.5	112	6.0
15	2.5	168	5.0
16	2.5	168	5.5
17	2.5	168	6.0
18	2.5	224	5.5
19	2.5	224	6.0
20	5.0	84	5.0
21	5.0	84	5.5
22	5.0	84	6.0
23	10.0	112	5.0
24	10.0	112	5.5
25	10.0	112	6.0

Source: Authors, (2023).

A total of 47, 48, and 25 experimental runs were considered for LP, GR, and NP, respectively.

II.4.2 ANN METHOD

Known as promising method studied by many researchers [40-42], ANN as a statistical learning algorithms has been used in recent years in order to estimate by approximation a mathematical relationship between inputs and outputs of a specific process. Through information, the stimulation as well as the processing of ANN are performed within the nervous system.

The transfer functions between the input and hidden layers in one hand, and between the hidden and output layers on another hand, were performed using a hyperbolic tangent TANSIG (sigmoid) and a Purline, respectively, while the normalization of data of inputs and outputs was done by PREMNMX function [43-44]. In addition, the chosen learning algorithm was Levenberg-Marquardt. Beside the coefficient of determination (R^2), another estimator or predictor number called mean square error (MSE) was used to determine the performance of ANN. For a good performance, MSE value should be as small as possible and in the best case close to zero. Furthermore a good performance of the model corresponds to a high R^2 value and a lower MSE value which shows a good interaction or connection between the parameters of the model. Equations 5, 6 and 7 illustrate the sigmoid, MSE, and R^2, respectively.

$$logsig(x) = \frac{1}{1+e^{-x}} \tag{5}$$

$$MSE = \frac{1}{N} + \sum_{i=1}^{N}(t_i - o_i)^2 \tag{6}$$

$$R^2 = 1 - \frac{\sum(t_i - o_i)^2}{\sum(o_i - \bar{o})^2} \tag{7}$$

where n, t, o, and ō represent the number of samples, the target value, the output, ant the mean of output, respectively.

In this paper, the RSM and MATLAB were used to generate a matrix of the experimental responses. The choice of learning on multilayer perception network was 80 for network training, 5 for testing, and 5 for validation. The network was selected in feed-forward mode, consisting of input layer, hidden layer and output layer. Depending on the process (LP or GP), the numbers of neurons in input and output layers were specific, while the chosen number of neurons in the hidden layer was 10 due to the lowest mean square error resulted. Figure 1 illustrates the ANN architecture used for the experiments.
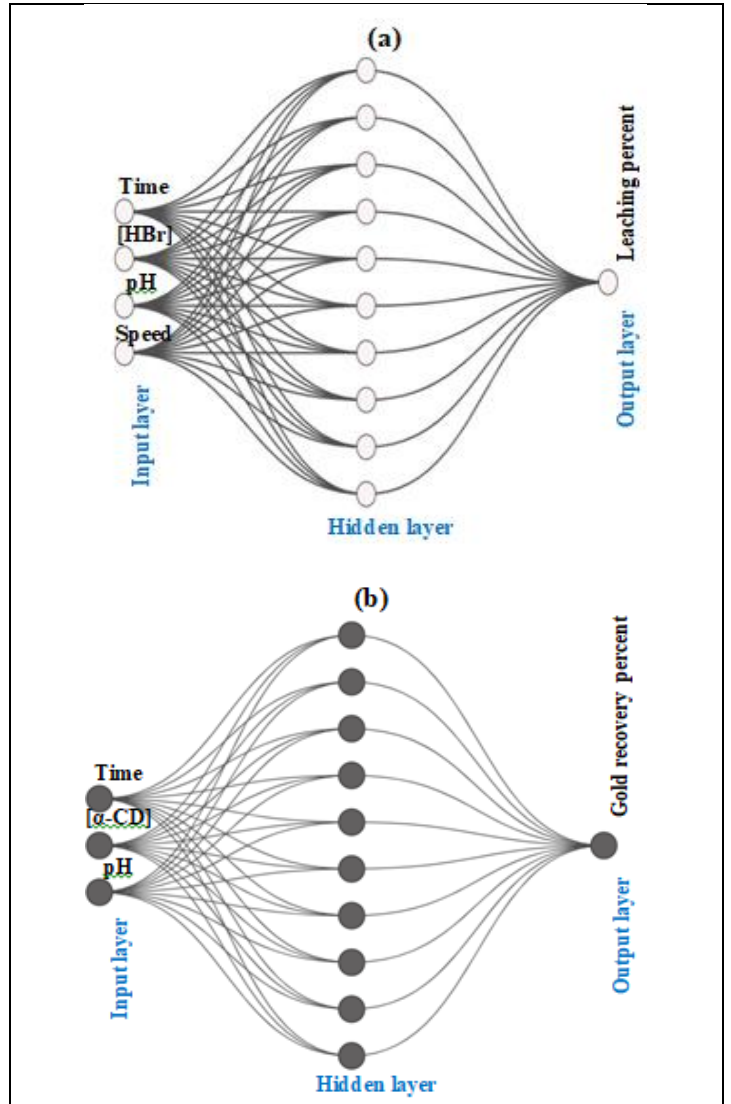
Figure 1: ANN architecture, (a): for LP and (b): for GP.
Source: Authors, (2023).

IV. RESULTS AND DISCUSSIONS

IV.1 RSM PREDICTION

The results of percent removals according to each process (LP, NP and GR) are investigated in this section. Note that these results were also obtained in another study conducted by the same authors of the present article taking into account central composite design (CCD), and the study has not yet been published. Table 3 presents the results of percent removals of the tests.

Table 3: Responses obtained for LP, NP and GR.

Run N°	Responses (%)		
	LP	NP	GR
1	0.001	54.4698	35.8545
2	67.879	65.1321	48.9586
3	33.927	73.7055	62.0582
4	70.399	40.9167	54.9625
5	36.432	51.6038	65.7851
6	72.815	60.2019	76.6032
7	36.432	18.4140	51.0053
8	56.121	37.7190	59.5463
9	20.617	70.0920	68.0830
10	57.042	77.7318	23.9828
11	48.654	83.3085	30.2424
12	68.595	67.7952	36.4973
13	86.060	75.4380	55.9201
14	26.361	81.0216	64.0012
15	86.060	67.7655	72.0779
16	49.990	75.4123	70.8062
17	69.890	80.9820	76.6058
18	84.806	81.4473	82.4011
19	35.271	87.0210	62.6271
20	55.170	79.0020	68.1253
21	70.206	81.5678	69.6590
22	34.054	82.1601	31.3830
23	53.995	86.4270	32.6146
24	9.061	78.7644	33.8518
25	32.773	69.0426	75.9856
26	52.755	-	79.0438
27	69.008	-	82.0976
28	73.270	-	86.6499
29	69.430	-	87.4266
30	61.855	-	88.1989
31	50.550	-	74.2500
32	49.104	-	72.7442
33	57.103	-	71.2351
34	53.301	-	38.7829
35	45.767	-	34.9965
36	34.504	-	31.2059
37	55.589	-	96.0508
38	83.120	-	94.0864
39	85.002	-	92.1173
40	11.107	-	98.8911
41	86.595	-	98.2474
42	51.502	-	93.9968
43	68.611	-	85.8708
44	33.604	-	79.3432
45	90.479	-	72.8130
46	66.944	-	46.1829
47	31.977	-	37.3737
48	-	-	28.5601

Source: Authors, (2023).

After obtaining the results of percent removals, the influences of studied parameters, as well as their interactions, on percent removals were evaluated through the generation of mathematical equations 8, 9, and 10 for LP, NP, and GR, respectively. The importance of the sign of the coefficient in the regression equation is in the fact that it can predict the nature of the studied parameters effects on the response. So that the positive sign of the coefficient implies the favorable increase of the response with the increase in parameters (variables) or their interactions, and vice versa. Moreover, the negative sign of the coefficient negative coefficients implies the decrease of the response with the increase in parameters (variables) or their interactions.

$$y = -91.3 + 31.74x_1 + 1.404x_2 - 4.0x_3 + 0.040x_4 - 0.465x_1^2 - 0.001773x_2^2 + 0.000097x_4^2 - 0.1860x_1x_2 - 0.96x_1x_3 - 0.0090x_1x_4 - 0.0740x_2x_3 - 0.000141x_2x_4 + 0.0139x_3x_4 \qquad (8)$$

$$y = -128.60 + 14.3489x_1 - 52.627x_2 + 68.667x_3 - 1.71718x_1^2 + 3.0403x_2^2 - 4.1153x_3^2 + 14.9734x_1x_2 - 4.07045x_1x_3 - 0.0077x_2x_3 \qquad (9)$$

$$y = -262.2 + 7.343x_1 + 16.209x_2 + 51.06x_3 - 0.001162x_1^2 - 0.45996x_2^2 - 0.953x_3^2 - 0.08385x_1x_2 - 0.9775x_1x_3 - 0.9306x_2x_3 \qquad (10)$$

where y, x_1, x_2, x_3, and x_4 have already been defined in Table 1.

The leaching efficiency is directly proportional to the increase in time, [HBr], stirring speed, and inversely proportional to the pH. The findings support [45] study, which concluded that the presence of HNO_3 as an oxidizing agent aids in dissolving gold. Thus, the higher concentration of HBr leads to an increase in HNO_3 concentration, which effectively acts as an oxidant for trivalent gold ions. The trivalent gold ions are subsequently reduced by HBr, resulting in the formation of tetrabromidoaurate anions or tetrabromoauric acid ($AuBr_4^-$).

The results indicate that when the reaction time is shorter, even with varying concentrations of HBr, the contact between the gold particles and leachate is insufficient, leading to the consumption of other metals present in the solution by HBr. Also, an increase in HBr concentration is favorable for the formation and precipitation of silver bromide (AgBr), confirming the syudy of [46]. This, in turn, prevents the dissolution of silver from MAR and results in an increased leaching percentage.

The results indicate that increasing the time, [KOH], and pH leads to an increase in the neutralization percentage, with an optimal pH range of 5-6. This is due to the precipitation of other metals that typically accompany gold, such as iron, aluminum, copper, and cobalt, with increasing pH or [KOH]. The ionic forms of these metals react with hydroxide ions from KOH and subsequently precipitate out. Another factor is the progressive oxidation of Fe^{2+} to Fe^{3+} by oxygen in the air, which leads to precipitation in the form of $Fe(OH)_3$, starting at a pH of 3.5, as confirmed by [47]. Additionally, aluminum precipitation occurs within the pH range of 4 to 5.5. The precipitation processes for aluminum and iron ions are illustrated by equations 11 and 12, respectively.

$$Al^{3+} + OH^- \rightarrow Al(OH)_3 \qquad (11)$$

$$Fe^{3+} + OH^- \rightarrow Fe(OH)_3 \qquad (12)$$
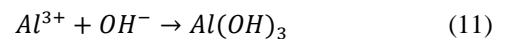
According to that, it can be observed that the increase of [α-CD] leads to the increase of percent removal but not indefinitely. So that, [α-CD] reaches a certain value (11.62 g/L) after which the opposite phenomenon is observed. This may be attributed to the saturation of α-CD with solute at this value. Additionally, the recovery was observed from the first minute of reaction and with the increase of contact time, while at a pH range of 5-5.8 yields good results with at least 85% of gold recovered.

Furthermore, the yield of recovery is low at low values of pH and time, but increases as these parameters values increase.

Gold recovery is a rapid process that commences within the first minute of the reaction between the extractant solution (α-CD) and the gold-containing solution (KAuBr$_4$). With time, AuBr$_4^-$ ions become encapsulated within the second sphere cavity formed between the primary OH faces of repeated face-to-face α-CD pairs. These pairs are stabilized by hydrogen bonding interactions, leading to an increase in recovery percentage, as demonstrated by [48]. On another hand, K$^+$, α-CD, and AuBr$_4^-$ molecules recognize each other, involving aureate anion [AuBr$_4$]$^-$ and hexa-aqua cation [K(OH$_2$)$_6$]$^+$ interacting non-covalently. This results in rapid co-precipitation of α-CD and KAuBr4 in water, eventually forming a 1:2 ratio complex (needlelike) $\{[K(OH_2)_6][AuBr_4]\subset(\alpha\text{-}CD)_2\}_n$, as concluded by Liu and Wang [39].

As α-CD concentration increases, recovery percentage also increases up to a maximum value before decreasing. Beyond this point, encapsulation ceases, and needlelike complex formation no longer occurs due to the absence of KAuBr$_4$ solution. The optimal ratio for complex formation is 1:2, where [AuBr$_4$]/[α-CD]=1/2. Performance decreases when the ratio falls below or exceeds this threshold. The neutralization of accompanying metals of gold during neutralization step plays an important role in increasing percent removal in gold recovery process.

ANOVA was investigated and some indicator values were found to analyse the model performance, such as R^2 and adjusted R^2 values, P-values, degree of freedom (df), and so on. The confidence level was 95%. Tables 4 and 5 show the results of ANOVA, and according to the results, it is obvious that: (1) for LP, the model, the time, as well as the time-[HBr] interaction are highly significant. In addition, the pH is significant and the remaining parameters ([HBr] and speed) are non-significant. (2) for GP, the model and all the parameters are highly significant.

Table 4: Analysis of variance for LP percentage.

Source	df	Sum of Square	Mean Square	F-Value	P-Value Prob>F	Observations
Model	4	3750.4	937.6	13.88	<0.0001	HS
x_1	1	792.3	792.3	11.73	<0.0001	HS
x_2	1	141.0	141.0	2.09	0.158	NS
x_3	1	909.9	909.9	13.47	0.001	S
x_4	1	24.3	24.3	0.36	0.553	NS
x_1^2	1	131.5	131.5	1.95	0.172	NS
x_2^2	1	631.7	631.7	9.35	0.004	S
x_4^2	1	0.8	0.8	0.01	0.913	NS
$x_1 x_2$	1	14451.2	14451.2	213.89	<0.0001	HS
$x_1 x_3$	1	21.8	21.8	0.32	0.574	NS
$x_1 x_4$	1	17.3	17.3	0.26	0.616	NS
$x_2 x_3$	1	61.4	61.4	0.91	0.347	NS
$x_2 x_4$	1	1.8	1.8	0.03	0.873	NS
$x_3 x_4$	1	1.5	1.5	0.02	0.882	NS
Error	33	2229.6	67.6			
Total	46	22365.2				

Note: F: function of Fishers, df: degrees of freedom, P-value: level of significance, NS: not significant; S: significant; HS: highly significant; CV=10.7259%; R^2=0.9003; Adj. R^2=0.7825.

Source: Authors, (2023).

Table 5: Analysis of variance for GR percentage.

Source	df	Sum of Square	Mean Square	F-Value	P-Value Prob>F	Observations
Model	3	14016.9	4672.28	13195.92	<0.0001	HS
x_1	1	4441.1	4441.10	12542.97	<0.0001	HS
x_2	1	9412.6	9412.63	26584.06	<0.0001	HS
x_3	1	163.1	163.13	460.73	<0.0001	HS
x_1^2	1	0.6	0.65	1.83	0.184	NS
x_2^2	1	6346.9	6346.87	17925.45	<0.0001	HS
x_3^2	1	0.6	0.60	1.71	0.199	NS
$x_1 x_2$	1	1318.2	1318.17	3722.90	<0.0001	HS
$x_1 x_3$	1	955.6	955.60	2698.90	<0.0001	HS
$x_2 x_3$	1	216.5	216.51	611.50	<0.0001	HS
Error	38	13.5	0.35			
Total	47	22868.7				

Note: F: function of Fishers, df: degrees of freedom, P-value: level of significance, NS: not significant; S: significant; HS: highly significant; CV=0.82515%; R^2=0.9994; Adj. R^2=0.9993.

Source: Authors, (2023).

The results of Tables 4 and 5 indicate that the R^2 values of 0.9003 and 0.9994 for LP and GP respectively were highly significant confirming a good reliability, reproducibility and precision of the models. The CVs of 10.7259% and 0.82515% for leaching and gold recovery respectively were also obtained. In addition, the obtained P-value <0.0001 for both models confirm

that the good prediction of the gold removal varying the parameters studied.

The optimization conditions were found for better gold removal in both LP and GR. From the results, the conditions were (1) time of 7.27 hours, [HBr] of 50 g/L, pH of 1 and stirring speed of 200 rpm for leaching percent of 98.540% and desirability of 1, (2) time of 40 minutes, [α-CD] of 11.6166 g/L and pH of 5 for gold recovery percent of 98.8736% and desirability of 0.99978. Under these conditions, the concentration of gold increased from 592.99 ppm to 3,372 ppm in the filtrate after LP, while it increased from 3,372 ppm to 11,944 ppm in the organic phase after GR.

IV.2 ANN PREDICTION

According to Table 3, the prediction of the response was done using ANN, and 75%-15%-15% learning choice was done for network training, testing and validation, respectively. The illustration of the observed mean square error (MSE) against the epochs for both LP and GP is given in Figure 2. According to [49], MSE also give information on the degree of correlation between the target and the predicted responses of the network.
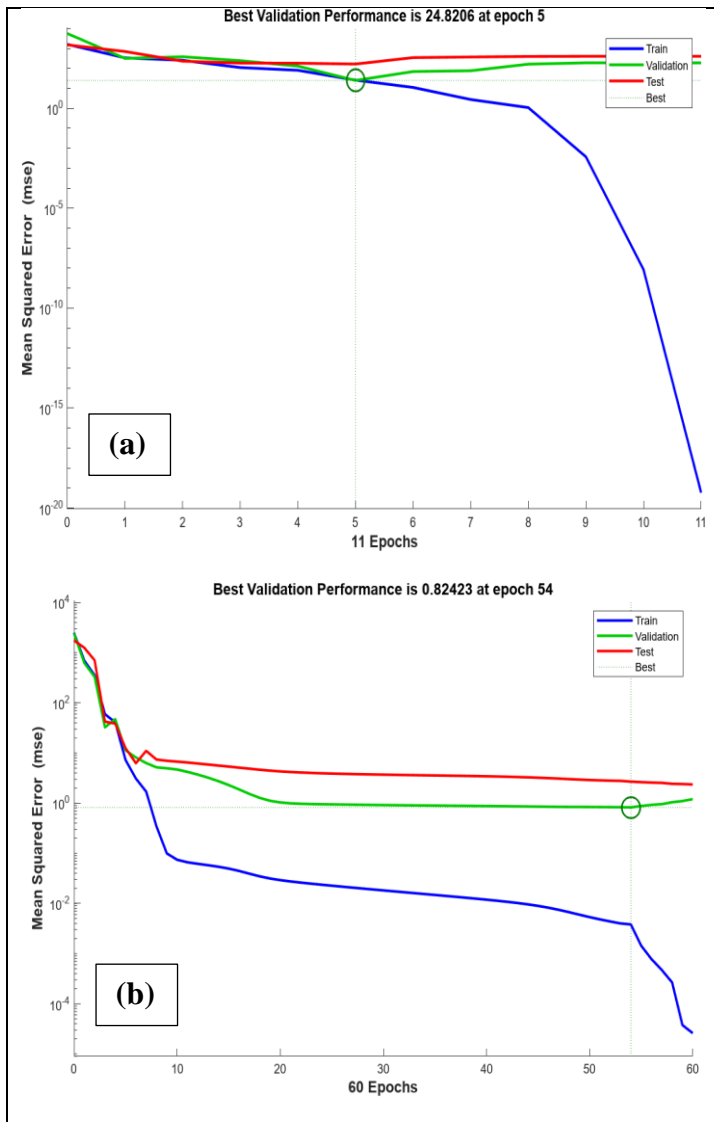

Figure 2: Performance of training, validation and testing (a) for LP, (b) for GR.
Source: Authors, (2023).

For LP (figure 2.a), it can be observed that for validation and testing there are steady decreases in MSE up to epoch 5, from where there is certain equilibrium up to epoch 11. In addition there is a regular decrease in MSE for training up to epoch 8 and then a sharp decrease is observed up to epoch 11. The best value of MSE is 24.8206 at epoch 5 involving the best performance and suggesting that the learning stage of the network at its best level is obtained after the fifth iterations. For GP (figure 2.b), MSE declines for training, validation and testing up to a certain equilibrium around epoch 9. Therefore, after 54 iterations, the best learning stage of the network is attained at MSE value of 0.8242 confirming a good correlation between gold recovery and the target. The error histograms of both LP and GP are presented in Figure 3 (a and b). It is seen that the errors are almost symmetrically distributed, so that they have a non-significant effect on the studied model. Furthermore, it is obvious that for GP, the mean value of the instances is closed to 5, which confirms the good performance of the model.
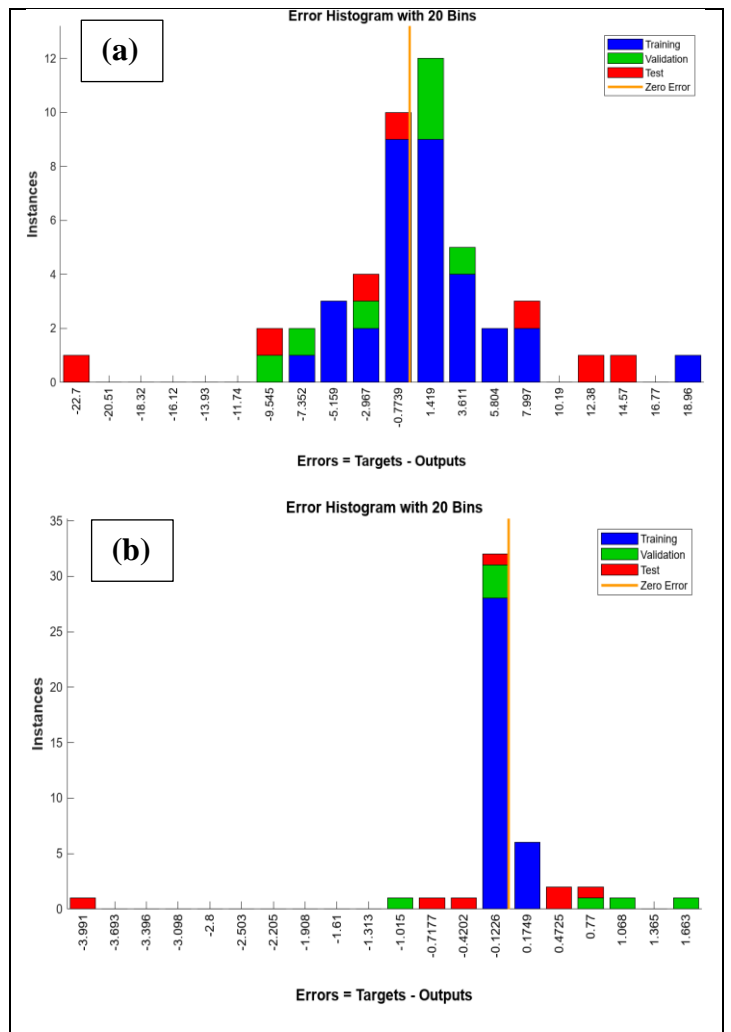

Figure 3: Error histograms (a) for LP, (b) for GP.
Source: Authors, (2023).

Figure 4 and 5 show the network performance related LP and GP, respectively. Considering the LP, it is obvious that the R^2 values for training, validation, testing and overall are respectively 0.99027, 0.90934, 0.71337, and 0.9392. According to the GP, the R^2 values of 0.99992, 0.99712, 0.99289, and 0.99952 were obtained for training, validation, testing and overall respectively.
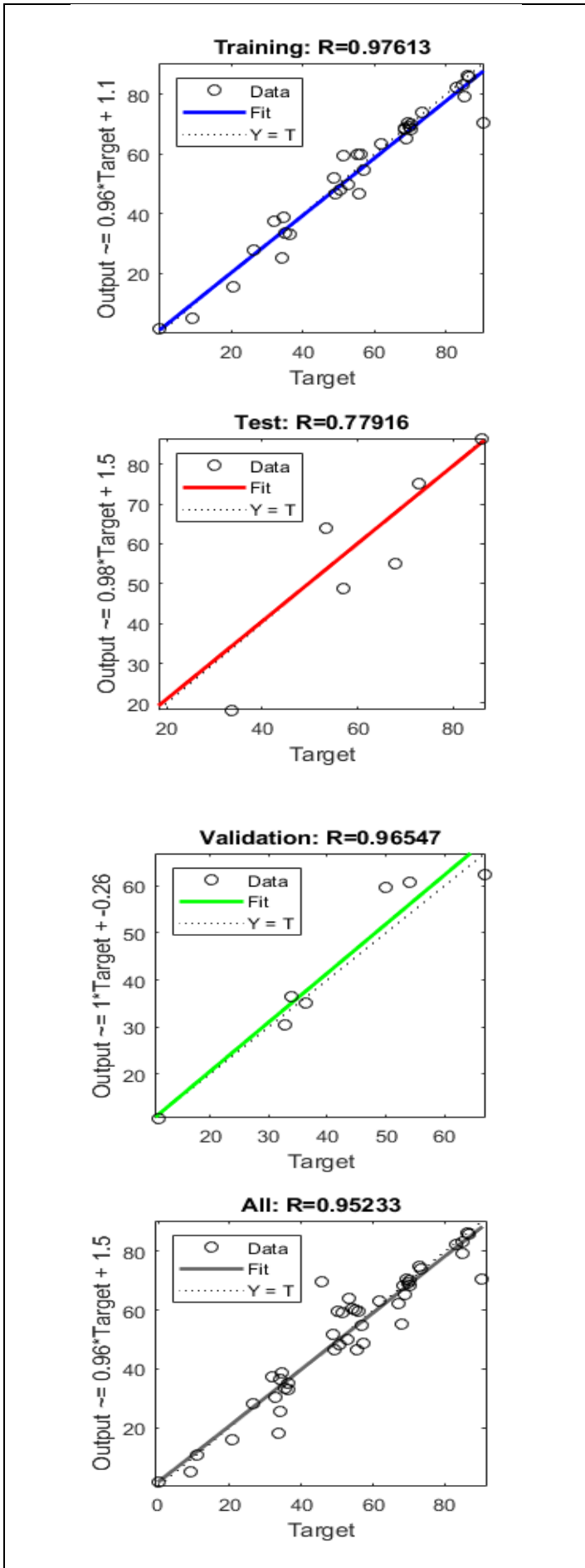
Figure 4: Four-in-one plot of network performance of LP.
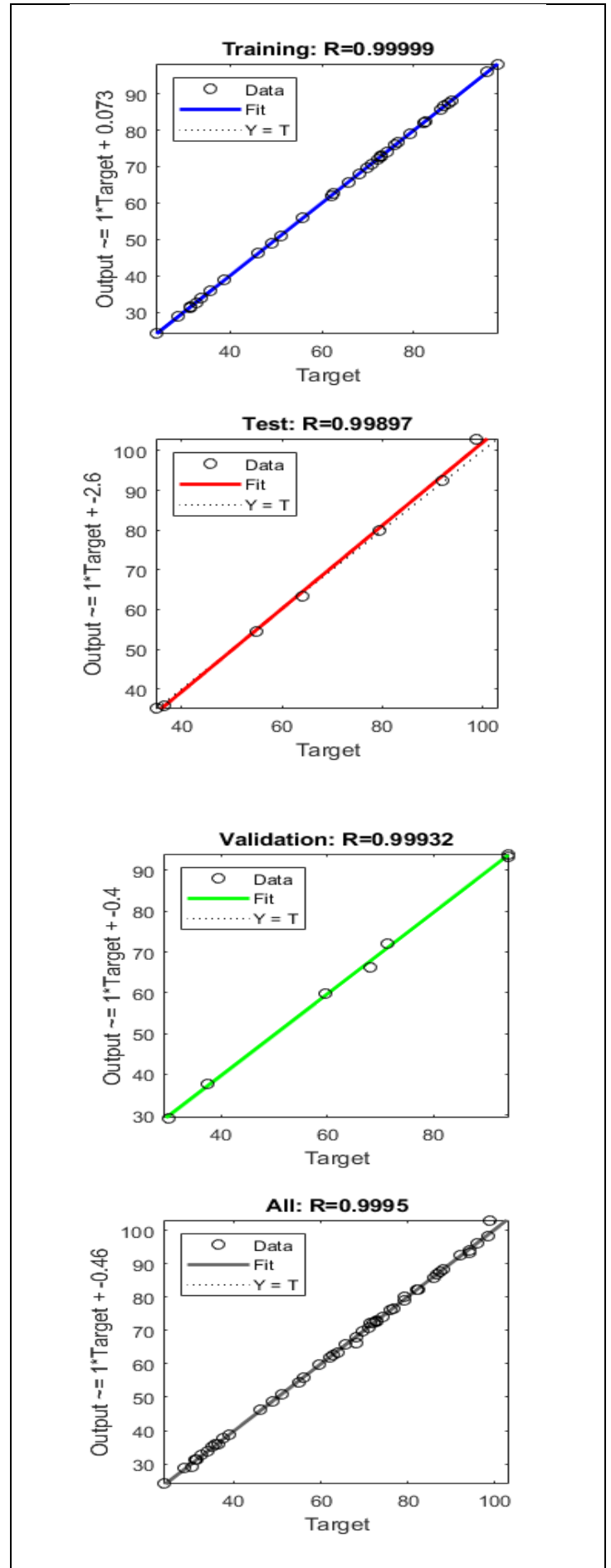Source: Authors, (2023).

Figure 5: Four-in-one plot of network performance of GP.
Source: Authors, (2023).

From these results, it is obvious that due to high values of R^2 which is >90%, the fitting performance of the neural network was highly significant although the observed low value of R^2 (0.71916) in testing stage for LP. The low observed value of R^2 was due to the non-sufficient data to test the network and a low learning choice (15%), but the overall performance of the network was not affected. The equations 13 and 14 show the relationship between the overall output and the target (All) for the determination of the overall predicted network model.

$$Overall\ output = 0.96 * Target + 1.5 \qquad (13)$$

$$Overall\ output = 1 * Target - 0.46 \qquad (14)$$

IV.3 COMPARISON OF RSM AND ANN, AND OPTIMIZATIONS

The use of the equations 13 and 14 allowed evaluating the performance of the models, followed by the comparison between the values of the experimental data, the predicted ANN and RSM values, either for of LP and GP, respectively. The results are presented in Table 6.

Table 6: Experimental data, RSM and ANN results for LP and GP.

Run N°	LP			GP		
	Exp. removal percent (%)	RSM pred. removal percent (%)	ANN pred. removal percent (%)	Exp. removal percent (%)	RSM pred. removal percent (%)	ANN pred. removal percent (%)
1	0.001	0.000	1.340	35.854	35.839	35.912
2	67.879	74.92	55.075	48.958	49.156	48.882
3	33.927	33.45	36.468	62.058	61.997	62.073
4	70.399	68.15	70.243	54.962	54.926	54.415
5	36.432	38.49	35.148	65.785	65.917	65.784
6	72.815	72.48	75.068	76.603	76.432	76.571
7	36.432	28.22	33.122	51.005	51.016	51.010
8	56.121	58.51	59.805	59.546	59.681	59.736
9	20.617	24.77	15.754	68.083	67.869	68.076
10	57.042	55.41	54.890	23.982	24.108	24.001
11	48.654	50.21	52.012	30.242	30.446	29.279
12	68.595	70.6	68.333	36.497	36.308	35.752
13	86.060	83.51	86.489	55.920	55.851	55.858
14	26.361	23.4	27.991	64.001	64.28	63.474
15	86.060	83.51	86.489	72.077	72.234	72.069
16	49.990	52.3	59.698	70.806	70.746	70.761
17	69.890	72.34	69.192	76.605	76.849	76.644
18	84.806	82.13	83.406	82.401	82.476	82.293
19	35.271	40.6	33.652	62.627	62.644	62.748
20	55.170	56.94	59.902	68.125	66.42	66.314
21	70.206	62.33	68.286	69.659	69.721	69.698
22	34.054	37.82	25.398	31.383	31.543	31.392
23	53.995	54.51	60.745	32.614	32.993	32.601
24	9.061	9.61	4.877	33.851	33.967	33.884
25	32.773	35.52	30.384	75.985	75.63	75.999
26	52.755	52.56	49.977	79.043	79.172	79.023
27	69.008	60.74	65.405	82.097	82.238	82.087
28	73.270	65.02	73.986	86.649	86.333	86.707
29	69.430	70.67	70.506	87.426	87.549	87.409
30	61.855	67.45	63.272	88.198	88.288	88.220
31	50.550	55.37	48.190	74.250	74.039	74.111
32	49.104	55.11	46.592	72.744	72.928	72.763
33	57.103	52.62	48.859	71.235	71.34	72.167
34	53.301	54.92	63.839	38.782	38.746	38.873
35	45.767	48.35	69.564	34.996	35.308	35.077
36	34.504	32.93	38.874	31.205	31.394	31.275
37	55.589	51.09	46.736	96.050	95.177	96.050
38	83.120	100.84	82.487	94.086	93.832	93.302
39	85.002	83.23	79.439	92.117	92.009	92.439
40	11.107	21.43	10.633	98.891	101.688	103.031
41	86.595	83.57	85.950	98.247	98.016	98.266
42	51.502	56.74	59.365	93.996	93.867	94.018
43	68.611	66.21	68.600	85.870	85.201	85.876
44	33.604	36.39	18.328	79.343	79.202	80.022
45	90.479	56.76	70.423	72.813	72.727	72.900
46	66.944	66.15	62.483	46.182	45.716	46.242
47	31.977	36.68	37.430	37.373	37.391	37.578
48	-	-	-	28.560	28.589	28.743

Source: Authors, (2023).

According to the results of Table 6, the values of R^2 related to LP between experimental data and predicted RSM results on one hand, and between experimental data and predicted ANN results on another hand, were calculated using Excel and the results were 0.9488 and 0.9423, respectively. In addition, concerning GP the value of R^2 for the relationship between the experimental data and predicted RSM results was 0.9997, while the R^2 associated to the relationship between the experimental data and predicted ANN results was 0.9995. Those results presented very high and significant performance of fitting for LP and GP, either in RSM and ANN. The optimization results of percent removal of LP and GP using RSM are carried out in Table 7, and based on the maximization of the equations 8 and 10. Concerning the optimization using ANN, the prediction equations 13 and 14 were used to develop a genetic-algorithm (GA) in MATLAB optimization tool.

Table 7: Optimization of gold recovery.

		Time (hr)	[HBr] (g/L)	pH	Speed (rpm)	Percent removal (%)	Validation experiment1 (%)	Validation experiment2 (%)
LP	RSM	7.27	50	1	200	98.54	97.58	98.22
	ANN	7.5	50	1	200	97.16	96.58	97.01
		Time (min)	[α-CD] (g/L)	pH	Percent removal (%)	Validation experiment1 (%)	Validation experiment2 (%)	
GP	RSM	40	11.61	5	98.87	98.45	97.87	
	ANN	39.8	10.71	5	99.98	99.95	99.26	

Source: Authors, (2023).

The best percent removals for LP using RSM were predicted at the following conditions: time=7.27 hours, [HBr]=50 g/L, pH=1 and stirring speed=200 rpm, with a removal efficiency of 98.54%. By using ANN-GA, the optimal conditions were closed (time of 7.5 hours, [HBr] of 50 g/L, pH of 1 and stirring speed of 200 rpm) to those obtained with RSM with a percent removal of 97.16%. Moreover, it was found that in GP the optimal gold percent removal using RSM was 98.87% with a contact time of 40 minutes, a [α-CD] of 11.61 g/L and a pH of 5. The use of ANN-GA method revealed the highest percent removal of 99.98% with time, [α-CD] and pH, of 39.80 minutes, 10.71 g/L, and 5.15, respectively. Therefore the results of comparison confirmed the best performance of both RSM and ANN in gold removal during LP and GP. However, Table 7 reveals a quite difference in LP between RSM and ANN-GA maximum percent removal (1.38%), while the difference between ANN-GA and RSM in GP is equal to 1.11%.

V. CONCLUSIONS

This paper demonstrates the successful use of alpha cyclodextrin (α-CD) for gold extraction from gold-bearing ore in the Democratic Republic of Congo (D.R.C). Through the implementation of Response Surface Methodology (RSM) and Artificial Neural Networks (ANN), the study identified the optimal gold removal conditions. Ore samples were initially processed to enhance leachability, and a modified aqua regia with hydrobromic acid was employed for the leaching process, leveraging the strong molecular recognition between gold bromide ion and α-CD. The experimentation involved adjusting various leaching parameters such as time, HBr concentration, pH, and stirring speed. RSM yielded optimal values of 7.27 hours, 50 g/L, pH 1, and 200 rpm, resulting in an impressive 98.54% gold removal. Meanwhile, ANN produced slightly lower values of 7.5 hours, 50 g/L, pH 1, and 200 rpm, with 97.16% gold removal. These results highlight the effectiveness of both RSM and ANN in optimizing gold extraction from the ore. Additionally, for α-CD gold recovery, RSM and ANN optimization resulted in 40 minutes, 11.61 g/L, and pH 5, achieving 98.87% and 39.8 minutes, 10.71 g/L, and pH 5, with 99.98% gold removal, respectively. These findings were further validated, reinforcing the success of RSM and ANN as methods for maximizing gold recovery from gold-bearing ore in the D.R.C. Overall, the use of α-CD in combination with RSM and ANN presents a promising approach for sustainable and efficient gold extraction processes in resource-rich regions like the D.R.C., potentially opening new avenues for environmentally friendly mining practices and enhanced economic opportunities.

VI. AUTHOR'S CONTRIBUTION

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RESEARCH ARTICLE   **OPEN ACCESS**

ASSESSMENT OF THE IMPACT OF URBAN SPRAWL ON INDIGENEOUS AGRICULTURE LAND IN IBADAN BETWEEN 2009 AND 2019: A CASE STUDY OF AKINYELE LGA

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ARTICLE INFO	**ABSTRACT**
	This work was aimed at monitoring the effect of urban sprawl on indigenous agricultural areas of Ibadan using Akinyele local government area as a case study with GIS and remotely sensed data as a tool for the analysis. Arc GIS 10.5 was used in processing and detection of changes in the imagery. It was revealed that by 2009 vegetation cover was dominant in Akinyele LGA with 59% of the total land cover and built up area was 38%, at the beginning of 2019 a total of 20% out of the initial 59% of vegetation cover has been loss to urbanization and development, vegetation cover was reduced to 39% and built up area increased to 55%. The total area covered by vegetation in 2009 was about 180 sqkm, in 2014 it was 216 sqkm and in 2019 it was 185 sqkm. Built up area as at 2009, 2014 and 2019 covered an area of about 180 sqkm, 231 sqkm and 262 sqkm, respectively. Finally, more land in the study area will expose to direct sun ray and the affected areas will be exposed to erosion thereby posing a threat to agriculture. The study recommended that effective policy implementation be embarked upon as a check against increase in urban centres, there is need to take adequate care of vegetation and there should be smart decision about how to solve human needs and policy makers should consider employing remote sensing and GIS techniques in providing solution to spatial problems.

I. INTRODUCTION

Urbanization has rapidly transformed urban environments into highly dynamic systems, with cities now housing nearly half of the global population. This trend, which started in the 19th century, continues to expand at an alarming rate [1]. Urban sprawl, as defined by the European Environment Agency (2006), refer to unplanned and gradual urban development that involves low-density land use patterns on the outskirts of cities, often encroaching on farmland areas." Population growth and territory expansion are inextricably related to urban growth or sprawl. [2]

established three stages of urban growth and created cases to assess the effects on key environmental metrics such as land usage, air quality, water and energy demand. According to their forecasts, by 2020, all accessible area suitable for development will be urbanized, resulting in increasing air pollution due to an increase in the number of automobiles.

[3] described the peri-urban area as the contiguous space surrounding a city that is impacted both positively and negatively by its proximity. It represents an interface that lies between the rural and urban systems. However, compared to rural areas, the provision of urban services is increasingly limited in the peri-urban

area, and ecological services are also diminished. The peri-urban population is made up of both rural and urban residents, with the rural component lacking access to clean air, productive farmland, and property ownership, while the urban component lacks access to essential urban services. The peri-urban communities are predominantly composed of low-income earners who rely on resources from both rural areas and cities for their livelihood and sustenance. These communities bear the consequences of urban encroachment, as their land uses are fragmented by various forms of urban development. The inclusion or exclusion of peri-urban areas from urban and regional strategies raises conceptual issues. As cities grow in population, complexity, and geographic extent, rural hinterlands and peri-urban communities suffer invasion without enough consideration for the effects on these vulnerable areas. In addition to improved accessibility, population growth, and the availability of large, inexpensive lots, these factors contribute to dynamic changes in land use. Consequently, the physical development pattern of peri-urban areas undergoes continuous transformation, particularly in cities of the developing world.

The scenario painted above on the effects of city urbanization on its surrounding peri-urban areas, especially as it concerns sub-Saharan African cities, is not very different from what is evident in Ibadan city core and its surrounding peri-urban areas.
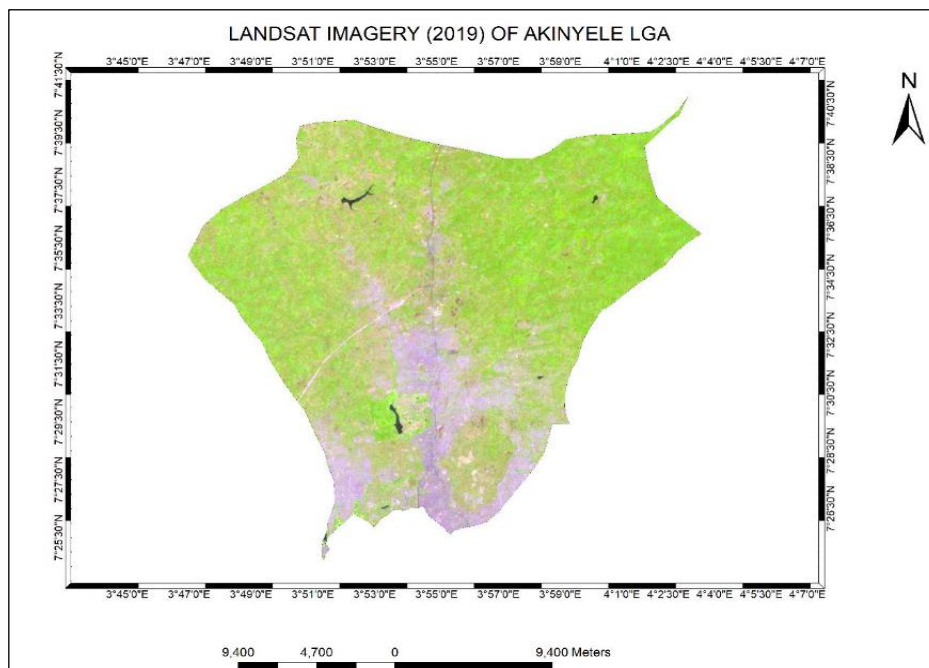

Figure 1: The map of the studied area (Akinyele local goverment area).
Source Authors, (2023).

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

According to [4], the city of Ibadan, established in 1829, is the largest traditional urban center in Sub-Saharan Africa and symbolizes the pinnacle of pre-colonial urban development in Nigeria. The earliest village, now known as the core area, was held by indigenous settlers. This portion of the city now has the oldest and least developed residential districts, as the buildings were built without regard for building standards or regulations. The pre-colonial city grew over time, encompassing an outlying territory impacted by modern activities. There is an obvious separation between the ancient parts of the city and the newer regions, which emerged from the British colonial authorities' enactment of the Town and Country Planning Ordinance in 1946. To some extent, the newer areas were subjected to planning interventions and development control. They also demonstrated the impact of population expansion on land cover in Ibadan further. Rapid national economic expansion during the oil boom period began in the 1970s, causing significant changes in the city's land use. In 1972, vegetation covered 92% of the total land, with peri-urban development accounting for 3.7% and the urban center accounting for 3.0%, respectively. Residential zones predominated in the peri-urban areas. Prior to 1972, there were no high-density regions, but by 1984, 11.42 square kilometers of the urban area had been designated as high density. This amount grew steadily, reaching 64.8 square kilometers in 2003. Meanwhile, the proportion of land covered by vegetation decreased from 63% in 1984 to 39% in 2003.

[5] investigated the impact of urban sprawl on sustainable urban development using remote sensing and social media data in Morogoro, Tanzania, from 2011 to 2017. Their findings revealed that population-driven urban expansion negatively affects ecosystem services, replacing essential grasslands and forests with built-up areas. The study's novel approach with social media data can inform urban planning in African cities where data is often limited or outdated. [6] focused on the impacts of urbanization on ecosystem services and societal perceptions in Boise, Idaho. They found that agriculture faces the highest risk of conversion due to urban growth. Differences in the perceived importance of ecosystem services were observed between the general public and experts, indicating the importance of incorporating social demand in urban planning for policy resilience and diverse perspectives. [7] explored the relationship between urbanization and agricultural land conversion in Hyderabad, Pakistan. The study analyzes population growth and land use changes, particularly in the Qasimabad sub-district. It reveals significant agricultural land conversion for urbanization, raising concerns about potential food and infrastructural challenges. Policymakers can use these findings to address sustainable land use planning for the city and beyond. [8] examined the consequences of urban expansion on green spaces and ecosystem services in Accra, Ghana. The study utilizes remote

sensing, the i-Tree Canopy model, and stakeholder interviews. Findings indicate a decline in green spaces due to urban growth, posing challenges to sustainability. The valued benefits of existing green areas underscore the necessity for effective management and conservation strategies to bolster the city's resilience amid climate change. [9] assessed the vulnerability of East Kolkata Wetland (EKW) to urban expansion. The rapid growth of Kolkata megacity encroaches upon the wetland, posing environmental threats. Using the Fuzzy MCDM method, the research identifies around 60% of EKW as highly to very highly vulnerable areas. Urgent conservation measures are needed, especially for wetland zones adjacent to urban development. The Fuzzy MCDM method's high reliability (AUC 93.7%) validates its use. The study calls for immediate action by local authorities to protect this ecologically valuable wetland. [10] analyzed urban sprawl, land use change, and agglomeration in Makassar City, Indonesia. The expansion of the city area impacts spatial dynamics and leads to environmental degradation in suburban areas. Urban sprawl, land-use change, agglomeration, activity systems, and transportation systems show positive correlations with environmental quality degradation, accounting for 85.9% determination coefficient. [11] evaluated the impact of urban sprawl on agricultural livelihoods in peri-urban Kumasi, Ghana. Through interviews with farmers, the research identified various responses, including agricultural intensification, extensification, diversification, and off-farm strategies. Livelihood outcomes varied based on assets like human and social capital. To address these challenges and reduce vulnerabilities, effective spatial planning, legislative enforcement, and expanding the market for agricultural goods and non-farm jobs were suggested as key policy interventions. [12] conducted a study on land use/land cover changes in Ghana's Greater Accra region using GIS and remote sensing techniques. The research revealed a significant increase in built-up areas by 277% over 24 years, leading to a decline in forest areas from 34% to 6.5% during the same period. The study projected a massive increase in urban extent, covering 70% of the area by 2025 compared to 44% in 2015. Spatial models proved valuable for sustainable city planning and environmental management, especially in developing countries like Ghana. [13] conducted a study on urban sprawl in China from 2006 to 2014 using urban land census and population data. The results showed significant urban sprawl (average USI of 3.16%), but with a declining rate after 2010. They identified regional disparities and factors like urban size, hierarchy, population density, GDP per capita, and industrial structure as influencing urban sprawl. Tailored urban planning and land use policies are essential considering these differences. [14] developed an innovative approach using machine learning and cellular automata integrated Markov Chain (CA-MC) to accurately predict urban expansion in South Auckland. The model outperformed traditional methods and predicted a significant expansion of urban areas to 1340.55 ha in 2026, mainly encroaching on grassland and open-bare land within planned growth zones. [15] conducted a comprehensive GIS and remote sensing analysis to assess the impacts of land use/land cover change on environmental sustainability in Ekiti State, Nigeria. By using supervised image classification, the study mapped land use/land cover change over a 4.5-decade period (1972–2017) and analyzed vegetation dynamics through normalized difference vegetation index and land surface temperature for temperature dynamics. The results revealed a significant decrease in forests and woodlands (-51.25% and -0.72%, respectively) and a notable increase in built-up areas, croplands, rocks/bare soils, and water bodies (267.58%, 197.30%, 714.11%, and 4421.43%, respectively). [16] conducted a study utilizing remote sensing and

GIS to analyze the spatio-temporal patterns of urban sprawl in the fringe area surrounding Ibadan, Nigeria. Focusing on Egbeda Local Government Area, they utilized aerial photos from different time periods and found that the urbanized part of the area expanded significantly over time. In 1964, it covered approximately 33 km², which increased to 76.50 km² in 2000, with a projected expansion to 191.7 km² by 2020. Low-density sprawl was observed between 1986 and 2000, and the expansion resulted in the loss of several villages and extensive consumption of agricultural land. [17] analyzed land use dynamics and the expansion of Benin City's built-up area. They discovered that the spatial structure of urban sprawl corresponded to ideas like the concentric zone, sector, and multiple-nucleus models. Economic activity focused in the city center drew sellers from the outskirts, resulting in human agglomeration and interaction. They identified commercial locations as development hubs, lending credence to the multiple-nuclei explanation. They also discovered a link between population expansion and built-up land use, which led to a decline in plant cover. The analysis emphasized housing demand as a result of population expansion and the move from agriculture to other land uses for higher economic returns. [18] highlighted the significance of infrastructure and public services in addressing the challenges of urbanization, particularly in developing countries. They estimated that $40 trillion of infrastructure spending is required to meet the needs of cities in developing countries. However, the main challenge lies in finding means of financing such vast expenditures.

As cities expand, they take over surrounding land, including natural green spaces, to build houses, roads, and paths to suit the demands of their citizens. urban sprawl refers to the growth of metropolitan areas into rural areas, farmlands, and woods on the periphery of cities. Both developed and underdeveloped countries are affected by urban sprawl. The implications can be particularly severe in developing countries, posing major dangers to health and hygiene. While industrialized countries may be in a better position, continual urban land growth at the expense of bordering areas poses a substantial risk to sustainability and quality of life. In the long run, the consequences can be devastating. Therefore, the focus of this research is to look into the impact of urban sprawl on the peri-urban area of Ibadan.

This study aims to investigate the effects of urban activities on peri-urban areas in Ibadan. It distinguishes itself from previous research, which predominantly focused on issues like resettlement, housing problems, and population growth within specific settlements, without specifically considering their impact on the spatial structure and well-being of peri-urban residents. The findings of this study will be valuable to urban policymakers in both the public and private sectors. Additionally, environmental monitoring agencies will benefit from the insights provided. Administrators responsible for development control and land regulation in the rural-urban fringe will find the information generated in this study useful for planning, development, and land management in Ibadan, as well as in other new towns within Nigeria and beyond. This study is confined to small study areas within the larger geographical region of Ibadan. Nevertheless, this study represents a significant effort in understanding some of the impacts of urban growth on the peri-urban areas of Ibadan land.

III. RESEARCH METHODOLOGY

The methodology involves the techniques and materials used in the execution of the project which the extraction of data processing and manipulating of data, thematic classification, database creation, buffering, overlay analysis and network analysis of data.

III.1 DATA DESIGN

The described process pertains to the creation of a detailed data model for a database, aiming to represent real-world entities and their relationships in an optimized manner, maximizing benefits while minimizing data usage [19]. In the context of computerized information systems, a database serves as a collection of interrelated data that supports one or more applications, relying on computer programs for its utilization. It may encompass multiple data files, and the design of such a database, referred to as data modeling in GIS, involves three interconnected phases.
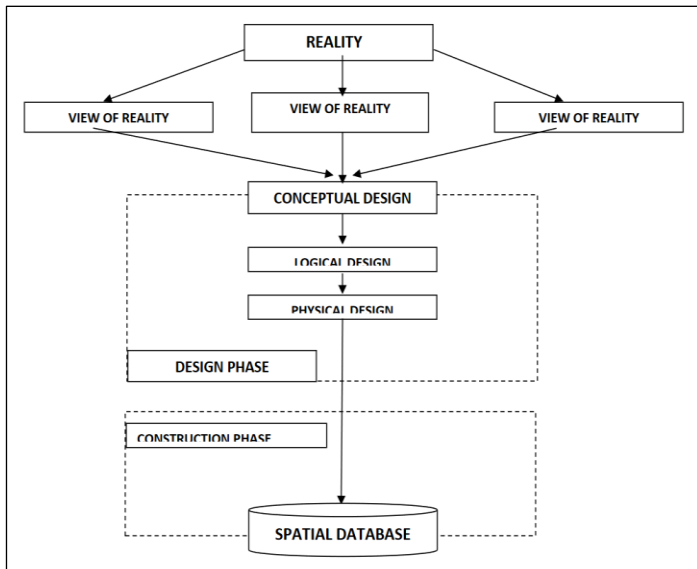

Figure 2: Design and Construction Phase of a Spatial Database.
Source: [19].

III.2 CONCEPTUAL DESIGN

This is the arrangement of human conceptualization of reality. It refers to how the view of reality could be presented in a simplified manner but still satisfy the information required of the organization concerned. There are three basic schemes for conceptual design, they are; Vector data model, Tessellation data model, Object oriented data model

III.3 LOGICAL DESIGN

This is the representation of data model, designed to reflect the recording of data in a computer system, the conceptual data model for this project was translated into relational data structure. The conceptual model was translated into logical schema and the following table relationship was derived.
1. VEGETATION/FARMLAND (VF_id, VF_use, VF_area, VF_location)
2. WATERBODY (WB_id, WB_area, WB_location, WB_name)
3. BUILT-UP AREA (BU_id, BU_name, BU_location, BU_use)

III.4 DATA ACQUISITION AND SOURCE

Generally, there are two major sources of data which are primary and secondary data, for the study, secondary data was used,LANDSAT imagery and shape file of Akinyele local government area for three period; 2009, 2014 and 2019 were acquired. Field survey was carried out to locate and validate the satellite imagery gotten.

III.5 SYSTEM SELECTION

Hardware refers to the computer components that form the visible frame work on which GIS runs; where data input, manipulation, analysis, and display takes place. For this project, the hardware used includes;
- HP ENVY TS 17 notebook PC with configuration of 1 Terabyte hard disk, 12GB RAM and core i7 2.20GHz processor.
- HP photosmart D5300 series printer
- Arc GIS 10.5 version software was used for digitizing, manipulation and performing the analytical functions employed in this project.

III.6 DATA CONVERSION

The satellite images of the study area were acquired and classified using ARC GIS 10.5. The shape file of Akinyele local government was used to clip and get the extent of the study area and the features that were created include waterbody, vegetation and built up area.
- Launch "ArcMap" on your desktop
- On ArcMap, go to file click on "add data"
- After clicking on "add data", go to the folder you save your Landsat imagery and click OK to import to Arcmap environment.
- Once the image has been imported into Arcmap, navigate to "table of contents" and right click the data(image)
- After right clicking the data(image), scroll down to the "properties" and click for it to display numerous options.
- Go to "symbology" and go to "unique values" in order to perform a task to remove background valueto "zero" after that you click "apply" and "ok".
- Back on the image on ArcMap, navigate to "catalogue" and go to the folder you save the particular shape file of the "AOI" and import it to the table of contents.
- In order to perform a processing extent of the AOI with the imported imagery, go to "Arc tool box" and drop down on "spatial analyst tools" and drop down on "extraction" and then click on "extraction by mask". This extraction is done in order to extract the satellite imagery on the specified AOI shape file.
- Once extraction is done, right click on the empty pane of the ArcMap interface and navigate to "image classification " in order for the tools to be displayed on the screen.
- Now to perform supervised classification, go to the image classification tool box and drop down the arrow button to display different options. Click on "Maximum likelihood classification "
- After clicking on the maximum likelihood classification, it will display some options in a window pane and input the necessary information needed, then click "ok" for it to perform supervised classification of the AOI.
- Once the supervised classification process has been performed, it will be displayed in the table of content
- Go to the supervised classification in the table of content to change the classified image colour classes to the desire colour of choice.
- Rigth click on the classified image and go to open attributes table to perform numerous task like Area, Percentage, etc.

- Once all this is done then you can move your image to layout view of the ArcMap in order to embellish your map
- Once the image classification tools has been displayed on the screen, go to the tools and click on "training sample" to display another window on the ArcMap
- After the training sample window has been displayed, go to image classification tools again and click on "draw polygon" and start drawing polygons on the features that is to be classified.
- After drawing the desired numbers of polygons on the feature, it will be displayed on the training sample window. Go to the training sample window and perform a task by merging all the drawn polygon classes as one, and name it the desired name of the feature.
- Once completed, on the training sample window, you save your training sample to a preferred file location and also navigate to the signature file icon and click on order to save the "signature file" and save it in any folder of your choice.

III.7 DATABASE MANAGEMENT

A database management system (DBMS), is a batch of tools that help to access the database by querying it, updating it, making back-ups, e.t.c. this includes the host of computer hardware and software, the procedure and structured data. It is used for the input, storage, analysis and retrieval of the data. It should also provide facility for data security, integrity and archiving. Database management system may be defined as a collection of software packages that facilitates the organization, storage, manipulation and retrieval of a data from the database. It allows one to interchange or cross reference data between different records.

Examples are Microsoft Access, Oracle Spatial, dBase, Sybase etc. DBMS comprises of user interface, data server, query optimizer, data dictionary, transaction handler and concurrent controller

III.8 DATABASE SUCURITY

The utmost important noticeable security to all database management system (DBMS) is the security of the data. The DBMS or some subsystem invoke by the DBMS must monitor user request and reject any attempt to violate the security and integrity defined by the DBA.

III.9 DATABASE INTEGRIY

Data integrity is used to refer to the accuracy or correctness of the data in the database. The following integration measures should be enforced
1. Entity Integrity: This restriction on primary key value ensures that no primary key attribute is null.
2. Referential Integrity: This is a restriction on foreign keys in a relation; neither foreign key's value must match the primary key value of some type in its own relationship table.

III.10 DATABASE MAINTENANCE

The accuracy of a database depends in its fitness for use as a Decision Support System (DSS). Database must be kept up to date and properly maintained in these ways.

1. Following the instruction in the user's manual.
2. Simplicity in the data process adopted.
3. Flexibility of the process of updating the database created.
4. The system should be prevented from heat, dust and probably operate the system in air-conditioned room.

IV. ANALYSIS AND PRESENTATION

Geographic Information System (GIS) has very powerful analytical capabilities because it can combine spatial and non-spatial data to create accurate findings that are excellent for long-term development planning and a critical decision-making tool. GIS operation and analysis are performed based on the nature of the project and end-user requirements.

GIS analytical capabilities differentiate it from other information systems. The capabilities are classified into measurements, retrieval, classification function, overlay function, neighbourhood, connectivity and topological functions (Aronoff, 1989).

IV.1 LAND AND USE MAPPING

A supervised classification technique was employed on three separate images, leading to the generation of final classification products.an overview of the land use of the study area in the year 2009, 2014 and 2019.

Three major categories of land use were/are identified; there are Water Body, Built Up and Vegetation
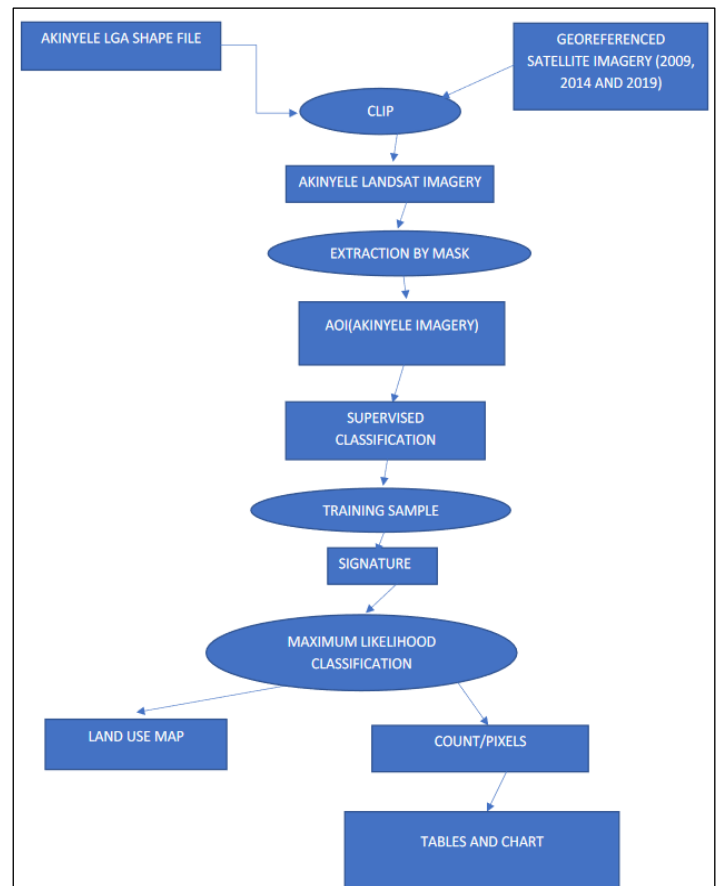

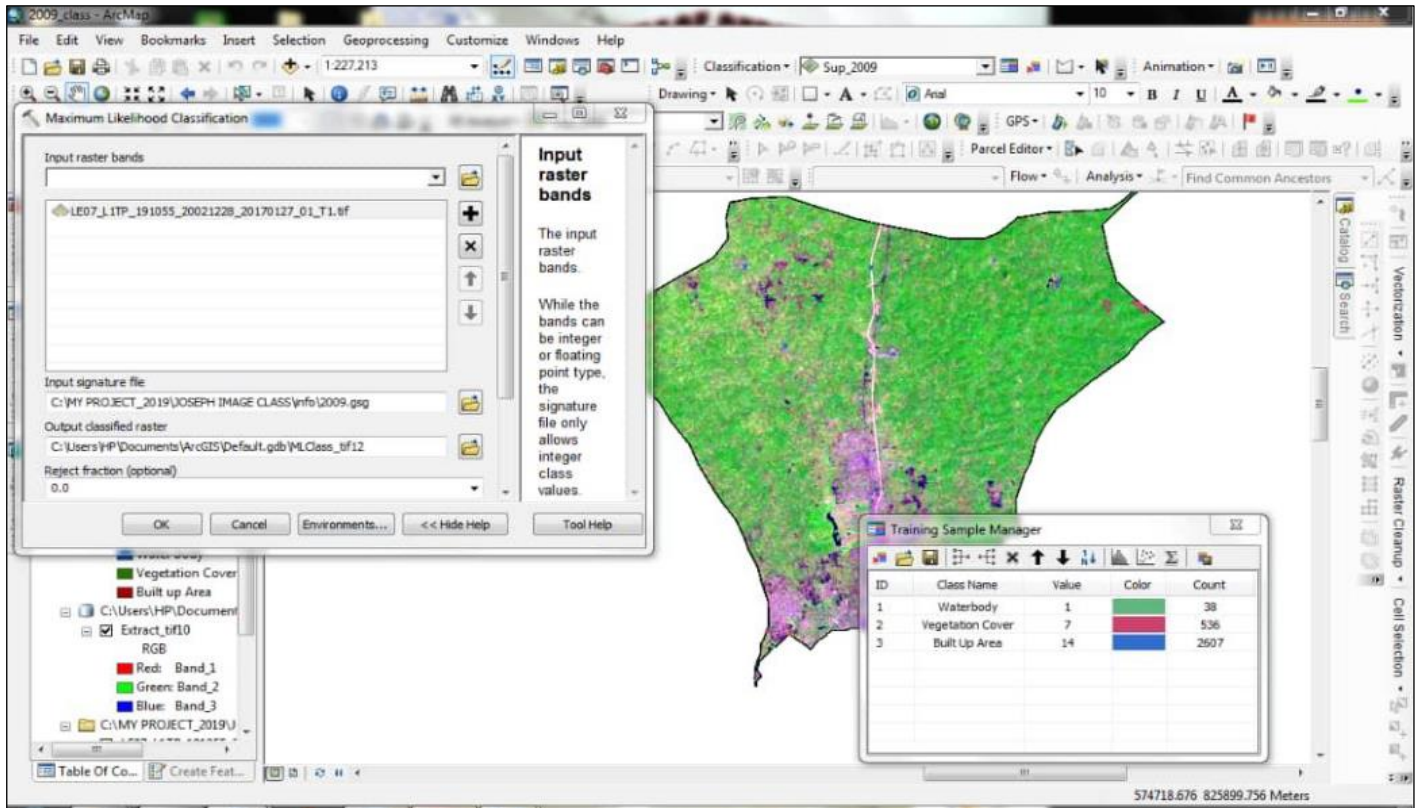Figure 3: Cartographic model.
Source: Authors, (2023).

Figure 4: Landsat imagery of Akinyele LGA Before classification (2009).
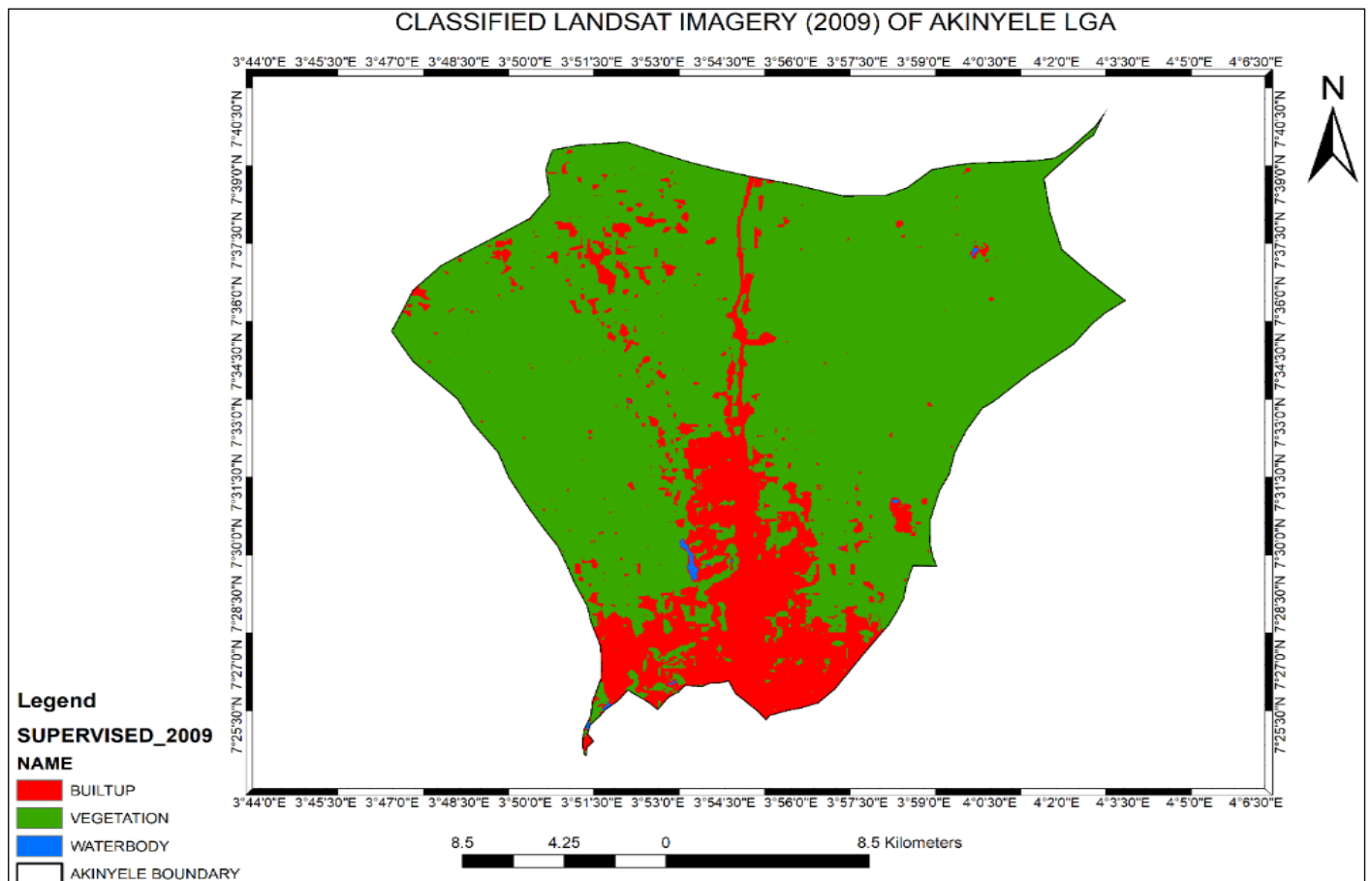Source: Authors, (2023).

Figure 5: Supervised classification of Landsat imagery of Akinyele LGA (2009).
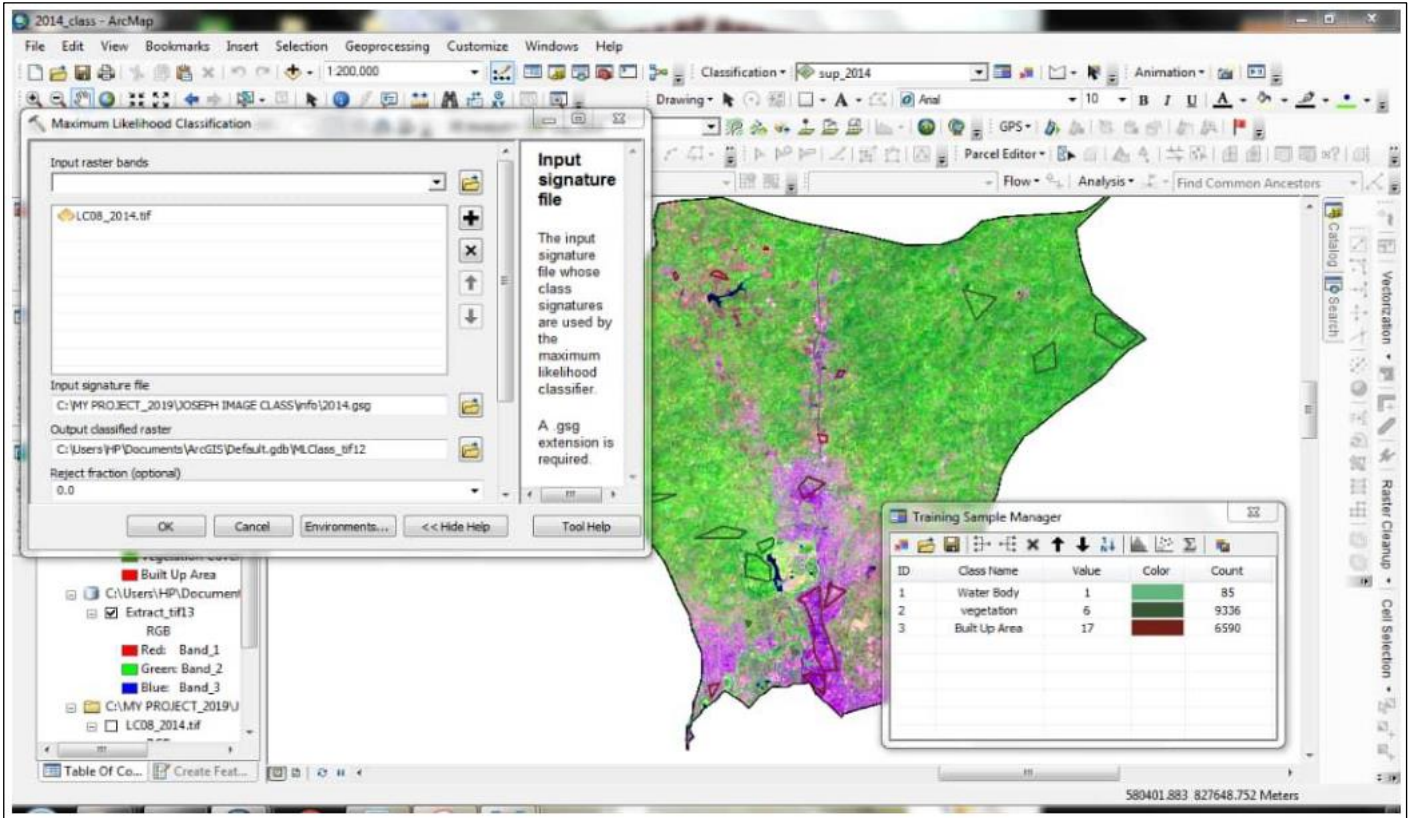Source: Authors, (2023).

Figure 7: Landsat Imagery of Akinyele LGA Before Classification (2014).
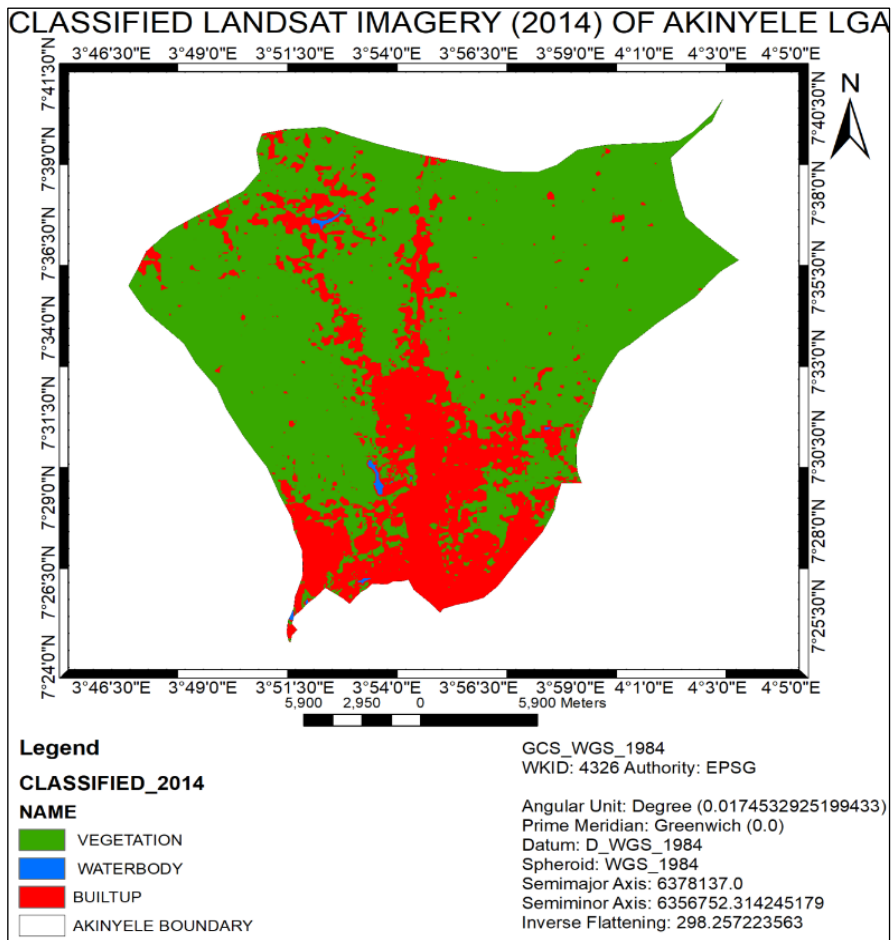Source: Authors, (2023).

Figure 8: Supervised classification of Landsat imagery of Akinyele LGA (2014).
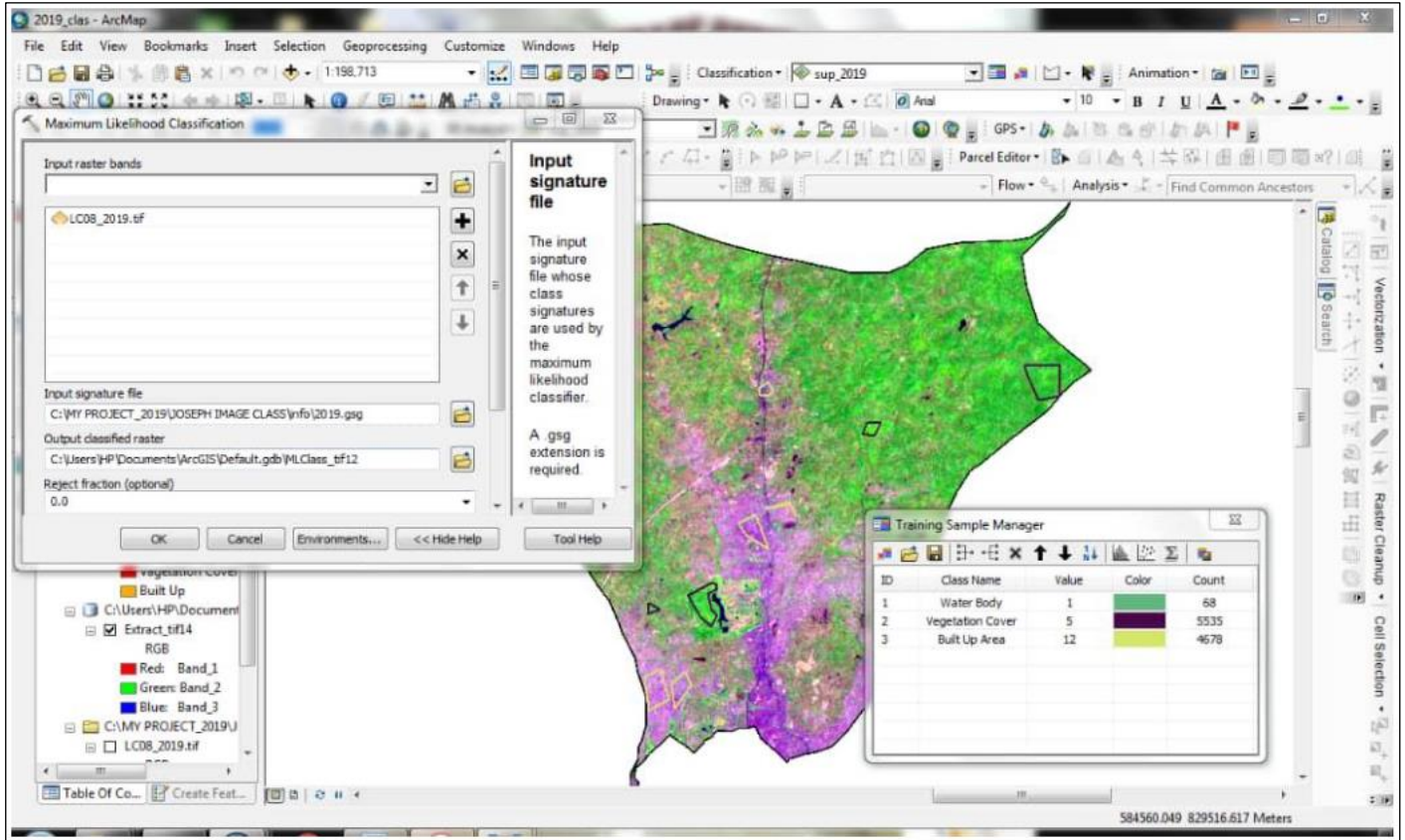Source: Authors, (2023).

Figure 9: Landsat imagery of Akinyele LGA before classification (2019).
Source: Authors, (2023).

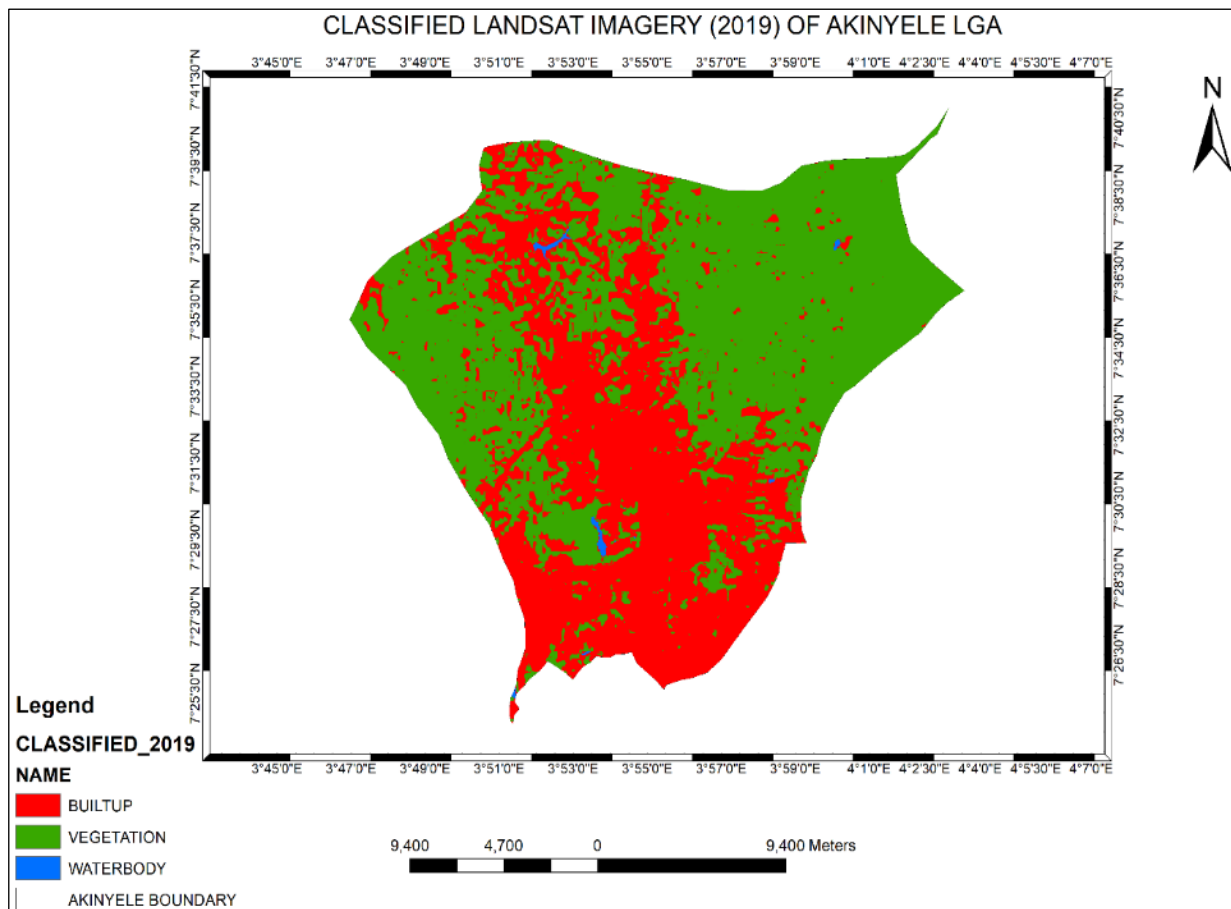Figure 10: Supervised classification of Landsat imagery of Akinyele LGA (2019).
Source: Authors, (2023).
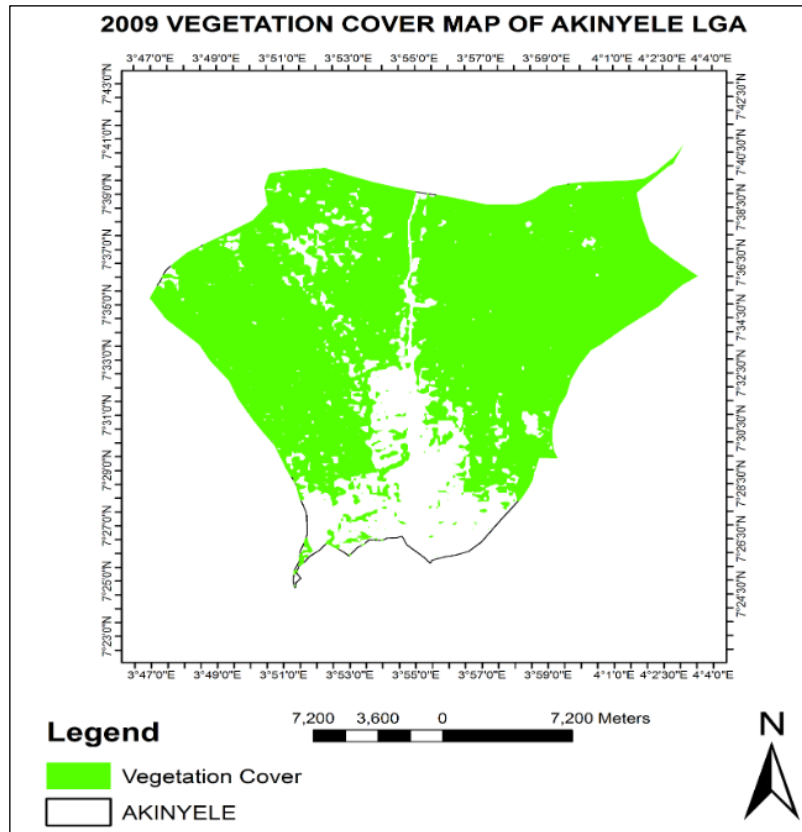
Figure 11: 2009 Vegetation Cover Map of Akinyele LGA.
Source: Authors, (2023).
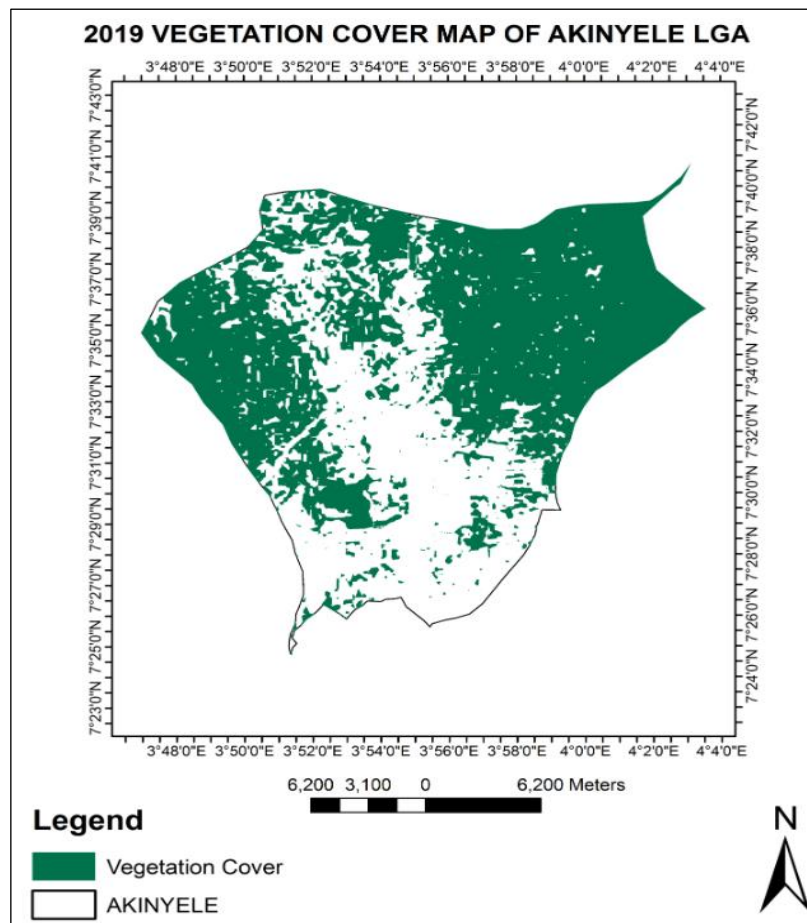
Figure 12: 2019 vegetation cover Map of Akinyele LGA.
Source: Authors, (2023).
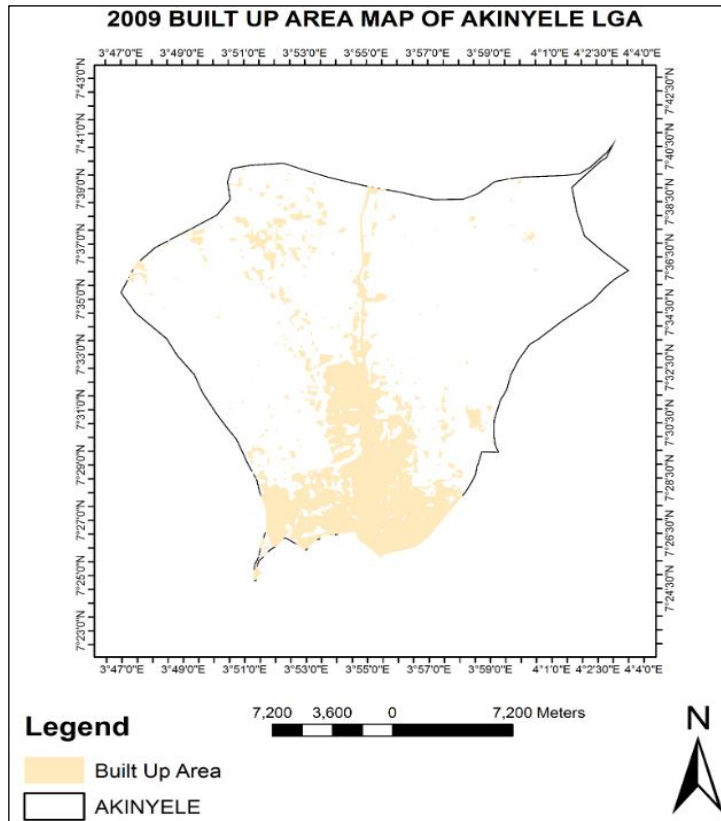
Figure 13: Map of Built Up Area of Akinyele LGA 2009.
Source: Authors, (2023).
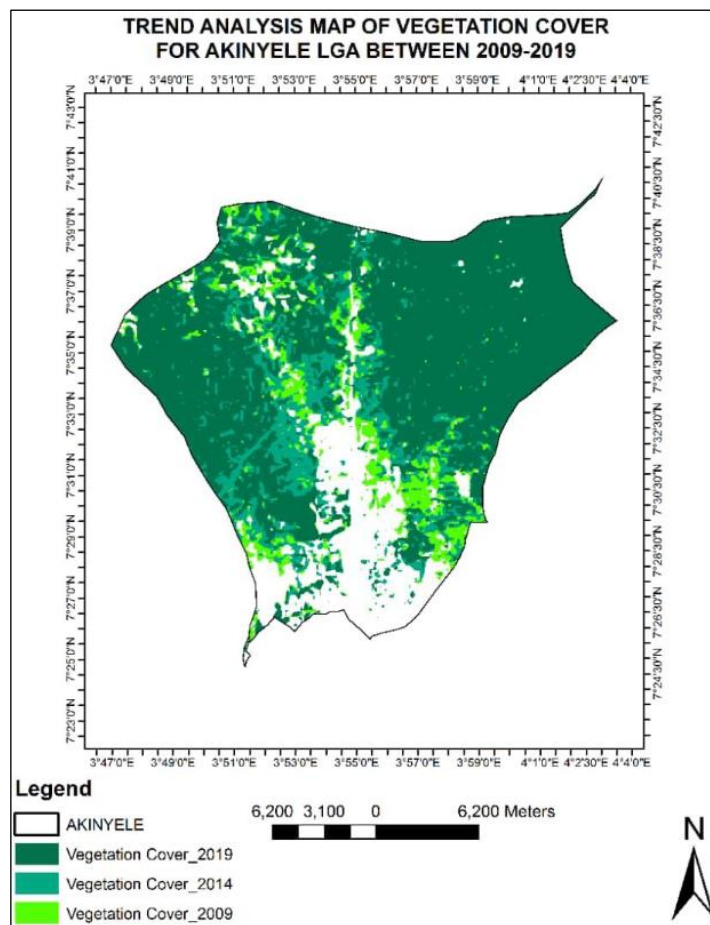
Figure 14: Map of trend of vegetation from 2009 – 2019.
Source: Authors, (2023).
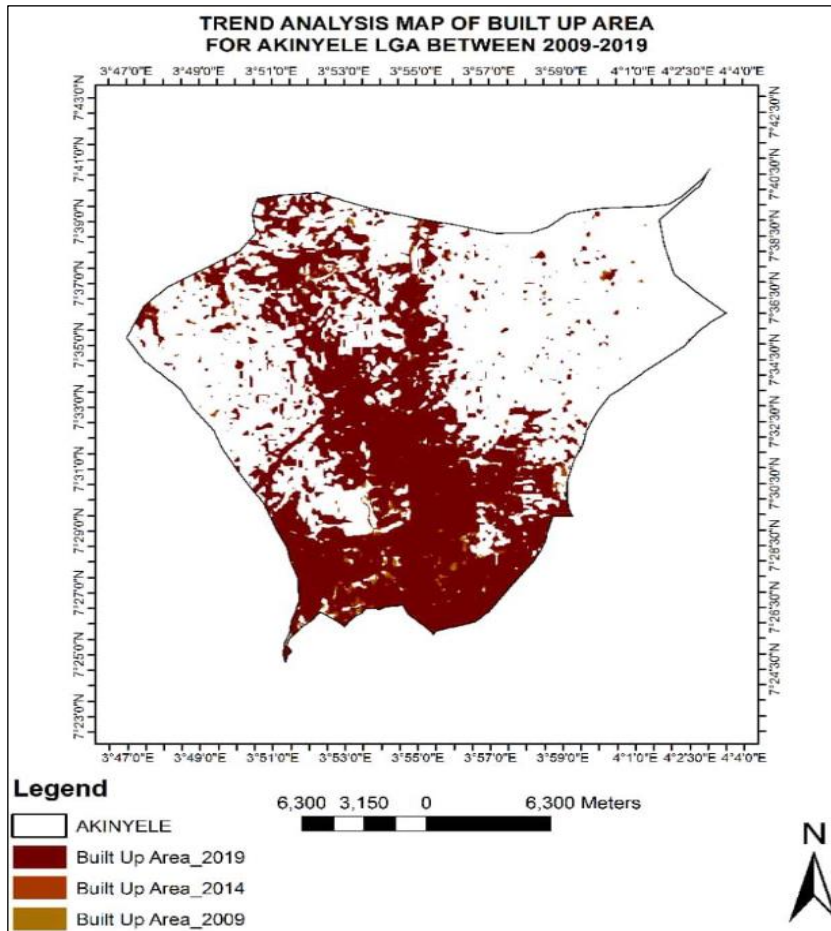
Figure 15: Map of trend of built up area from 2009 – 2019.
Source: Authors, (2023).
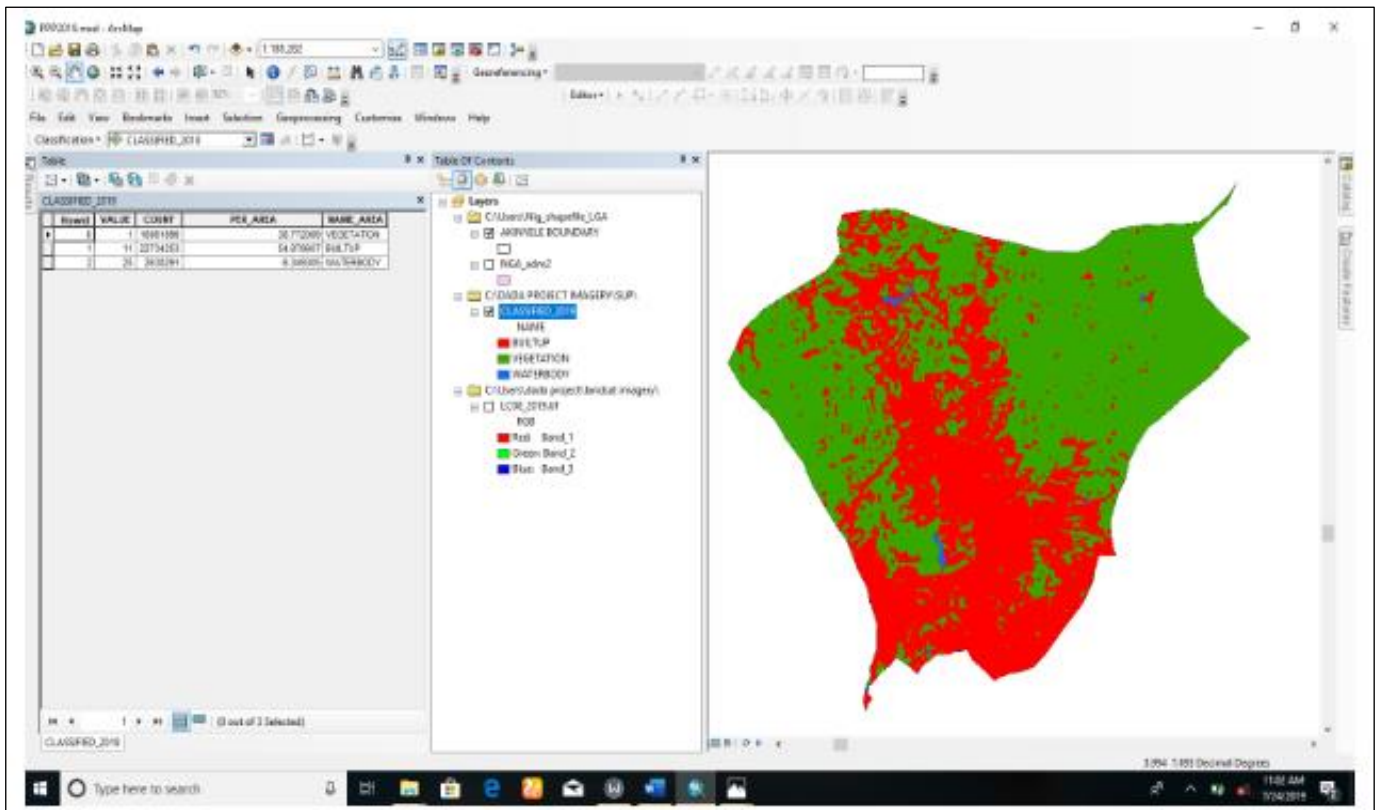
Figure16: Count of pixels on ARC GIS 10.5 (classified Landsat image of 2019).
Source: Authors, (2023).
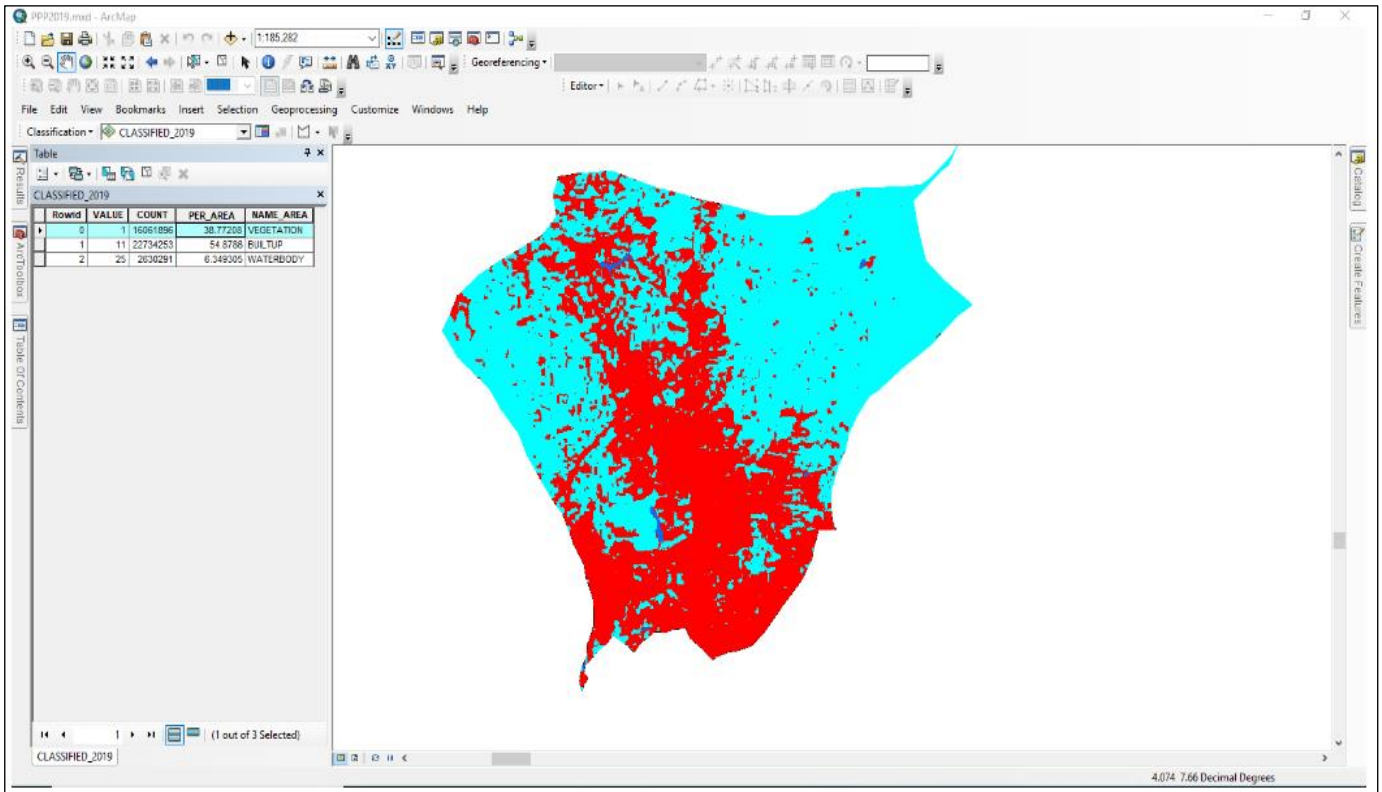
Figure 17: Query for selection of vegetation (classified image 2019).
Source: Authors, (2023).
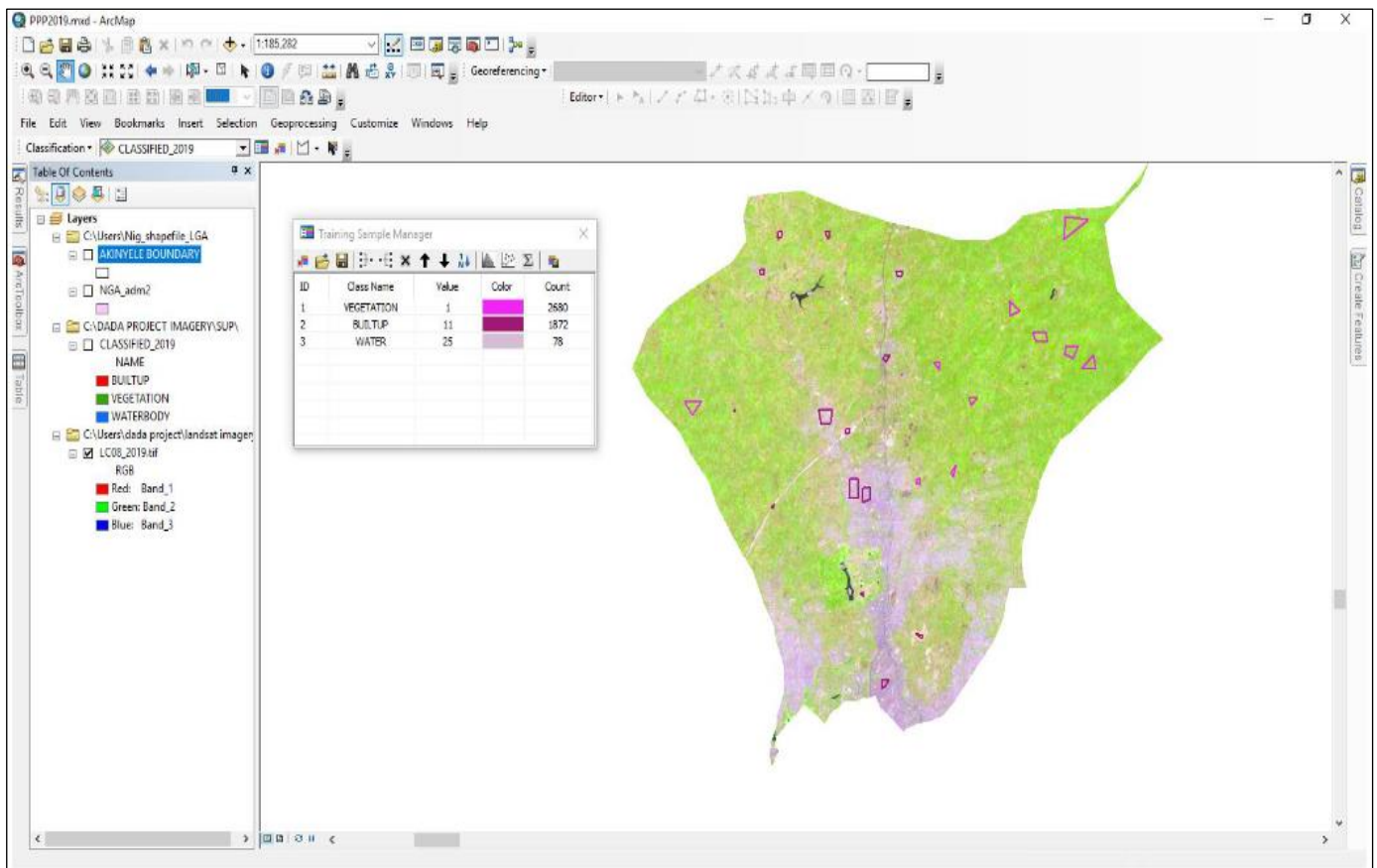
Figure 18: Training sample for 2019 Landsat imager.
Source: Authors, (2023).
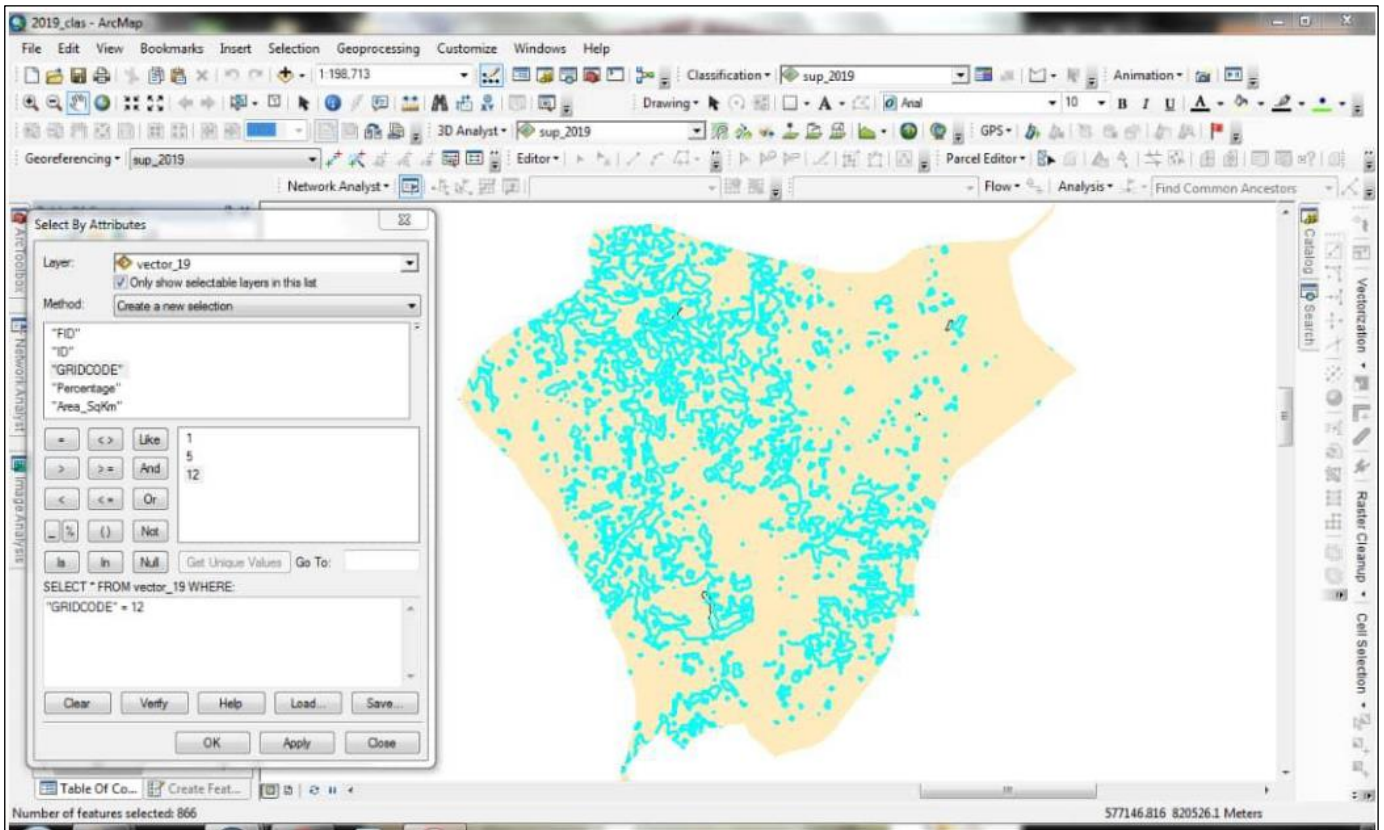
Figure 19: Query for Built up Areas 2019.
Source: Authors, (2023).
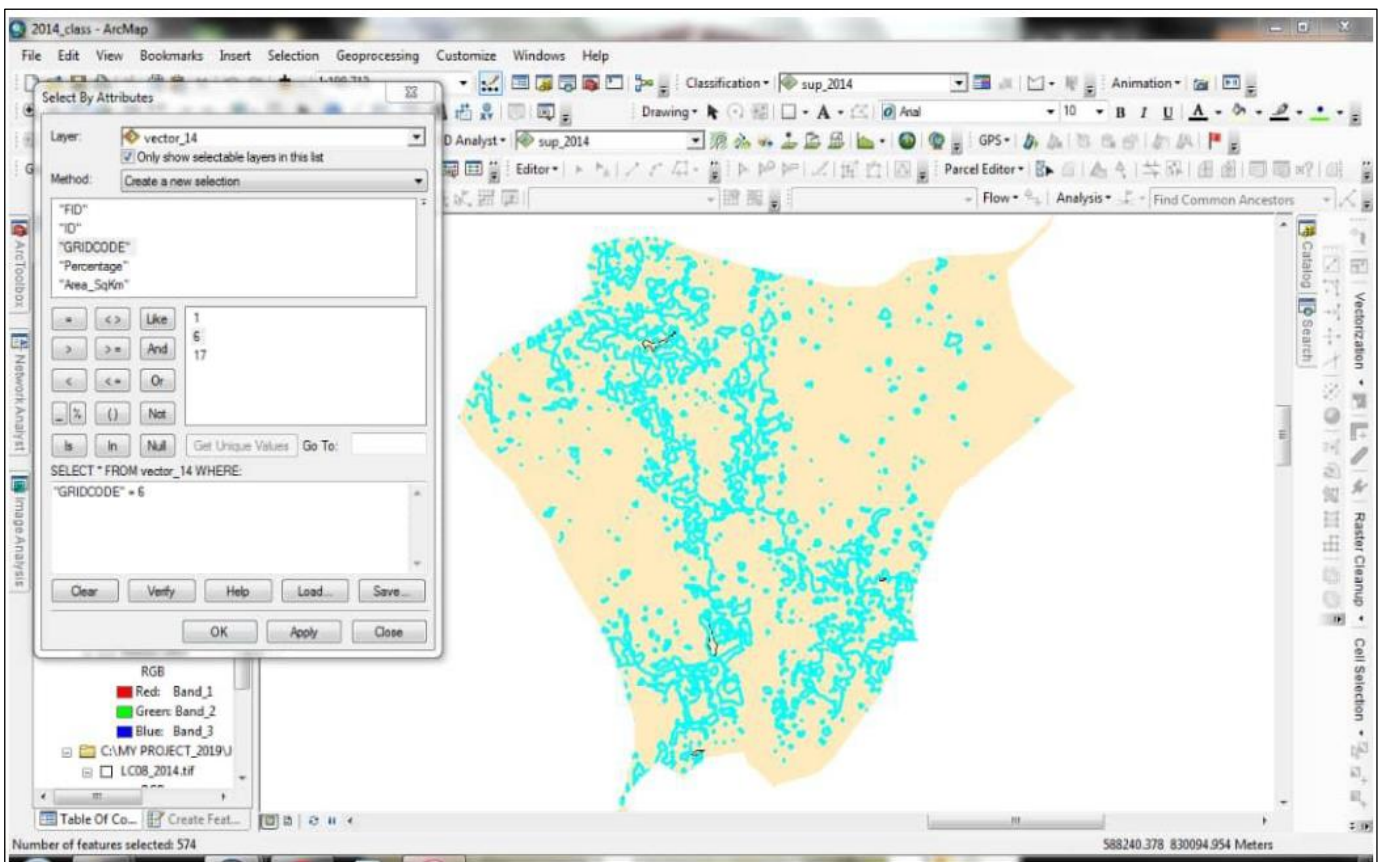
Figure 20: Query for Built up Area 2014.
Source: Authors, (2023).
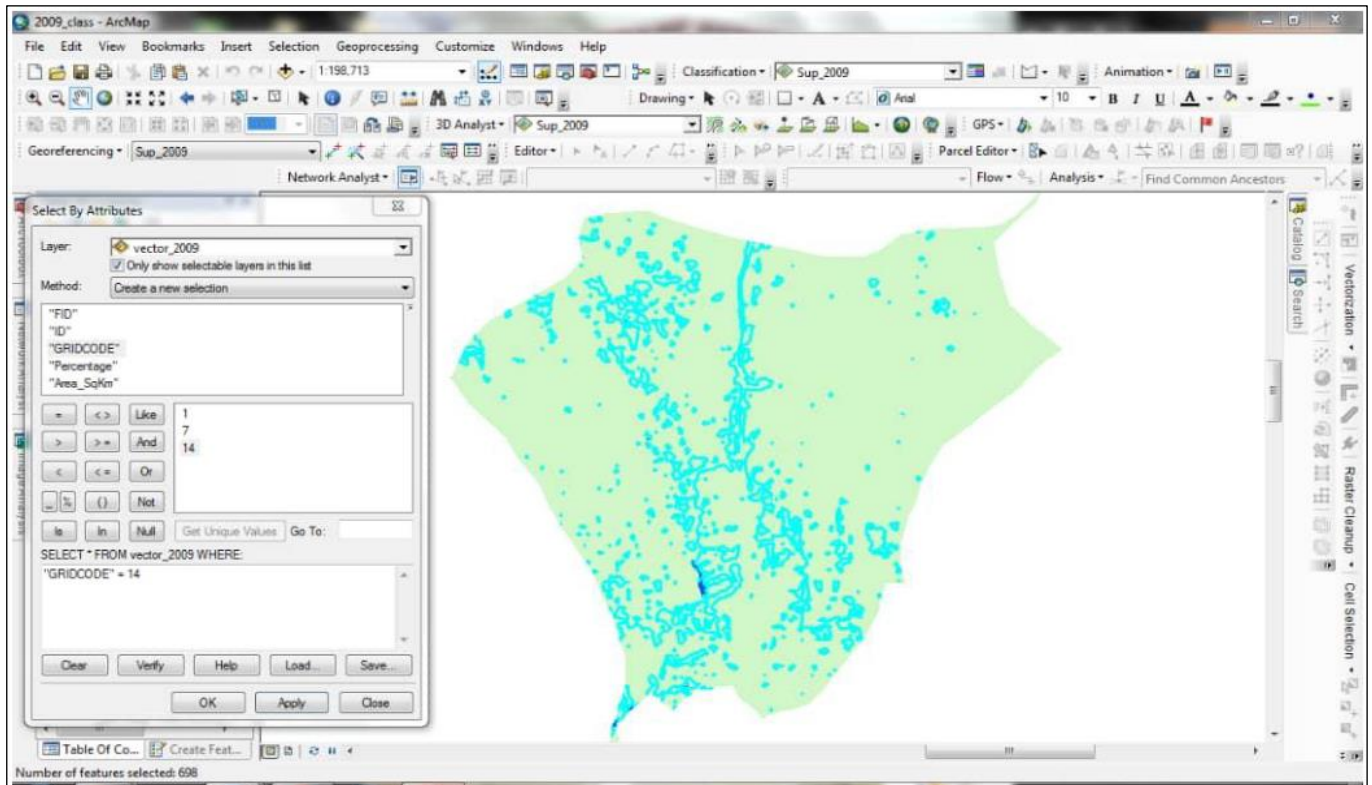
Figure 21: Query for Built Up Areas 2009.
Source: Authors, (2023).

IV.2 LAND COVER INVENTORY AND AREA CALCULATION

Below are area calculations in square kilometer and percentage of the overall land use showing the amount of change that has occur over the year.

IV.2.1 Land use for 2009
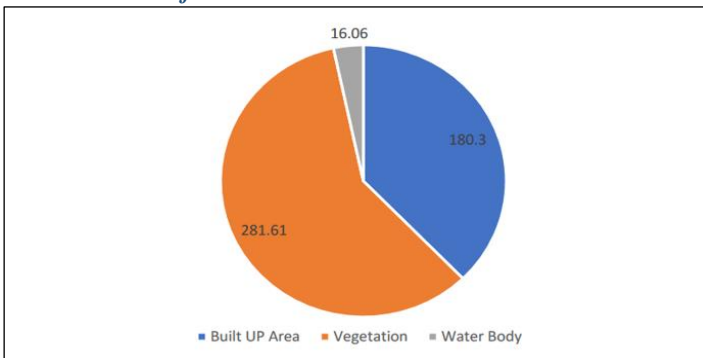
Figure 22: Pie Chart showing the area covered by different land use in 2009.
Source: Authors, (2023).

IV.2.2 Land use for 2014
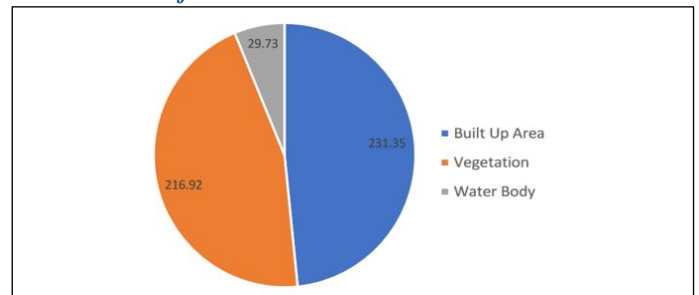
Figure 23: Pie chart of area covered by different land use in 2014.
Source: Authors, (2023).

IV.2.3 Land use for 2019
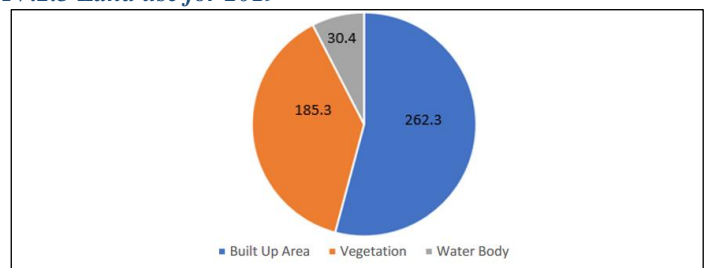
Figure 24. Pie chart of area covered by different land use in 2019.
Source: Authors, (2023).

Table 1: Summary of land cover inventory and area calculation.

Land use class	2009		2014		2019	
BuiltUp Area	Area (sqkm)	Area (%)	Area (sqkm)	Area (%)	Area (sqkm)	Area (%)
Vegetation	180.30	37.71655	231.35	48.396	262.28	54.87860
Water Body	281.61	58.914095	216.92	45.384	185.32	38.77208
	16.06	3.369355	29.73	6.2192	30.35	6.349305
Total	**478**	**100**	**478**	**100**	**478**	**100**

Source: Authors, (2023).
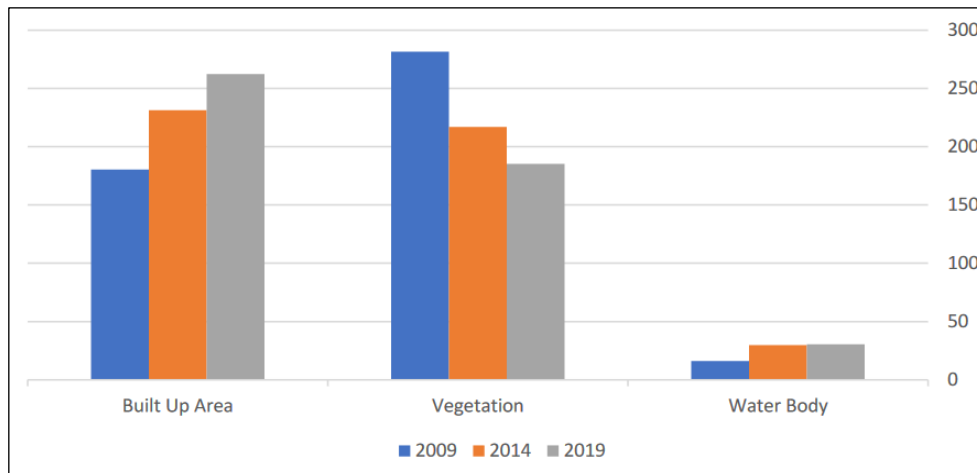
Figure 25: Multiple bar chart showing the relationship between different land use in 2009, 2014 and 2019.
Source: Authors, (2023).

V. DISCUSSION OF FINDINGS

Anthropogenic activities accounted for the nature of change in the study area which has led to rapid growth of human population and loss of indigenous agricultural land. From 2009 to 2019, built up area is increasing at an outrageous speed. By 2009, built up area accounted for about 38% of the total area, by 2014 this has increased by 10% making it a total of 48% at the end of 2014 and about 54% by January, 2019, an increase in built up area causes a causal effect in vegetation that is, an increase in the built-up area will lead to a direct decrease in the vegetation of the study area. Vegetation reduced drastically from 2009, 2014 and 2019. Vegetation reduced with a percentage of about 13% from 2009 to 2014, this is as a result of intense market activity in Akinyele market, there is also a marked decrease in vegetation from 2014 to 2019 which is about 8% decrease. The percentages of vegetation in 2009, 2014 and 2019 are 58%, 45% and 38% respectively. The creation of Oyo-Akinyele road has effect on the vegetation of the study area which resulted in linear type of settlement.

Landsat imagery of 2009, 2014 and 2019 of Akinyele LGA were analyzed in order to ascertain the changes in indigenous agricultural areas that was affected by an increase in urban areas of Ibadan city, which made people to move to Akinyele LGA. Three major classes were identified and use as the land use classes, which are: built up area, water body and vegetation.

V. CONCLUSIONS

This study checked the dynamics of vegetation change in Akinyele LGA, in a view to mapping, discovering the change rate using remote sensing and GIS techniques. This study is helpful in enhancing better decision making and policy formulation for policy makers. In the project, the landcover map for Akinyele LGA was generated using supervised classification of remote sensing operation using ARC GIS 10.5. Human activities such as urbanization plays a vital role in the vegetation modification/alteration which resulted in land cover changes as confirmed in this work.

The study shows that land cover changes significantly from 2009 to 2019, using three epoch year for analysis; 2009, 2014 and 2019. The vegetation reduced from 58% in 2009 to 38% in 2019. Built up area increased drastically from 37% in 2009 to about 55% in 2019, while water body increased from 3% in 2009 to 6% in 2014 and 2019 respectively, this is due to increase in built up area which increased run-off. The southern part of the study area shows concentrated disturbance of vegetation, which is due to sprawl move from Ibadan North LGA.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Joseph Olajuwon Dada, Ayodeji Olatunbosun Ajani, Adedayo Olujobi Alagbe and Oluwatosin Ibukunoluwa Ilesanmi.
Methodology: Joseph Olajuwon Dada and Ayodeji Olatunbosun.
Investigation: Joseph Olajuwon Dada, Ayodeji Olatunbosun Ajani, Adedayo Olujobi Alagbe and Oluwatosin Ibukunoluwa Ilesanmi.
Discussion of results: Joseph Olajuwon Dada, Ayodeji Olatunbosun Ajani and Adedayo Olujobi Alagbe.
Writing – Original Draft: Joseph Olajuwon Dada.
Writing – Review and Editing: Joseph Olajuwon Dada and Ibrahim Ademola Fetuga.
Resources: Joseph Olajuwon Dada.
Supervision: Ayodeji Olatunbosun Ajani and Adedayo Olujobi Alagbe.
Approval of the final text: Ayodeji Olatunbosun Ajani, Adedayo Olujobi Alagbe and Oluwatosin Ibukunoluwa Ilesanmi.

VII. ACKNOWLEDGMENTS

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RESEARCH ARTICLE   **OPEN ACCESS**

BUILDING SURVEYING PRACTICE IN THE NIGERIAN CONSTRUCTION INDUSTRY: PROSPECTS, BARRIERS AND ENHANCED MEASURES

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ARTICLE INFO

ABSTRACT

The building surveying profession is an emerging field of expertise that professionals in the Nigerian building industry have not yet embraced. This study, therefore, aims to investigate the barriers constraining the uptake of the profession and suggest measures for its survival amidst other professions in the Nigerian built environment. A survey research strategy was espoused to elicit empirical data from 108 construction experts in Nigeria who were randomly selected. The data collected were analyzed using Statistical Packages for Social Sciences (SPSS version 23.0) and Microsoft Excel. The study revealed that barriers constraining the practice of building surveying in Nigeria were a lack of public awareness, limited education and training opportunities, and resistance from existing professions. While developing better relations, reviewing the academic curriculum, and raising awareness were key strategies for its uptake. The study concludes that the building surveying profession is deemed important by the majority of built professionals in Nigeria, and possesses significant prospects, but constrained by the lack of public awareness and resistance from existing professions in the built environment. It is therefore recommended that building surveyors should strengthen their relationships with existing professional bodies. This may be accomplished through establishing periodic forums for idea-sharing and collaboration.

I. INTRODUCTION

The building industry plays a pivotal role in the economic development of any nation [1], and Nigeria is no exception. As the country experiences rapid urbanization and infrastructural development, the demand for competent building surveyors becomes increasingly crucial. [2] note that the building surveyors expertise is essential to ensure the safety, quality, and sustainability of buildings amidst bustling construction activities. Thus, within this dynamic context, the building surveying (BS) profession emerges as an indispensable aspect of the construction process, providing specialized knowledge and services in various areas such as building inspection, assessment, maintenance, and project management. The emergence of the BS profession reached a pivotal point in the 1970s, particularly within the United Kingdom, where it became firmly established [3]. Over the years, building surveyors in the UK have played a crucial role in the planning, design, and construction of structures, as well as in the ongoing maintenance and management of buildings. [4] posit that building surveyors expertise extends to various domains, including building control works and activities pertaining to the built environment. However, beyond the UK, Hong Kong, and Australia, the awareness of BS practice remains relatively limited, necessitating further efforts to promote and expand the profession's reach [5, 3]. While the BS profession has already established itself as a well-regarded profession in these developed countries, Nigeria still faces challenges in fully exploring and utilizing its potential. [6] stressed that the utilization of building surveys by individual building owners, professionals in the building industry, and the government in Nigeria is alarmingly low, and in most instances, not employed at all. According to [7], this lack of implementation has resulted in significant challenges confronting the Nigerian construction industry. Moreover, [8] opined that regardless of the promising

growth potential in the construction sector, the BS profession currently faces a significant shortage of skilled professionals. This has created a gap in the uptake of the BS profession in the building construction industry. [9] corroborate that the BS profession in Nigeria is not practiced as it should. These constraints limit the profession's capacity to deliver its full range of benefits to the sector and the wider society. As the construction industry continues to evolve in Nigeria, the expertise of building surveyors stand poised to play a vital role in shaping a sustainable and prosperous future for the nation's-built environment. In order to reduce the aforementioned barriers, this study aims to bridge the knowledge gap by identifying barriers constraining BS practice and propose key measures for BS profession uptake in the Nigerian construction industry. The objectives of the study are to; determine the prospects of the BS profession in the Nigerian building construction industry, identify the barriers constraining the practice of BS, and propose measures that can enhance BS practice in Nigeria. The study hypothesizes that the barriers constraining the practice of the BS profession do not significantly differ among organization practice. The significance of this study is in its ability to pinpoint the barriers constraining BS practice in the industry, hence provide enhanced measures for its implementation and survival in the Nigerian construction industry.

II. THEORETICAL REVIEW

II.1 GLOBAL PERSPECTIVES ON THE BS PROFESSION

The global adoption of the BS profession into the construction and built environment industries may be achieved through improving building surveyor competences in accordance with growing roles and service expectations [4]. Developed countries with advanced construction industries and well-established regulatory frameworks have witnessed widespread adoption of BS practices. Nations such as the United Kingdom, Australia, Hong Kong, and New Zealand have integrated building surveyors as indispensable professionals in their construction processes [2]. In these regions, building surveyors play a significant role in ensuring compliance with building codes, regulations, and sustainability standards. Their active involvement in various construction stages, from pre-construction inspections to safety assessments and project management, has contributed to the successful completion of complex projects with high-quality standards. Conversely, many developing countries still lag behind in recognizing BS as a distinct profession and face challenges in fully embracing its practices [6]. Limited resources, inadequate infrastructure, and less stringent regulatory enforcement can hinder the widespread implementation of BS in these regions. Cultural attitudes and perceptions of the BS profession also influence its adoption across different countries. In some nations, like Malaysia, the role of building surveyors may be less established, leading to difficulties in gaining recognition and trust among stakeholders [10].

II.2 BARRIERS CONSTRAINING THE BS PRACTICE

Over the years, building disasters and advancements in materials and technologies have necessitated the introduction and revision of new standards, building regulations, and legislation, significantly impacting the building surveying profession [8]. While countries like the UK and Malaysia have well-established professional bodies governing the BS profession, such as RICS and RISM, and have recognized building surveyors as integral to the construction industry, challenges persist in widespread adoption [4]. One of the primary barriers to BS practice is the lack of awareness and recognition among stakeholders in the construction industry [2]. Building surveyors often face difficulties in communicating the value of their expertise and the benefits they bring to construction projects. Consequently, clients, contractors, and regulatory authorities may not fully appreciate the contributions building surveyors can make throughout a project's lifecycle. Insufficient regulatory support is also a concern, as some regions may not fully recognize or emphasize the role of building surveyors, leading to fragmented approaches to construction oversight [11] Another challenge is the limited integration of building surveyors into various stages of construction processes. Oftentimes, building surveyors are brought in only for specific tasks, such as building inspections or defect assessments, rather than being involved throughout the entire project lifecycle. Therefore, building surveyors must actively position themselves as proactive partners, advocating for early involvement in projects to ensure better coordination, risk management, and adherence to quality standards [10]. The acceptance of BS profession by the existing construction professions poses another significant barrier to the establishment of the BS profession. It is argued that other professionals in the built environment, such as builders, engineers and architects, possess comparable knowledge and ability and thus, BS may not be necessary. This ongoing confrontation against the establishment of the BS profession hinders its widespread adoption [11]. Furthermore, public recognition, poor understanding of surveyor skills, and limited job opportunities act as barriers to the adoption of building surveying [2]. In cost-sensitive or competitive construction markets, cost considerations may discourage clients or stakeholders from engaging building surveyors. The perception that BS services add an extra financial burden may lead to their exclusion from projects [12].

II.3 MEASURES FOR THE UPTAKE OF BS PROFESSION

One of the key measures for BS practice is actively promoting awareness and education about the profession's value and contributions. [4] advocate for universities to take a strategic educational approach by rethinking academic course material to complement the capabilities required and create a paradigm shift in BS practise and education. [2] adds that collaborating with architects, engineers, contractors, and other construction professionals can lead to more comprehensive project involvement and enhance the value of BS services. Additionally, [13] note that active participation in industry associations and forums provides opportunities for knowledge exchange, professional development, and staying updated with industry trends. Embracing technology and innovation is a crucial survival strategy for building surveyors to remain competitive and efficient in their practices. Adopting Building Information Modelling, laser scanning, drones, and other digital tools can streamline BS processes, improve data accuracy, and enhance the quality of deliverables [14]. Technology-driven solutions not only differentiate building surveyors in the market but also enable them to offer valuable insights to clients, facilitating better decision-making throughout the construction lifecycle. Engaging the government, and private organisations to embark on a strategic enhancement of BS so that the profession achieves local and global recognition [4]. Establishing strong professional networks is vital for building surveyors to gain visibility and credibility within the construction industry. To enhance BS adoption globally, collaboration and knowledge exchange play crucial roles. International organizations, academic institutions, and professional associations can facilitate the transfer of best

practices and expertise across borders [2]. Collaborative research projects, conferences, and training programs can promote the standardization of BS practices and foster mutual learning among professionals worldwide.

III. MATERIALS AND METHODS

This study used a quantitative research design to gather and analyse data from the participants in Lagos metropolis, Nigeria. The population of the study comprised key built environment professionals involved in the construction and maintenance of building infrastructure in the Nigerian construction industry, which comprises Architects, Builders, Civil Engineers, Estate surveyors and valuers, and Quantity surveyors. The sample size refers to the number of participants chosen from the population to represent the entire population [15]. The sample size for this research was determined using Cochran's equation. [16] proposed the following equation to obtain a representative sample for proportions.

$$\text{Cochran's Equation}$$
$$n = \frac{p(1-p)z^2}{e^2} \qquad (1)$$

Where: n = sample size; p = population proportion; e = acceptable sampling error; z = value at reliability level of significance level. For an acceptable error of 10% and reliability level of 95% or significance level 0.05, $z = 1.96$, and assuming a maximum variability in the proportion, p = 0.5. Therefore, the resulting sample size is shown below

$$n = \frac{(0.5)(1-0.5)1.96^2}{(0.1)^2} = 97 \text{ Professionals.}$$

Hence, a sample of 97 professionals was calculated. A total of 130 questionnaires were administered out of which 108 numbers were duly completed and returned, representing an 83.1% response rate. To choose a representative sample of built environment professionals from the population of interest, a simple random selection procedure was utilised. Simple random sampling is a strategy in which every member of the population has an equal probability of being chosen for the study's sample [17]. This helps to ensure that the sample is representative of the population, and reduces the risk of bias in the selection process. The study made use of primary data obtained through a questionnaire survey and secondary data from existing information. The questionnaire was designed to gather information on the prospects, barriers and measures for the uptake of the BS profession in Nigeria. The questionnaire was divided into four sections to cover the various aspects of the research topic. Data collected through the questionnaire was stored electronically and handled in accordance with ethical principles and confidentiality requirements. Section A provided information about the respondents and their orgnisation, including their professional background, professional affiliations, academic qualifications, years of experience, and organisation practice. Section B provided the respondents with questions on the prospects for the uptake of BS profession in Nigeria, on a 5-point Likert scale where 1 represents very poor, 2 represents poor, 3 represents moderate, 4 represents good, and 5 represents very good. Section C of the survey instrument focuses on the barriers constraining the practice of BS on a 4-point scale where 1 represents not significant, 2 represents less significant, 3 represents significant, and 4 represents most significant. While Section D focused on the measures for the uptake of the BS profession amidst other professions in Nigeria using a 5-point Likert scale where 1

represents least effective, 2 represents less effective, 3 represents moderately effective, 4 represents effective, and 5 represents most effective. The structured questionnaires were self-administered to the respondents and were retrieved after completion. Prior to the analysis, the Cronbach's Alpha (CA) reliability test was carried out on the variables of the questionnaire. CA is a statistical method used to evaluate the reliability of an instrument by measuring the extent of shared variance or covariance among its constituent items, in relation to the total variance where CA < 0.6 = poor, 0.6 to < 0.7 = moderate, 0.7 to < 0.8 = good, 0.8 to < 0.9 = very good, 0.9 > = excellent [19]. Table 1 presents a summary of reliability analysis conducted for the research construct. Based on the given Table, the questionnaire used for this study is reliable.

Table 1: The summary of reliability analysis on constructed items.

Section	Constructs	CA	CA based on standardized items	No of items	Strength of association
C	Barriers	0.860	0.856	17	Very good
D	Measures	0.928	0.928	15	Excellent

Source: Authors, (2023).

At the end of the survey period of 8 weeks, 108 copies of the questionnaires were retrieved and processed with the aid of Statistical Packages for Social Sciences (SPSS Version 23.0) and Microsoft Excel. The data collected were analyzed using descriptive statistical tools such as frequencies, percentages, relative index, and ranking. While the inferential results were analysed using the Analysis of Variance (ANOVA) test. The analysis was carried out based on the objectives of the study to provide the expected results. The demographics were analyzed using frequency tables and percentages. Objective one is to determine the prospects of the BS profession in the Nigerian building construction industry was also analysed using frequency table and percentage. Meanwhile, objective two which seeks to determine the barriers constraining BS practice was analysed using relative significant index (RSI).

The RSI is calculated as:

$$\text{RSI} = \frac{\Sigma W}{AN} \qquad (2)$$

Where,

W = weight given to each factor by the respondents and ranges from 1-5, A = the highest weight = 5, N = the total number of respondents [19]. The RSI score varies between 0 and 1. Each factor's resulting value provides an indication of its level of significance.

The third objective proposes measures that can enhance BS practice in Nigeria. The relative importance index (RII) was used in analyzing this objective.

The RII is calculated as:

$$\text{RII} = \frac{\Sigma W}{AN} \qquad (3)$$

Where,

W = weight given to each factor by the respondents and ranges from 1-5, A = the highest weight = 5, N = the total number of respondents [19]. The RII score varies between 0 and 1. Each factor's resulting value provides an indication of its level of importance.

IV. RESULTS AND DISCUSSIONS

IV.1 DEMOGRAPHIC INFORMATION

The demographic information of the respondents and organisations are shown in Table 2.

Table 2 reveals that 16.7% of the respondents have Architecture background, 27.8% have Building background, 31.5% have background in Civil engineering, 8.3% have background in Estate management, while 15.7% have background in Quantity surveying. The result shows that the respondent with civil engineering background constitute a greater percentage of the respondents and were closely followed by respondents with a background in building construction. The other professionals are equally well represented and the information provided can be relied upon. About 16.7% of the sampled respondents are affiliated to Nigerian Institute of Architects (NIA), 27.8% are affiliated to Nigerian Institute of Building (NIOB), 31.5% are affiliated to Nigerian Society of Engineers (NSE), 8.3% are affiliated to Nigeria Institute of Estate Surveyors and Valuers (NIESV), while 15.7% of the respondents are affiliated to Nigerian Institute of Quantity Surveyors. As a result, the research may rely on the respondents' professionalism and commitment to delivering honest and legitimate replies, assuring the trustworthiness of the data obtained. In terms of academic qualification, 4.6% of the respondents have National Diploma Certificates, 22.2% have Higher National Diploma Certificates, 48.1% have Bachelors' degree, 23.1% have Master's degree, while 1.9% have Doctorate degree. This indicates that the respondents have received extensive formal education and specialised knowledge in their respective fields, making them more capable of understanding complex issues and providing thoughtful responses to the research questionnaire. Table 2 further shows the distribution of the years of experience of the respondents. About 71.3% of the respondents have over 10 years of experience in business, while 28.7% have below 10 years of work experience. Thus, majority of the respondents have considerable track record in the industry and the data supplied can be relied upon. Moreover, 27.8% of the respondents work in consulting organisations, 42.6% in contracting organisations, while 29.6% in consulting and contracting organisations. The contracting organisations constitute a greater percentage of the organisations surveyed. The results indicate a high degree of overlap and integration between these two practices within the organizations surveyed.

Table 2: Demographic Information.

Description	Frequency (N)	Percentage (%)
Professional Background		
Architecture	18	16.7
Building	30	27.8
Civil engineering	34	31.5
Estate management	9	8.3
Quantity surveying	17	15.7
Total	108	100.0
Professional Affiliation		
NIA	18	16.7
NIOB	30	27.8
NSE	33	30.6
NIESV	10	9.3
NIQS	17	15.7
Total	108	100.0
Academic Qualification		
National Diploma	5	4.6
Higher National Diploma	24	22.2
Bachelors	52	48.1
Masters	25	23.1
Ph.D.	2	1.9
Total	108	100.0
Years of Experience		
1-5 Years	17	15.7
6-10 Years	14	13.0
11-15 Years	41	38.0
16-20 Years	20	18.5
21 years and above	16	14.8
Total	108	100.0
Organisation Practice		
Consulting	30	27.8
Contracting	46	42.6
Consulting & contracting	32	29.6
Total	108	100.0

Source: Authors, (2023).

IV.2 PROSPECTS OF THE BS PROFESSION IN NIGERIA

The viewpoints of the respondents on the prospects of BS profession in the Nigerian construction industry are shown in Table 3. The response rates for the potential of embracing the BS profession by the professionals are as follows. 1.9% of the respondents sees a very poor potential of the BS practice in the Nigerian construction industry, 25.9% of the respondents indicated "poor" prospect, 23.1% indicated a "moderate" propsect, 32.4% indicated "good", while 16.7% indicated "very good". Moreover, the mean value for the prospects of BS profession in the Nigerian construction industry was interpreted using the following scale; $1.00 \leq MS < 1.49$ represents 'Very poor', $1.50 \leq MS < 2.49$ represents 'Poor', $2.50 \leq MS < 3.49$ represents 'Moderate', $3.50 \leq MS < 4.49$ represents 'Good' and $4.50 \leq MS \leq 5.00$ represents 'Very good'. The mean score value as calculated in Table 3 is 3.36. This suggests that the respondents have a moderate viewpoint toward BS uptake in the building construction industry. According to the findings, the majority of respondents feel the BS profession has a moderate potential for practice in the Nigerian built environment. This moderate disposition among professionals towards the BS profession validates one of the barriers constraining BS adoption in Nigeria. This reflects the resistance that the BS is facing from existing built environment professionals.

Table 3: Prospects of BS profession in Nigeria.

Type	Response rate (%)					SD	MS
	1	2	3	4	5		
Prospect	1.9	25.9	23.1	32.4	16.7	1.098	3.36

Note: 1= very poor; 2= poor; 3= moderate; 4= good; 5= very good; SD= Standard Deviation; MS= Mean Score.
Source: Authors, (2023).

IV.3 BARRIERS CONSTRAINING BS PRACTICE IN NIGERIA

Table 4 shows the descriptive analysis result of barriers constraining BS practice in the Nigerian construction industry. The objective of the study was to determine the barriers constraining the practice of BS in the Nigerian construction industry. In order to achieve the objective, seventeen barriers were presented to each respondents through the questionnaire. The respondents were asked to rate the level of significance of each barrier using a 4-point rating scale. Where 1 represents not significant, 2 represents less significant, 3 represents significant, and 4 represents most significant. The results of the analysis is presented in Table 4. To interpret the results, a graduated scale of 1-4 was used and the RSI were calculated. The RSI were calculated using the scale of 0.76 and above to indicate most significant, 0.67 – 0.75 indicates significant, 0.45 – 0.67 to mean less significant, and below 0.45 indicates not significant. The result shows that the respondents rank the lack of public awareness on the profession (RSI=0.90), resistance from existing built environment professionals

(RSI=0.89), lack of BS programme in tertiary institutions (RSI=0.86), lack of patronage by stakeholders (RSI=0.84), unwillingness of other professions to specialize (RSI=0.80), inadequate skills to produce a building survey report (RSI=0.79), insufficient workshops and trainings on BS and the lack of professional recognition from other professions in a tie (RSI=0.77) respectively were the most significant barriers constraining the practice of BS in the Nigerian built industry. The significant barriers according to the respondents are failure to adapt to new work techniques (RSI=0.73) and the construction industry resistance to change (RSI=0.68). The barriers which the professionals perceive as less significant were cultural attitudes and perceptions of the BS profession (RSI=0.59), lack of cost data on the previous work undertaken (RSI=0.56), inadequate building codes and legislation (RSI=0.54), non-involvement of Building surveyors throughout the entire project life cycle (RSI=0.53), unfavorable perceptions of homebuyers to engage building surveyors (RSI=0.50), and high cost of conducting a building survey (RSI=0.45). While the lack of quality assurance to oversee survey activities (RSI=0.40) was not significant. The findings on the lack of public awareness of the BS profession conforms with those of [2] and [4] who discovered that the barriers constraining BS practice is the lack of public awareness and recognition among stakeholders in the construction industry. Besides, the authors corroborate the research findings on the lack of BS programme in tertiary institutions with the notion that the BS profession is offered as a course in Architecture, Engineering and Construction in tertiary institutions in Nigeria and not a degree program. [6] further buttressed that many developing countries still lag behind in recognising BS as a distinct profession and face challenges in fully embracing its practices. Also, the barrier on the resistance from existing built environment professionals conforms to the results of [11] that the ongoing confrontation against the establishment of the BS profession by other professions hinders its widespread adoption. Furthermore, the barrier on inadequate skills to produce a building survey report agrees with the findings of [2] who noted that poor understanding of surveyor skills is a barrier constraining the practice of BS. Moreover, the findings on inadequate building codes and legislation corroborate the results of [11] that insufficient regulatory support from the government is a barrier constraining BS practice. Meanwhile, the findings on the high cost of conducting a building survey supports the results of [12] that BS services add an extra financial burden leading to their exclusion from project. The barrier on the non-involvement of building surveyors throught the entire project lifecycle conforms to the findings of [10] that limited integration of building surveyors into various stages of construction is a key barrier to BS practice uptake. The findings on the lack of patronage by stakeholders conform with the results of [9] that the BS profession is not being practiced. The barrier on the lack of patronage by stakeholders align with the findings of [2] that the lack of understanding of the building surveyor's skills, and limited job opportunities act as barriers constraining BS practice.

Table 4: Barriers constraining the practice of BS in Nigeria.

Barriers Constraining BS Practice in Nigeria	1	2	3	4	N	SD	RSI	R
Lack of public awareness on the profession	0	5	34	69	108	.581	0.90	1
Resistance from existing built environment professions	1	10	23	74	108	.700	0.89	2
Lack of building surveying programme in tertiary institutions	0	4	54	50	108	.567	0.86	3
Lack of patronage by stakeholders	1	11	46	50	108	.699	0.84	4
Unwillingness of other professions to specialize	0	13	61	34	108	.633	0.80	5
Inadequate skills to produce a building survey report	12	17	23	56	108	1.054	0.79	6
Insufficient workshops and trainings on building surveying	5	20	46	37	108	.846	0.77	7

Barriers Constraining BS Practice in Nigeria	1	2	3	4	N	SD	RSI	R
Lack of professional recognition from other professions	1	21	56	30	108	.714	0.77	7
Failure to adapt to new work techniques	8	26	42	32	108	.912	0.73	9
The construction industry's resistance to change	6	30	60	12	108	.734	0.68	10
Cultural attitudes and perceptions of the building surveying profession	12	50	43	3	108	.713	0.59	11
Lack of cost data on previous works undertaken	11	61	35	1	108	.639	0.56	12
Inadequate building codes and legislation on the building surveying practice	10	72	25	1	108	.583	0.54	13
Non-involvement of building surveyors throughout the entire project lifecycle	21	59	22	6	108	.782	0.53	14
Unfavourable perceptions of homebuyers to engage building surveyors	22	69	14	3	108	.670	0.50	15
High cost of conducting a building survey	30	52	25	1	108	.742	0.45	16
Lack of quality assurance to oversee survey activities	60	33	13	2	108	.773	0.40	17

Note: 1= not significant; 2= less significant; 3= significant; 4= most significant; N= frequency; SD= standard deviation; RSI= relative significant index; R= ranking.

Source: Authors, (2023).

IV.4 EFFECTIVE MEASURES FOR BS UPTAKE IN NIGERIA

Table 5 shows descriptive results of enhanced measures for the uptake of the BS profession in the Nigerian construction industry. To quantify the measures for BS uptake, fifteen measures were presented to each respondents through the questionnaire. The respondents were asked to rate the level of importance of each measures using a 5-point Likert scale. Where 1 represents not eefective, 2 represents slightly effective, 3 represents moderately effective, 4 represents effective, and 5 represents most effective. The results of the analysis is presented in Table 5. To interpret the results, a graduated scale of 1-5 was used and the RII was calculated. The RII were calculated using the scale: 0.81-1.00 implies most effective, 0.61-0.80 implies effective, 0.41-0.60 moderately effective, 0.21-0.40 implies less effective, and 0.00-0.20 implies least effective. This decision rule for the RII is adapted and modified from [20]. The rsults confirmed that developing better relations with other professions (RII=0.95), introducing BS programme in tertiary institutions (RII=0.92), raising awareness on the significance of conducting building survey (RII=0.88), organisation of workshop and training programs (RII=0.85), stakeholder's engagement (RII=0.84),

adjusting services (RII=0.83) and ensuring students gain hands-on experience (RII=0.82) are the most effective measures for BS uptake in Nigeria. The results further showed that leveraging tecchnology to enhance precision and effectiveness (RII=0.78), government legislation and supports to sustain the profession (RII=0.75), marketing strategy development, and control of BS procedures (RII=0.74) respectively, emphasizing health and safety when conducting a survey (RII=0.72), implementing quality assuarance and control during survey procedures and documenting previous surveys conducted (RII=0.66) respectively and seeking knowledge of the contractual aspect of the profession (RII=0.64) are effective measures for BS uptake in the Nigerian construction industry. All the evaluated measures are effective to enhance the uptake of the BS profession irrespective of the RII ratings of the measures. [4, 21] highlight raising awareness as key measure for BS practice admist other professions. The findings of [13, 14] corroborate the findings that leveraging technology to enhance precision and effectiveness are crucial measures for the uptake of BS practice. [21] support the findings of this study that introducing the BS program in tertiary institutions is a key measure to BS practice. Meanwhile, [2] agree that developing better relations by collaborating with other built environment professionals is a key measure for the uptake of the BS professio.

Table 5: Enhanced measures for the uptake of BS in Nigeria.

Enhanced measures for BS uptake	1	2	3	4	5	N	SD	RII	R
Developing better relations with other professions	1	1	1	18	87	108	.613	0.95	1
Introducing building surveying programme in tertiary institutions	0	0	2	38	68	108	.527	0.92	2
Raising awareness on the significance of conducting a building survey	1	4	5	39	59	108	.820	0.88	3
Organisation of workshops and training programs	0	3	16	42	47	108	.804	0.85	4
Stakeholder's engagement	1	1	22	35	49	108	.862	0.84	5
Adjusting services	0	1	27	35	45	108	.830	0.83	6
Ensuring students gain hands-on experience	1	17	7	29	54	108	1.132	0.82	7
Leveraging technology to enhance precision and effectiveness	0	10	21	47	30	108	.917	0.78	8
Government legislation and supports to sustain the profession	4	12	24	33	35	108	1.132	0.75	9
Marketing strategy development	3	13	31	30	31	108	1.101	0.74	10
Control of building surveying procedures	3	8	34	39	24	108	.994	0.74	10
Emphasizing health and safety when conducting a survey	1	18	28	39	22	108	1.024	0.72	12
Implementing quality assurance and control during surveying procedures	3	21	33	40	11	108	.994	0.66	13
Documenting previous surveys conducted	1	8	62	29	8	108	.759	0.66	13
Seeking knowledge of the contractual aspect of the profession	13	12	33	41	9	108	1.131	0.64	15

Note: 1= least effective; 2= less effective; 3= moderately effective; 4= effective; 5= most effective; N= frequency; SD= standard deviation; RSI= relative significant index; R= ranking.

Source: Authors, (2023).

IV.5 ANOVA TEST RESULT ON BARRIERS CONSTRAINING THE PRACTICE OF BS

Table 6 shows the inferential results of barriers constraining BS practice in the Nigerian construction industry. To further analyze the barriers constraining the uptake of BS profession, an hypothesis was postulated as follows:

Ho_1: The barriers constraining the practice of the BS profession do not significantly differ among organization practice.

It can be seen from the results of the one-way ANOVA presented in Table 6, there is no significant difference on the perception of the respondents among the organisation of practice on 15 out of the 17 hypothesized barriers constraining the BS profession with p-values greater than 0.05 (P>0.05). Barriers constraining the practice of BS profession for which there is no significant difference and for which the null hypothesis was accepted includes; lack of professional recognition from other professions, lack of public awareness on the pofession, high cost of carring out a building survey, non-involvement of building surveying throughout the entire project lifecycle, lack of quality assurance to oversee survey activities, resistance from existing built environment professions, inadequate skills to prepare a building survey report, unfavorable perceptions of homebuyers to engage surveyors, the construction industry's resistance to change, inadequate building codes and legislation on building surveying practice, lack of cost data on previous work undertaken, insufficient workshops and trainings on building surveying, lack of building surveying programmes in tertiary institutions, lack of patronage by stakeholders, and the unwillingness of other professions to specialise. Whereas, barriers constraining BS profession for which there is significant difference with p-values less than 0.05 (p<0.05) and for which the null hypothesis was rejected includes; cultural attitudes and perceptions of the building surveying profession and failure to adapt to new work techniques.

Table 6: ANOVA Test Results on the barriers constraining BS profession among organisation practice.

Barriers	DFb	DFw	DFt	F	P-value	Remark	Decision
Lack of professional recognition from other professions	2	105	107	2.262	.109	NS	Accept
Lack of public awareness on the profession	2	105	107	.355	.702	NS	Accept
High cost of carrying out a building survey	2	105	107	.739	.480	NS	Accept
Non-involvement of building surveying throughout the entire project lifecycle	2	105	107	.026	.974	NS	Accept
Cultural attitudes and perceptions of the building surveying profession	2	105	107	6.829	.002	S	Reject
Failure to adapt to new work techniques	2	105	107	7.648	.001	S	Reject
Lack of quality assurance to oversee survey activities	2	105	107	.637	.531	NS	Accept
Resistance from existing built environment professions	2	105	107	.441	.645	NS	Accept
Inadequate skills to produce a building survey report	2	105	107	.224	.800	NS	Accept
Unfavourable perceptions of homebuyers to engage building surveyors	2	105	107	.738	.481	NS	Accept
The construction industry's resistance to change	2	105	107	.539	.585	NS	Accept
Inadequate building codes and legislation on building surveying practice	2	105	107	.738	.482	NS	Accept
Lack of cost data on previous works undertaken	2	105	107	.086	.918	NS	Accept
Insufficient workshops and trainings on building surveying	2	105	107	.121	.887	NS	Accept
Lack of building surveying programme in tertiary institutions	2	105	107	.781	.460	NS	Accept
Lack of patronage by stakeholders	2	105	107	.167	.846	NS	Accept
Unwillingness of other professions to specialize	2	105	107	.383	.683	NS	Accept

DFb represents degree of Freedom between groups, DFw represents degree of Freedom within groups, DFt represents degree of Freedom total, NS represents no significant difference, S represents Significant difference. Note: P is significant at P ≤ 0.05.

Source: Authors, (2023).

V. CONCLUSIONS

Based on the findings of this study, the study draws the following conclusions.

There is a moderate disposition among the respondents on the possible implementation of the BS profession in the construction industry. This implies that as the programme is a relatively new one that is not being offered by tertiary institutions in the country, there are currently no institution in place that make it a degree course, thus the professional are hesitant. Despite this, if efforts are made towards eliminating the barriers constraining the uptake of BS and the proposed measures are implemented, this tendency should reverse, as it has in countries where the BS profession is being practised.

The study further identified seventeen (17) barriers constraining effective implementation of the BS profession in Nigeria. The topmost three significant barriers among them are the lack of public awareness on the profession, resistance from existing built environment professionals, and the lack of BS programme in tertiary institutions. The implication of the lack of public awareness of the BS profession is that it impedes long-term growth of this critical area of expertise thereby resulting in insufficient building upkeep, hazardous constructions, and poor resource utilization. In the same vein, the findings on the resistance from existing built environment professionals implies that the BS profession cannot be fully embraced due to opposition from existing construction professionals. As a result, this limits holistic project insights thereby hampers accurate assessment, maintenance, and safety, which leads increased costs and potential oversights. Also, the

implications of the findings on the lack of BS programme in tertiary institutions constrain the number of professional employees entering the industry. The unavailability of the BS programme in tertiary institutions impedes expansion of the sector, hinders accurate construction evaluation, and restricts sustainable development.

Moreover, the study proposed fifteen effective measures for the uptake of BS profession in Nigeria. Topmost 3 measures are developing better relations with other professions, introducing BS programme in tertiary institutions, and raising awareness on the significance of conducting building survey. The implication of the first measure on deveolping better relations with other professions is that it strengthens institutional ties among the professions, establish relationships that drive collective growth, increase productivity, and foster a cohesive professional community that respects each profession's unique contributions. Meanwhile, the implication of introducing BS degrees is that institutions which provide BS degrees give their students specialized knowledge for the building sector. Graduates will be better equipped to evaluate structures, oversee maintenance, and improve safety and by closing the knowledge gap, sustainability and industry standards are ensured, and professionals are produced. Furthermore, the findings on raising awareness on the significance of conducting building surveys implies better protection of the general public, encourages openness, and raises industry standards, which eventually results in more secure and satisfying property transactions.

Based on the conclusion drawn, the study therefore recommends that increased awareness of the BS profession is needed. This may be accomplished through workshops, internet advocacy, and seminars that promote the benefits of BS. Besides, building surveyors should improve their relationships with existing professional bodies in the construction sector. This may be accomplished through establishing periodic forums for idea-sharing and collaboration. Moreover, the BS programme should be offered as degree courses at Nigerian tertiary institutions. This will be achievable if the Nigerian University Commission and other players in the country's education sector work together to design an all-encompassing curriculum for BS.

VI. AUTHOR'S CONTRIBUTION

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