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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

# Monitoring of urban indoor farming, case study: tomboy tomatoes.

*Submitted in partial fulfilment of the requirements for the award of*

**MASTER OF SCIENCE IN INTERNET OF THINGS**

**WIRELESS INTELLIGENT SENSOR NETWORKING**

**(MSC in IoT-WISENET)**

*Submitted by*

**MURANGWA Aimable - Reg. No. 220014131**

**Submission Date: April, 2022**

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*Under the supervision of*

Supervisor: **Dr. NDASHIMYE Emmanuel**

Co-Supervisor: **Dr. NSENGIYUMVA Philbert**

**April 2022**

# DECLARATION

I, Aimable Murangwa, declare that this research project entitled "Monitoring of urban indoor farming, case study: tomboy tomatoes" is my original work based on the research and implementation of its prototype. All resources used in this research project have been quoted in references. The research project was done as part of fulfilling the requirements for being awarded a MSC in Internet of things with specialization in Wireless Intelligent Sensors Networks at the African Center of Excellence in Internet of Things (ACEIoT), College of Science and Technology (CST), University of Rwanda (UR).

.................................... 06/12/2021

AIMABLE MURANGWA ........................................ DATE

# BONAFIDE CERTIFICATE

This is to certify that this dissertation report is a record of the original work done by Mr. Aimable MURANGWA (Ref: 220014131), graduate in MSc in Internet of Things (IoT) with major in Wireless Intelligent Sensors Networks (WISeNet), at University of Rwanda – College of Science and Technology in the African Center of Excellence in Internet of Things (UR/CEST/ACEIoT). I certify that the work reported here does not form a part of any other research project.

| Supervisor: | Co-Supervisor: |
|---|---|
| | 06/07/2022 |
| Dr. Emmanuel NDASHIMYE | Dr. Philibert NSENGIYUMVA |

**The Head of Masters studies and Training ACEIoT**
Dr. James RWIGEMA
Signature: 06/07/2022

# ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to support offered to me in various ways and made it possible to complete this Research project. Special thanks go to my supervisors: Dr. Ndashimye Emmanuel, and Dr. Nsengiyumva Philbert for their direction, guidance and advices during my thesis writing journey and for their patience and understanding. I would like to acknowledge with much appreciation the University of Rwanda for granting me the opportunity to study for masters in IoT.

I thank and appreciate the center's staff, my lecturers, and my classmates for their crucial role that shaped my experience at the university.

Finally, I wish to express my very profound gratitude to my family for their encouragement and support; special thanks to my wife Adeline for her diligent patience.

Thank you.

# ABSTRACT

Monitoring of urban indoor farming is an alternative to the traditional farming of outdoor farms that yield a low harvest due to climate change, dependence on rainfall, soil degradation, much water need for irrigation, requires fertilizers, pesticides, prone to soil diseases, plants diseases, pests, erosion, floods etc. Those problems hinder the investment in this type of farming due to risks associated with it. Growing plants indoor, offers benefits such as being practiced on small space, can be done in proximity to the harvest buyers in cities, attracts investments and offer new job opportunities. Those benefits make it suited to urban places. Such farming type is believed to be the farming of the future, and it is attracting the attention of researchers, technology innovators and economic actors. Urban indoor agriculture is practiced largely in developed countries, while developing countries are still lagging behind. However, the rise in technology is stimulating acquisition of indoor farms, which use hydroponic growing system.

Rwanda, being one of the developing countries, is embarking on modernizing its agriculture sector. The country is prioritizing the activities of growing vegetables, fruits, and cassava as well as sweet potatoes by means of hydroponic farming technique. This research project is carried out as a contribution to the availability of urban indoor prototype of tomboy tomatoes that can be used in Kigali. Internet of things is applied for the sake of adding monitoring features to the farm. The benefits of combining indoor farming with Internet of things (IoT) are: the possibility of adding devices, such microcontrollers, sensors, and actuators, Wireless module to indoor grow environment in the sake of having a real time farm monitoring and yielding more. This is done using a small space, less water, having a full monitoring of crops nutrients and its growth.

In Kigali City, agricultural activities are carried out in valleys and parts of the city, which are less urbanized; a big number of actors do those activities in outdoor setting. Early indoors farms focused on mushrooms growing. However, with the rapid urbanization of the city new initiatives in indoor farming are emerging and are dominated by foreign investors. For instance Holland GreenTech, a company operating in Rwanda, Uganda and Kenya; offers greenhouse among its services (Greentech, 2021). In interview with GreenTech's receptionist, the company sell greenhouses with soil based farming to customers in Kigali and other provinces. One greenhouse cost around 8 Million Rwandan Francs as many materials to make them are imported. Although expensive, this is a good sign showing that with the rapid urbanization of the Kigali city, indoor farms will increase in number and will be using Internet of Things technology. This research study has a focus on indoor farming for tomboy tomatoes in urban places, and looks for adding IoT technology to produce an indoor farm prototype.

Enabling factors for indoor farming of tomboy tomatoes using IoT in kigali city there is 3G and 4G networks, the availability of potential buyers of tomatoes year-round, investors, labor, materials, water and tanks to keep it. Local research on the use of Internet of things for indoor farming aiming at availing technology based local solutions are still rare. For this reason, this study builds on that background and propose a homegrown technology offering efficient method and proper control of indoor growing environment for tomboy tomatoes. The indoor grow method selected is Ebb and Flow; the environment parameters monitored in this project are Humidity, temperature, PH, nutrients flow, light.

**Keywords:** Internet of Things (IoT), Hydroponic, PH Sensor, Arduino Microcontroller, GSM Module.

# ABBREVIATIONS AND ACRONYMS

ACEIoT : African Center of Excellence in Internet of Things

CST : College of Science and Technology

UR : University of Rwanda

WISeNet : Wireless Intelligent Sensor Networks

FAO : Food and Agriculture Organization

IOT : Internet of things

NTF : Nutrient film technique

VF : Vertical farming

VCC : Voltage Common Collector

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# CHAPTER ONE: INTRODUCTION

## 1.1 Background to the study

The number of people around the world who live in and around cities is increasing rapidly. The "State of the World Cities" by UN- Habitat (2004) predicts that by 2030, 60 percent of the world's population will live in cities (Veenhuizen, 2006). This growth will requires countries to look for strategies to increase agricultural harvest to feed that population in urban places. FAO has estimated that, in order to meet food demand in 2050, annual world production of crops and livestock will need to be 60% higher than it was in 2006 (Garrido, 2018). Increasing foodstuff to feed the growing population in cities is an activity that can take place in urban places; and has historical background.

Urban agriculture existed earlier in 10,000 years ago, where civilizations in Egypt, China, and India illustrated farming as part of the daily lifestyle in the remnants that have been preserved and recorded by anthropologists and scientists (Philips, 20013). Development continued at the level of bringing soilless farming activities indoor. Following the outbreak of world war in 1939, soilless gardening received a further stimulus. In that time, both the American Army and the Royal Air Force opened hydroponic units at military bases to feed their troops. By the 1950s, there were viable commercial farms in America, Europe, Africa and Asia (Shrestha, 2017).

Due to the fact that developed countries have many viable indoor farms, their urban citizens get flesh food such as tomatoes, lettuce, cucumbers and peppers as well as ornamental crops such as herbs, roses, freesia and foliage plants. The current situation in developing countries does not exclude farming in urban places. The livelihood of a large number of people in cities in developing countries, especially the poor and women, depends completely or partly on urban agriculture (Veenhuizen, 2006). This dependence on urban agriculture shows the usefulness and need of the improvement urban farming activities. Advantages are numerous: increasing food availability, job creation, and social inclusion of disadvantaged groups, urban greening and maintenance of green open spaces. As the urban traditional farming alone cannot help to feed city residents in developing countries, there is a need of taking into consideration of other farming types such us indoor farming with hydroponic systems.

In Rwanda, through the family contract, since 2006 citizens were sensitized to own vegetables' gardens "Uturima tw'igikoni" (Sabiiti, 2021). Such gardens can exist in the urban and yield more harvest by means of technology and indoor farming. A part that, in valleys of the city, agricultural farms largely used of growing vegetables, other farming activities are practiced in less urbanized areas of the city. The farming in Kigali city, is not limited to the outdoor farm setting, indoor farming of mushrooms does exists. Other kind of emerging indoor farms are done in greenhouses whereby crops are planted in soil and grow in a covered environment. The government of Rwanda pledged to invest Rwf 8.2 billion in research infrastructure by upgrading and constructing greenhouses and hydroponic facilities by 2024 (Nkurunziza, 2021). This research project is undertaken as a contribution to the journey leading to an increased number of urban indoor farms that use hydroponic farming system for growing Tomboy tomatoes in Kigali City.

With farming indoor using hydroponic growing system, the aim set is to reap the benefits such system offers. Those benefits include but not limited to the use of small space, less water, harvest in all seasons, possibility to use abandoned or unused properties, independence to outside whether conditions. While the problem of climate change and drought is likely to continue (Adele Samami, 2010); using hydroponics in urban places enables to growing food in proximity of the consumers, reduce fuel consumption in food transport; and add on varied efforts of protecting the world.

This study sought to help to have a greater understanding of indoor farming and avail an adapted prototype matching the need Kigali city's residents. The farming type selected by the research is hydroponic farming system with Tomboy Tomatoes. The choice of Tomatoes crop is based on the existing local markets and exports of tomatoes done to DRC Congo, Tanzania, Sudan, Uganda and Burundi. The research project suggests the integration of Internet of things (IoT) to the indoor grow environment consisted on adding devices such as microcontrollers, sensors, wireless modules to the farm in the sake of monitoring of the growing environment' parameters such as temperature, pH, electrical conductivity, oxygen content, among others.

The reviewed literatures state the technology used in indoor farming and the benefits of it compared to the traditional farming. However, little is said on the suitable solution for urban places in developing countries. Thus, a need of making a porotype that is adapted to the context of Kigali city.

## 1.2 Statement of the problem

In 1960, the population living in cities was around 1 billion; in 1986, it doubled, and in 2005 was 3.2 billion (Bassi, 2017). On the African continent, urban population urban growth rate is 3.5%, which is the highest among all continents (Shukla, 2019). For Kigali City, the urban population is growing at 3.34% rate, which is far different to the one of the continent (Worldpopulationreview, 2021). Following that pattern, the challenge of feeding urban population will be there for decades in developing countries.

This is also true in Kigali city, where the number of people joining the city from different corners of the country increases daily. Such movements lead to the reduction of land for cultivation. The challenge to address is the one of making available enough agricultural harvest to feed urban residents using the available space.

Looking to the existing farming types in the Kigali city, the big part is accomplished in traditional style, on a small land. In addition to that, other problems such as climate change effects, limited technology, erosions, dependence on rainfall contribute to the low yield generated by traditional farms. People directly affected by such problems are city residents because the shortage in harvest leads the increase of the cost of living in the city. The food markets and industries processing food are also affected.

It is certain that alternative solutions to that concern of availing enough food for urban can be developed. An experiment was carried out on a small structure of 2m x 4m at SOS Technical high school compound in May 2021 with Tomboy tomatoes' variety. It was observed that the watering plants from a sewage system's water lead to death of plants died in first three days. It was also observed that the adoption of water from a water tap was leading to huge use of water for those tomatoes. Even with those challenges, in July 2021 after 3 months, new plants of the same variety afforded to yield around 52 tomatoes' fruits per plant. Following two harvests, the remaining tomatoes started to roast when the rain season started. This was done in outside setting, and required the presence of human being to always monitor the irrigation. The observed problems in such small experiment are not far different from what farmers in Kigali face when they conduct their farming activities using the outdoor farm setting. From such experiment, an idea of conducting a research project was born. The aim is to avail alternative, which grows Tomboy tomatoes indoor; using hydroponic farming system. Such farming can help to complement the existing traditional farming type and contribute significantly the food increase. Other expected outcomes are the possibility to harvest the year round and improving quality of crops**.** This farming type being new in Rwanda, and needs to be supported with research in order to come up with hydroponic systems adapted to the Kigali context.

## 1.3Study Objectives

### 1.3.1 General objective

The main aim of this study is to design an IoT prototype for indoor farm on the Tomboy tomatoes crop. The new system will offer remote access to the user and allow taking required decisions. The grow method selected is Ebb and Flow (Flood and Drain) hydroponic.

### 1.3.2 Specific objectives

The following objectives will be used to realize the study:

1. Investigate existing indoor farming
2. design and implement an IoT system for monitoring the grow environment of Tomboy
3. Test and evaluate the performance of the proposed IoT system.

## 1.4 Significance of the research

This research examined issue of feeding the urban population that is occurring in developing countries, the same issues have increasing tendencies to keep developing in the future. The focus was set to Kigali as a city belonging to small country in which land is a concern and pressed with population growth. The study focussed at helping to avail locally made prototype that can be used by urban farmers to grow tomboy tomatoes in small land. The outcomes of the study will be useful to whoever wants to invest in hydroponic farming of tomboy tomatoes, policy makers, researchers, owners of tomatoes processing factories, and traders.

## 1.5 Hypothesis

Urban farmers doing agricultural activities in outdoor setting faces problems such suing much water in irrigation, crop damage due to heavy rain, soil diseases, plants diseases, pests leading to low yield of their farms. Based on suggestion given by research respondents, applying internet of things (IoT) to indoor farms will improve their farming activities and reduce problems they facing in doing farming in outdoor setting and enables them to have more yield and more income. A prototype for growing tomboy tomatoes hydroponically will help to collect data in the grow environment using sensors, and respond to it in automated way, it will be also able transmit information to the farm owner using GSM module. This will improve significantly the farming activities of Tomboy tomatoes in Kigali City and contribute to the handling of increasing population in urban place looking for food and enables the creation of new jobs in environment friendly way.

## 1.6 Delimitation of the study

This study focussed on small farmers who practice farming on small land. The crop type is Tomboy tomato variety; selected among many crops that can be grown indoor with hydroponic farming type. The implementation focussed on a prototype with the size, features selected match with available materials and research budget.

## 1.7 Definition of significant terms used in the study

### Urban agriculture

Urban agriculture can be defined as the growing of plants and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, and the processing and marketing of products (Veenhuizen, 2006).

### Hydroponic

Hydroponic is defined as "the science of growing or the production of plants in nutrient-rich solutions or moist inert material, instead of soil". The term hydroponics has its derivation from the combination of two Greek words, hydro meaning water and ponos meaning labor, i.e., working water (Jr., 2005).

Professor William Gericke coined the word hydroponics in the early 1930s; to describe the growing of plants with their roots suspended in water containing mineral nutrients. This technique helps to grow plants in nutrient solutions with or without the use of an inert medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, coconut fibre, etc

### Hydroponic systems

a. **Wick system,**

It is a simplest hydroponic system requiring no electricity, pump and aerators

b. **Drip system,**

Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump. The drip hydroponic system is widely used method among both home and commercial growers.

c. **Ebb-flow system,**

This is first commercial hydroponic system, which works on the principle of flood and drain. Nutrient solution and water from reservoir flooded through a water pump to grow bed until it reaches a certain level and stay there for a certain period of time so that it provides nutrients and moisture to plants.

d. **Deep water culture system**

In deep water culture, roots of plants are suspended in nutrient rich water and air is provided directly to the roots by an air stone.

e. **Nutrient film technique (NFT)**

In this system, water or a nutrient solution circulates throughout the entire system; and enters the growth tray via a water pump without a time control.

The study has the scope of Hydroponic system with Wick system for tomato crop. The tomato crop selected because it needed on daily basis in household's consumption.

## 1.8 Organisation of the study

The first chapter deals with the introduction and has the background to the study, statement of the problem, objectives, hypothesis, limitation of the study, definitions of key terms. The second chapter offered a literature review on indoor farming, farming types, technology used in hydroponic etc. The third chapter covered the research methodology of the system implementation. The fourth chapter contains the system design, implementation and experimental results. The fifth chapter dealt with the general conclusion and recommendations.

## 1.9 Thesis contribution

The contribution of this thesis can be set in three categories: Technical, academic, Socio-economic categories. Academically, this research will serve as the basis for future researches in IoT applied to the agriculture sector of activities.

Technically, this work will prove the possibility of coming up with a technology that helps to monitor indoor farms in a local context with the possibility of sharing the related information wirelessly.

For the socio-economic part, farms that may be build based on this research will contribute the creation of new jobs as a result of new farmers joining indoor farming activities, the increase in yield of Tomboy Tomatoes will help meet the food demand of tomatoes for urban residents, related sales will increase revenues from taxes whenever profit is realized on the side of farmers.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

The population keeps increasing in urban places; both urban farming and indoor hydroponic systems can be amplified to supply significant amounts of food, grown near population centers with a far smaller land and water footprint (Ahuja, 2016). Contrary to that, farms which are far from cities pave ways of the consumption of much fuel in the transport food. John Adair Carroll stated that in today's world, millions of gallons of diesel fuel/gasoline are consumed daily bringing various food crops from farms, orchards, and dairies directly to all cities (Carroll, 2018). Researchers have advanced myriad methods of urban and vertical farming in the hopes of contributing to the sustainable food production (Patten, 2004).

This chapter provide an appraisal of previous studies related to urban indoor farming. It highlights the technology related to grow crops indoor and justify the need for this study.

## 2.2 Indoor farming using hydroponic

The literature review shows that indoor farms including hydroponic growing systems are used to grow primarily lettuce, leafy greens and microgreens. These systems are very efficient with water, so much that the different farms report that they use only 1-10% of the water used by traditional farming methods (Proksch, 2017). Previous research states that hydroponics use a form of soilless agriculture; and defined hydroponic as method of growing plants in a water-based, nutrient-rich solution (Editor, 2018). With this technique, plant roots are suspended in either a static, continuously aerated nutrient solution or a continuous flow or mist of nutrient solution (Jr., 2005).

This farming type is not new; according the same author, the growing of plants in nutrient-rich water has been practiced for centuries. For example, the ancient Hanging Gardens of Babylon and the floating gardens of the Aztecs in Mexico were hydroponic in nature (Jr., 2005).

### 2.2.1 Hydroponic advantages

In 1981, Jensen listed the advantages and disadvantages of the hydroponic technique for crop production, many of which are still applicable today (Jr., 2005). Those advantages are:

a. Crops can be grown where no suitable soil exists or where the soil is contaminated with disease.

b. Labor for tilling, cultivating, fumigating, watering, and other traditional practices is largely eliminated. c. Maximum yields are possible, making the system economically feasible in high-density and expensive land areas.

d. Conservation of water and nutrients is a feature of all systems. This can lead to a reduction in pollution of land and streams because valuable chemicals need not be lost.

e. Soil borne plant diseases are more readily eradicated in closed systems, which can be totally flooded with an eradicant.

f. More complete control of the environment is generally a feature of the system (i.e., root environment, timely nutrient feeding or irrigation), and in greenhouse-type operations, the light, temperature, humidity, and composition of the air can be manipulated.

g. Water carrying high soluble salts may be used if done with extreme care. If the soluble salt concentrations in the water supply are over 500 ppm, an open system of hydroponics may be used if care is given to frequent leaching of the growing medium to reduce the salt accumulations.

h. The amateur horticulturist can adapt a hydroponic system to home and patio-type gardens, even in high-rise buildings. A hydroponic system can be clean, lightweight, and mechanized.

Hydroponics is superior to growing in soil because you can give plants maximum levels of the exact nutrients they need. Precise control of nutrient uptake makes it possible to reap higher yields faster (Patten, 2004). Though it presents many advantages, it has also drawbacks.

### 2.2.2 Disadvantages (Jr., 2005):

a. The original construction cost per acre is great.

b. Trained personnel must direct the growing operation. Knowledge of how plants grow and of the principles of nutrition is important.

c. Introduced soil borne diseases and nematodes may be spread quickly to all beds on the same nutrient tank of a closed system.

d. Most available plant varieties adapted to controlled growing conditions will require research and development.

e. The reaction of the plant to good or poor nutrition is unbelievably fast. The grower must observe the plants every day.

## 2.3 Related studies

Hydroponic system can be adapted to different situations and context, thus it is scalable. For it to be successful, the grower needs to determine how best to monitor the nutrient solution based on cost and the requirement of the selected growing system (Jr., 2005).

Researchers conducted on indoor farming are varied and proposed different grow systems and technologies for implementation. Hydroponics (APCHPA) farming system was proposed (Asif SIDDIQ, 2019) for automating the farm environment. The technology proposed used sensors control the temperature, humidity, soil moisture and light intensity and revealed the benefits of water reusability and low plant damage. The same system was also evaluated by (Paolo Sambo, 2019) and highlighted the benefits of higher efficiency in the use of water and nutritional resources. Research conducted in the same year by (Mazhar H. Tunio, 2019), was interested on growing potatoes with Aeroponic system; the benefits presented are the increases potato production and the protection from pests and soil-borne diseases. Growing plants using Vertical farming (VF) with Hydroponics was proposed by (Kumar, 2019) and stated the benefits of higher growth rate of plants, generating fresh vegetable, off-season production, high nutrition food. The researcher (Gokul Anand. K. R, 2020) Proposed an Ebb-flow hydroponics with pH Sensor, Moisture Sensor, Ultrasonic Sensor, Temperature and Humidity Sensor. The researcher noted that in building such systems the moisture content and temperature must be in a balanced state for the growth of the plant. In hydroponics systems, the monitoring of PH is very important. Factors causing its variations have been discussed by (Judith, 2019) and (Everhart, 2021). Related information summarized in a table.

***Table 1: Causes of PH variations and their remedy***

| Causes of 'pH up' and 'pH down' variations | | Remedy | |
|---|---|---|---|
| Farm type | Causes | Small Systems | Big Systems |
| **In soilless based farm** | -Amount of nutrients drop,<br>- Inorganic matter ( i.e Gravel, sand) raises PH | Monitor nutrient solution levels, keep the reservoir full, and regularly test the PH in the reservoir. | Monitor nutrient solution levels,<br>Keep the reservoir full, Regular test of the pH in the reservoir. |
| | | Add weak acids such as vinegar or citric acid. | -Use purchased products,<br>-<u>Automatic PH</u> controllers |
| | Hard Water | Affordable method for reducing water hardness | Method for reducing water hardness |
| **In soil based farm** | Organic<br>-soil itself fluctuates PH<br>- Algae and bacteria in roots consume acidic carbon dioxide during the day (drop PH) and it increases in evening | - For highly acidic soil Apply a material that contains some form of lime<br>- For soil is alkaline: lower PH or make it more acidic by means of products such as sphagnum peat, elemental sulphur, aluminium sulphate, iron sulphate, acidifying nitrogen, and organic mulches. | |

**Source:** Summary produced based on information from online content of (Judith, 2019) and (Everhart, 2021)

Plants have specific requirements as far as PH level is concerned, and that is why technology innovators need to take plants variety into consideration. Researchers dealt with varied grow methods; however, none focused on Tomboy Tomatoes variety, its characteristics and requirements. The yield of Tomboy Tomatoes is high compared to the variety of Rutgers. A related study conducted during the 1959 season shown that Tomboy produced 11.5 tons per acre, yielding 66 percent of this during the first two weeks of harvest, compared to 5.3 tons per acre of 53 for Rutgers (Lambeth, 1960). According to Lambeth's research, Tomboy tomato plant reaches maturity 2 weeks earlier that Winsall, and averages about 70 days from field transplanting to first harvest. This research also lack the component of technology. For the nutrients, plants need in much quantities Macronutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Chloride (Cl); plants need also Micronutrients such Iron (Fe), Boron (B), Manganese (Mn), Copper (Cu), Molybdenum (Mo), and Zinc (Zn) (Mark Kroggel, 2021). Tomatoes need three primary nutrients Nitrogen, Phosphorus and potassium and those nutrients are in most fertilizers (Malone, 2020).

Each plants may have characteristics it shares with others and other the plant own in particular. In reviewed literatures, none dealt with tomboy tomatoes and proposed a prototype which takes into consideration the particular characterizes of that variety. The current research fills the gap by taking into consideration Tomboy tomatoes variety in indoor faming with Ebb and Flow hydroponic method. The goal is the make an affordable prototype, easy to maintain and financially sustainable in case it is implemented in real life. This match with the argument of Esther Ndumi who suggested that Africans have to figure out kinds of systems that works bests for the (Ngumbi, 2017).

Table 2: Tomboy tomatoes characteristics and requirements

Scientific name: Lycopersicon Esculentum (Tomboy Tomato)

| CHARACTERISTICS | | REQUIREMENTS | |
|---|---|---|---|
| **Cultivar** | Tomboy | Light Range | Sun to full sun, 6 hours of continuous, direct sun per day |
| **Family** | Solanaceae | PH Range | 5.5to 7 |
| **Size** | Height: 6ft to 20ft<br>Width: 0 ft to 0 ft | Soil range | Some sand to some clay |
| **Plant category** | Annuals and binennias, vegetables | Water range | -Normal to moist (Moist and Well Drained)<br>-3 Inch layer of mulch<br>- outdoor watering: depth of 6 to 7 inches (1' being better) |
| **Plant characteristics** | Medium Leaves | | |
| **Flower Characteristics** | Old Fashioned/heritage | | |
| **Flower color** | Whites, Yellows | | |
| **Tolerances** | Heat & Humidity | | |

**Source:** adapted from internet (BackyardGardener, 2021)

The proposed prototype took into consideration the characteristics of tomboy tomatoes variety.

## 2.4 Main components description

### 2.4.1 PH Sensor

This study uses a PH sensor; the recommended pH for hydroponic culture is between 5.0 and 6.0 reason being that the overall availability of nutrients is optimized at a slightly acidic pH (Shrestha, 2017). The sensor of PH was used to measure of the acidity of the substrate and is used to determine how plants interact with different nutrients.

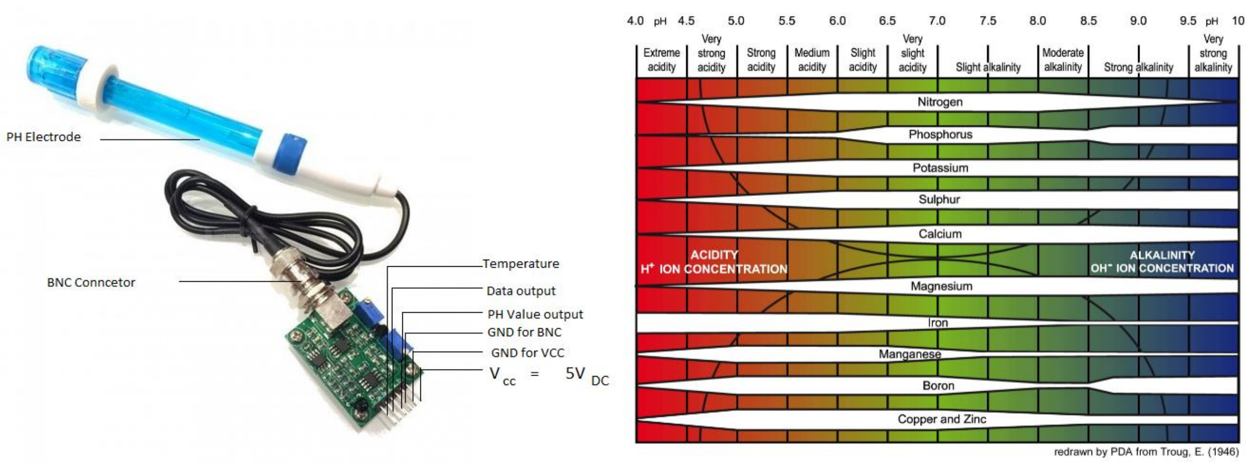



*Figure 1: PH Sensor and PH range*

**Source:** adapted from internet (Ryan, 2017).

The recommended PH for tomatoes is 6.0, they grow well with a PH in slightly acidic.

### 2.4.2 Light Sensor

The light sensor is a sensor, which converts the light energy into an electrical signal output. This sensor is knows as a photoelectric device or a photo sensor because it convert light energy (photons) into electronic signal (electrons).

The sensor used is LDR light sensor, it changes the resistance depending on the light it receives.

*Figure 2: LDR Light Sensor*

Table 3: Plant light requirements

| Plant | Light requirements | Comments |
|---|---|---|
| Beans | Medium-High | Most require moderate light intensity over long season; flowering initiated high temperatures |
| Lettuce | Low | Grows best in partial shade or filtered light; may be grown in a sunny window indoors; long-day |
| Tomato | High | Provide ample light and warm temperatures; day neutral; flowering initiated by high temperatures; provide supplemental lighting indoors and in winter greenhouses |

**Source:** adapted from (Jr., 2005)

### 2.4.3 Temperature and Humidity sensor

The sensor is used for temperature and humidity; it can measure temperature from 0°C to 50°C and humidity from 20% to 90% with an accuracy of ±1°C and ±1%. The temperature for the hydroponic grow environment ranges between 65 and 80 degrees Fahrenheit (18 to 26 C). DHT11 measure the ambient temperature.


*Figure 3: Temperature and Humidity Sensor*

### 2.4.4 NPK sensor

The nutrients needed by tomatoes are mainly three namely: nitrogen, phosphorus and potassium. As the NPK soil sensor can detect those nutrients, it has been used as it is available compared to other nutrients sensors.

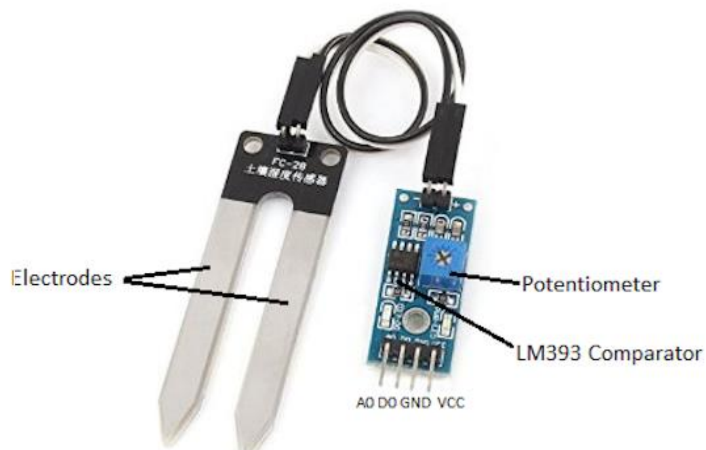



*Figure 4: NPK Sensor*

### 2.4.5 Capacitive moisture sensor

The Capacitive Moisture Sensor Module is used in this research project to determine the amount of moisture by measuring changes in capacitance to determine the water content of sand in plant holder. This will help to signal an alert to the system that the plant needs nutrients from its reservoir. In this research project, the researcher used a capacitive moisture sensor v1.2.


*Figure 5: Capacitive moisture sensor*

### 2.4.6 Arduino Microcontroller

Arduino consist of hardware part  and the software part (IDE), the software part is used to write codes that are uploaded to the hardware part, which is connected to the computer. The hardware part executes codes interacting with input and output devices such as sensors, motors, lights etc.

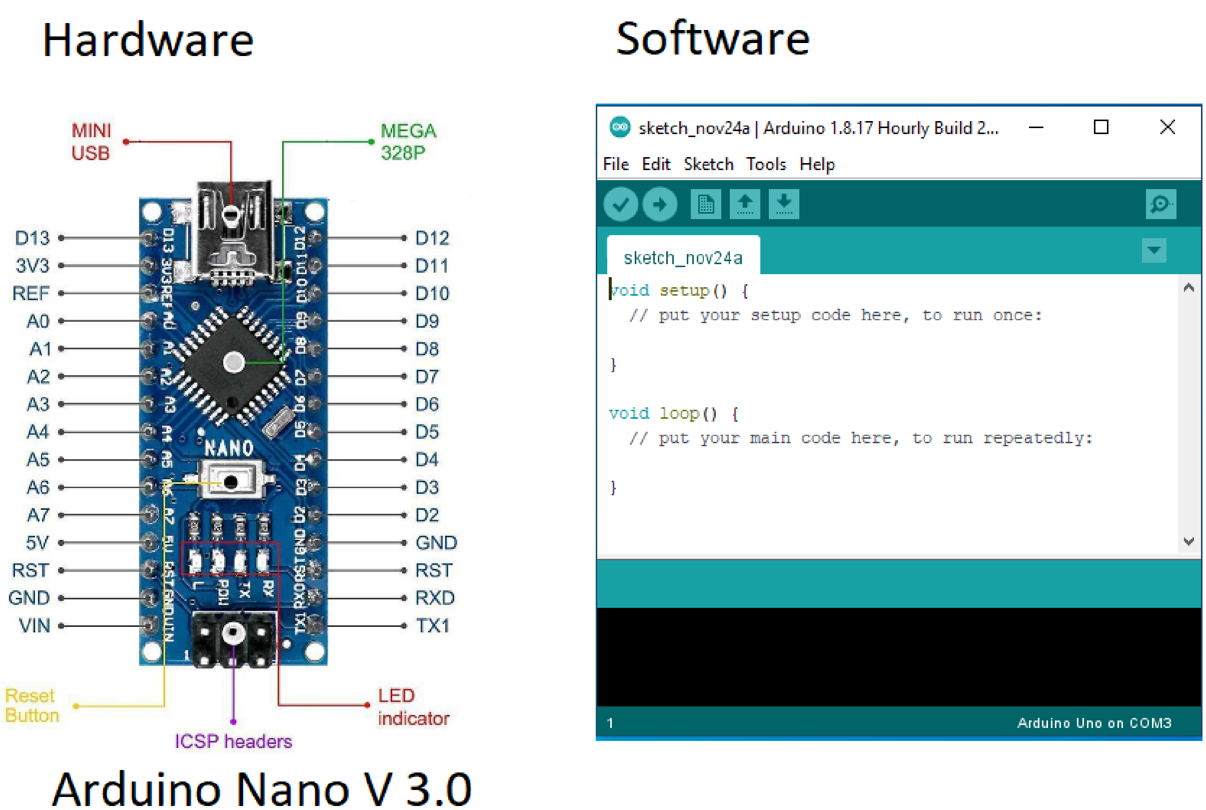



*Figure 6: Arduino Nano V3 Microcontroller*

### 2.4.5 Communication module (GSM)

A GSM module is a hardware device that uses GSM mobile telephone technology to provide a data link to a remote network; it used to transmit mobile voice data service.

*Figure 7: GSM SIM 800L*

### 2.4.6 Thingspeak for cloud

ThingSpeak is an IoT analytics platform service which allows to aggregate, visualize, and analyze live data collected by sensors and be streamed in the cloud; one can build predictions with ThingSpeak in the MATLAB interface.

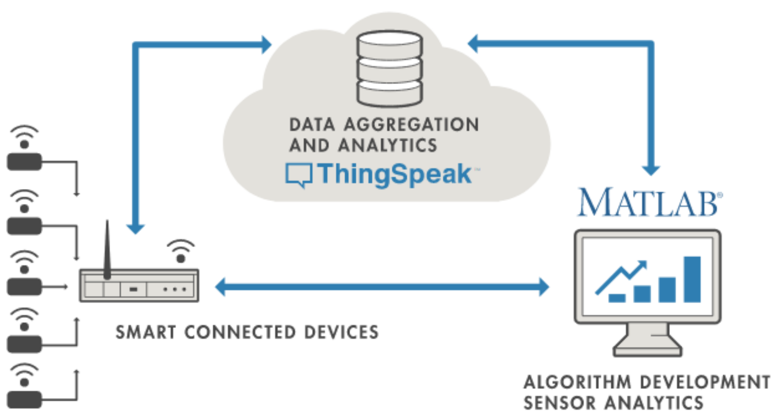



*Figure 8: Thingspeak*

Source: Internet (ThingSpeak, 2021)

# CHAPTER THREE: RESEARCH METHODOLOGY OF THE SYSTEM IMPLEMENTATION

## 3.1 Introduction

The main aim of this research project was to build a prototype for an urban indoor farm. The system needs to be affordable and requiring low maintenance. To create a system, the design took into consideration three parts namely: Data Acquisition part, data processing part, and data communication part. To reduce the cost, the prototype was built with available and inexpensive materials.

## 3.2 Methodology

### 3.2.1 Indoor farm structure

Indoor farm structures are made of materials of different natures depending on the investment funds. In areas where income is limited, structures made of materials available locally contribute to the reduction of setup cost. This aspect is taken into consideration in the system design. The structure will house the following components: Plants and their grow media, nutrients reservoir and the monitoring system.

### 3.2.2 The monitoring system

The implementation of the system is subdivided in different parts: Data Acquisition part, data processing part, and data communication part.

The data acquisition part consists of sensors; the data processing part is mainly the microcontroller, and the data communication part is the GSM module connected sending data to the ThingSpeak. Those parts are assembled together to make a system monitoring the indoor growing environment.

Testing was done in calibrating sensor values and programming until required result is reached.

### 3.3.3 Data collection

Observation and interview have been used with the aim of gathering the information that helps to get insight on what exists in farming activities done in urban place.

*Table 4: Visited companies in Kigali*

| Company/Institution + Visit date | Location (District) | Area of interest | Information |
|---|---|---|---|
| Agrotech Rwanda<br><br>28/11/2021 | Nyarugenge | Nutrients for indoor plants (Tomatoes) | Not sold In their shop |
| Holland Greentech<br><br>28/11/2021 | Kicukiro | Nutrients for indoor plants (Tomatoes) | -Not sold In their shop<br><br>-Sell Greenhouses with soil based farming method<br><br>Own website: https://hollandgreentech.com/<br><br>-Recommended client owning their greenhouses: Kinyinya |
| Balton Rwanda<br><br>May/2021 | Gasabo | Plant seeds, Nutirents | Nutrients available, others can be imported on demand depending on clients' needs.<br><br>Own website: baltoncp.com |

**Source:** Adapted based on Researcher interview (2021)

It was observed that indoor farms using nutrients are rare in existing in Kigali city, and buying nutrients is a challenge, which may hinder its development and adoption. The related questions asked are added in Appendix 1.

*Table 5: Observed places with farms with build structures*

| FIELD LOCATION | IMAGE | OBSERVATION |
| --- | --- | --- |
| Velley Near Former ULK building Plot, Kigali |  | -Semi Covered trees growing garden to protect plants from excess sun shines,<br>-Structure covering large place (valley)<br>-Watering with fuel based water<br>- Workers dwell in the farm |
| SOS Technical School (Gasabo, Kinyinya) |  | - Small structure of 2m x 4m with TomBoy Tomatoes, with water tap based irrigation. |

**Source:** Adapted based on Researcher observation (2021)

The combination of the information summarized in tables above paved the way to the implementation stage having a clear understanding of the existing problems, challenges and expectations, which at the end are compared to the system implementation.

# CHAPTER FROUR: SYSTEM DESIGN, IMPLEMENTATION AND EXPERIMENTAL RESULTS

The main objective of the research study is the design of an indoor prototype which is used to monitor the grow environment of tomboy tomatoes for urban residents. The related system has the ability of detecting when the plant needs nutrients by means of sensors and add it using pumps from the nutrients reservoir. The system uses sensors to collect data, microcontroller for processing data, communication part linked with the cloud storage.

## 4.1 System design

The prototype under this research study has three key parts: 1. the plant medium 2. IoT components 3. Cloud Storage 5. User interface.

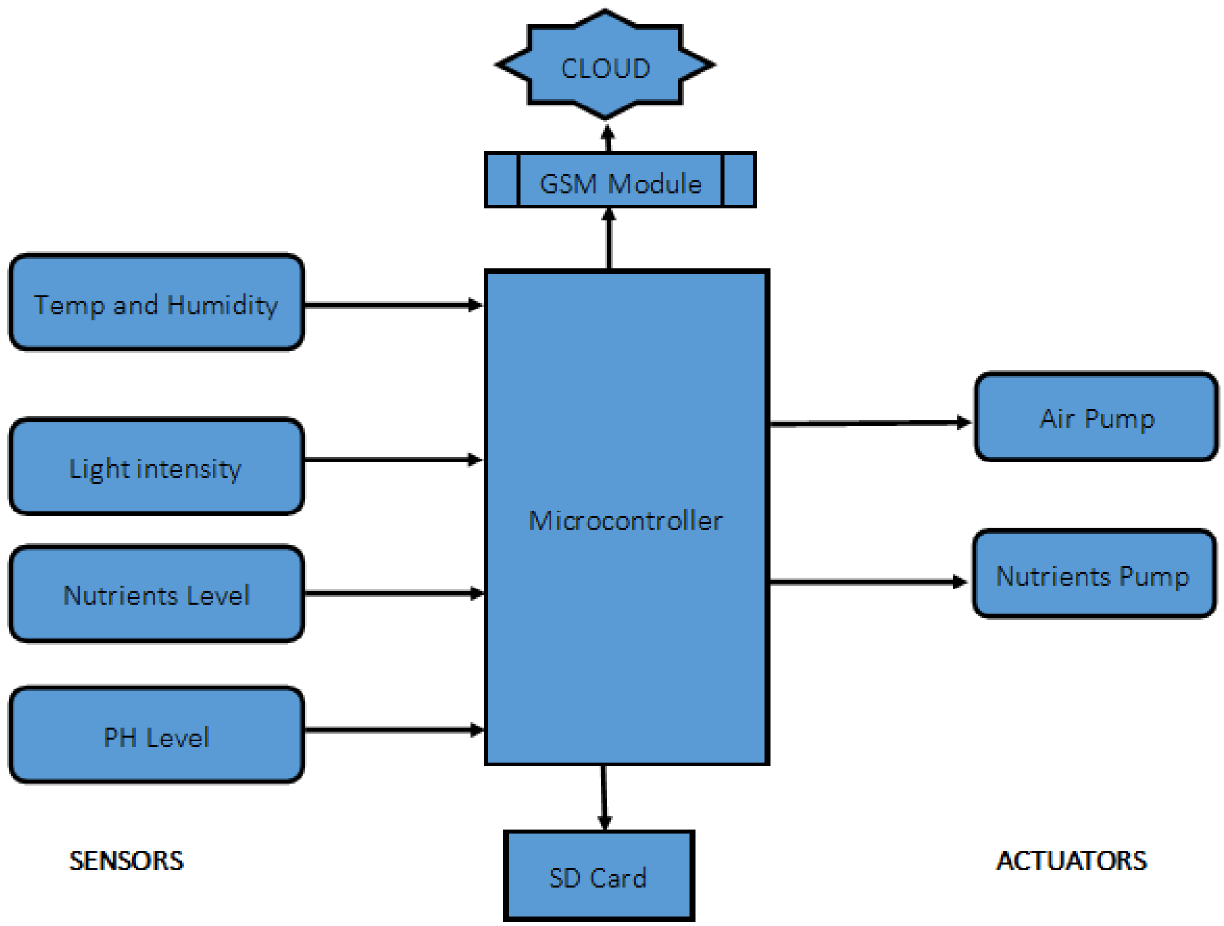
### 4.1.1 Plant medium

The hydroponic grow system selected for this research study is plant medium provide oxygen, water, nutrients and support for the plant. Medium moisture retention is determined by its particle size, shape and porosity. Grow media for indoor farm range from foam, gravel, perlite, rockwool, sand, Hydroton, coco coir and pumice. For this system, the choice go to sand and gravel as you can obtain any of the two in Kigali city easily. The Ebb and Flow method is selected; a pump will be supplying nutrients to the plant container each time the low moisture is detected. Gradually, nutrients liquid will be flowing away back to the container. Air pump is used to generate air to the plant roots.

### 4.1.2 IoT Components

The IoT components used in this prototype are varied; some are used to collect data (sensors), microcontroller for processing data, actuators. The IoT components can be depicted from the following block diagram.

*Figure 9: Block diagram of indoor system*




**Source:** Researcher design (2021)

The system has the sensing modules, the processing modules with the microcontroller Arduino Nano, the actuators part, and communication part (GSM module sending data to the cloud), and local storage of data on SD card.

Sensors used are:

1. DHT11 Sensor for temperature
2. Capacitive moisture sensor
3. PH sensor
4. NPK Sensor (on layout RS 485_long)

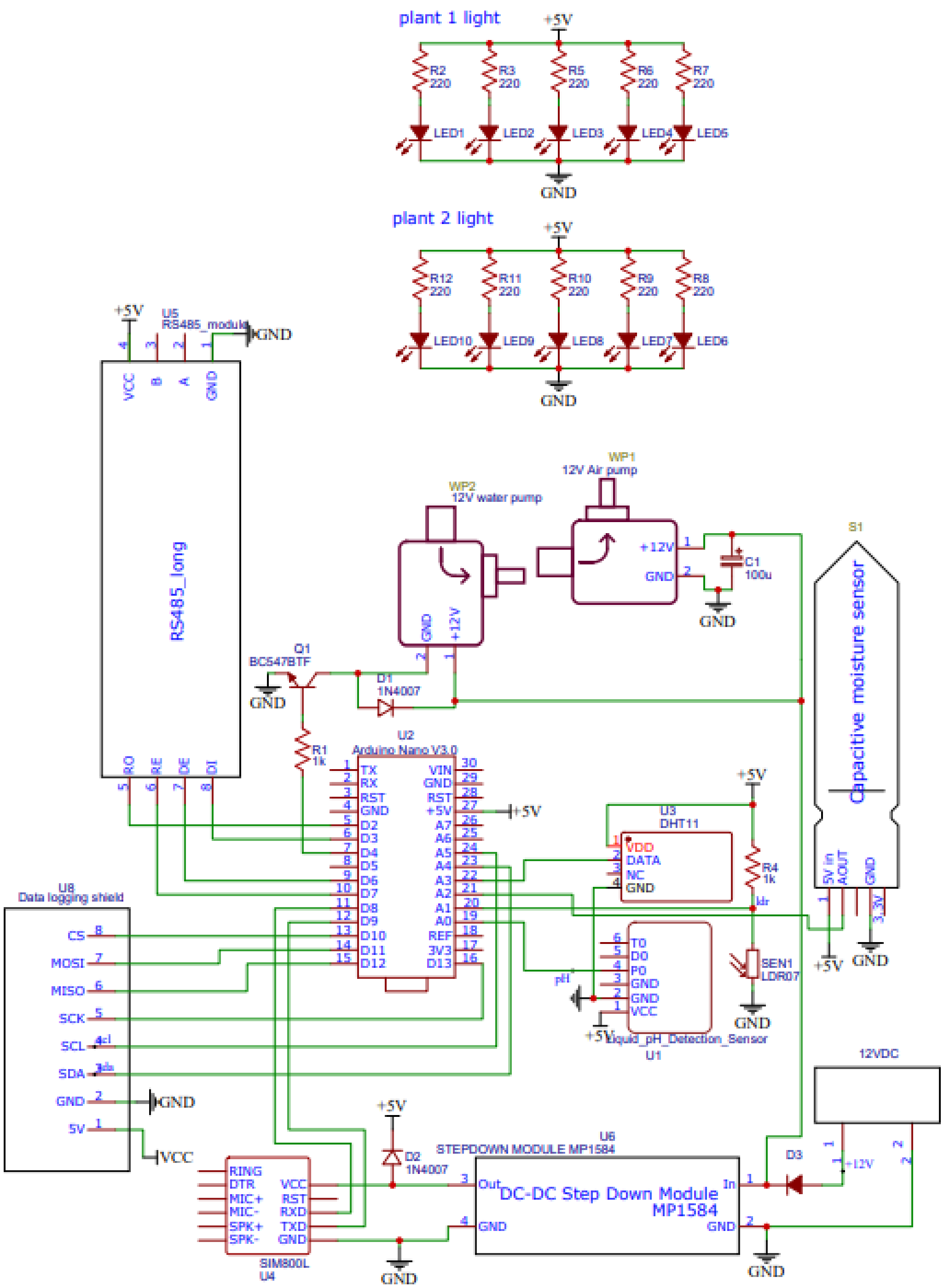
Actuators

1. Water pump

2. Air pump

The circuit diagram of the proposed indoor system is as follows:

*Figure 10: Circuit Diagram of the indoor system*




**Source:** Researcher design (2021)

The circuit diagram of the indoor system shows that the system will use 2 lighting units each having 5 LEDs. The main part of the system is the Arduino Nano with Atmega328P processor it's supplied power of 5v; on this microcontroller various IoT devices are connected to its pins.

Firstly, sensors DHT11 connected to A3, PH detection sensor connected to A0, capacitive moisture sensor connected to A1, NPK Sensor (RS485) connected to D2, D3, D6, D7. Those sensors input data to the microprocessor.

Secondary, actuators using 12v labeled WP1 and WP2 are also connected to the microcontroller on D4 with a Resistor R1 of 1k.

Thirdly, data logging shield is connected to the central part via D10, D11, D12, D13, A4, A5 it serves the purpose of collecting and recording data from sensor output automatically.

The system has also a DC-DC converter labeled DC-DC step down Module MP1584. This module to fit with the system power needs regulates the adapter power of 12v; pumps are directed supplied 12v.

The wireless GSM module labeled SIM800L is connected to the microcontroller via D8 and D9.

### 4.1.3 Cloud storage

Data collected by the sensors are locally kept on memory card; the GSM module is used to push data to the cloud of ThingSpeak.

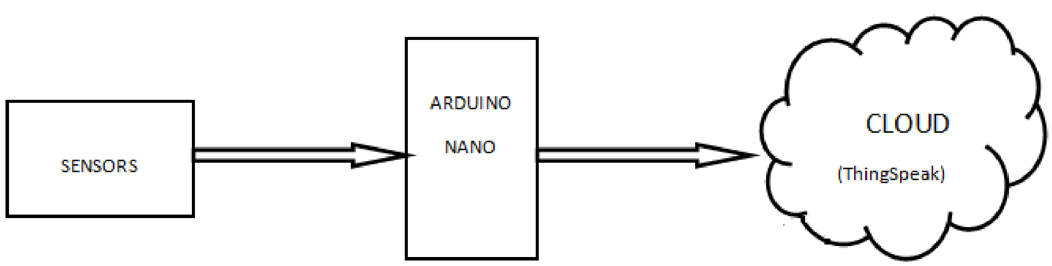



*Figure 11: ThingSpeak for Cloud storage*

**Source:** Adapted based on internet information (ThingSpeak, 2021)

## 4.2 Implementation and Experimental results

This section deals with system implementation and experimental results for the sensor part, cloud part, and interfaces for the system user.

### 4.2.1 Implemented system

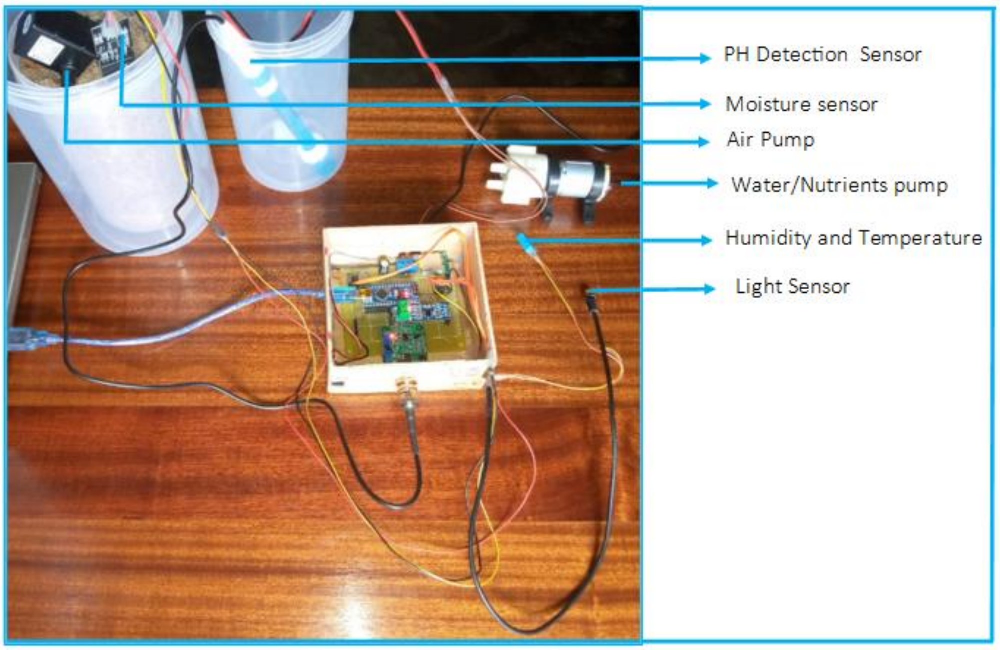



*Figure 12: Actual indoor system for data acquisition, processing and user access*

Source: Researcher design (2021)

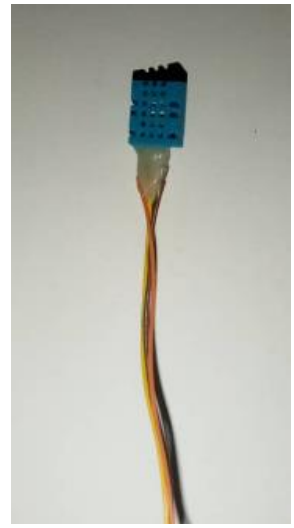
#### *4.2.1.1 Sensors for the system*

Sensors used to the system collect data from the indoor farm environment and send them to the microcontroller for processing. They serve as inputs part for the system.

PH Sensor


Moisture Sensor

Light Sensor



Temperature Sensor

*4.2.1.2 Actuators of the system*

Nutrients and Air Pumps

**Nutrients Pump**

**Air Pump**

Air pump works continuously while the Nutrients pumps works based on data collected by the moisture sensor. When the sensor detects the significant redetection of nutrients and water in the grow media, the motor is on to supply nutrients and water to the plant.

*4.2.1.3 Box with key system components*

Beside the Sensors and actuators, the system has a central part housed in a box for protective purpose.

**Box Covered**

**Box uncovered**


**Indications of connectors**

In the box there is a Microcontroller Arduino Nano with Atmega328P processor, GSM module and other electronic circuits connected to the main circuit boards as per circuit diagram in figure 10.

The system is proposed to be added to a designed structure of 2m x 4m at SOS Technical High School, where tomboy tomatoes growing took place at experimental stage since May 2021. It can be also used to other places.

### 4.2.1 Sensor inputs

Sensors used in the system are temperature and humidity sensor, PH sensor, Moisture sensor, Light Sensor and NPK sensor. They generate that which serve as inputs to microcontroller. The components that output data to the systems are the actuators. They have been tested for checking their functionality.

### 4.2.2 Codes for the cloud

In this research project, the research used IoT on data logging shield by means of GSM Module. The selected device is SIM800LU4 Module with Arduino Nano and is used to send data from sensors to ThingSpeak Server.

An account on ThingSpeak has been created, and an API link with API key obtained. A SIMCARD was used for the sending activity, with the checking of the codes by the system.

### 4.2.3 Interfaces for the user

The interfaces presented in this section are screenshots taken from the ThingSpeak, the help to visualize different graphics related to the data collected by the system and stored to the cloud.

#### *4.2.3.1 ThingSpeak Channel*

With ThingSpeak, the research created a channel to store data sent from different devices of the system. Using different settings, there is a possibility to send and retrieve data to and from the channel.

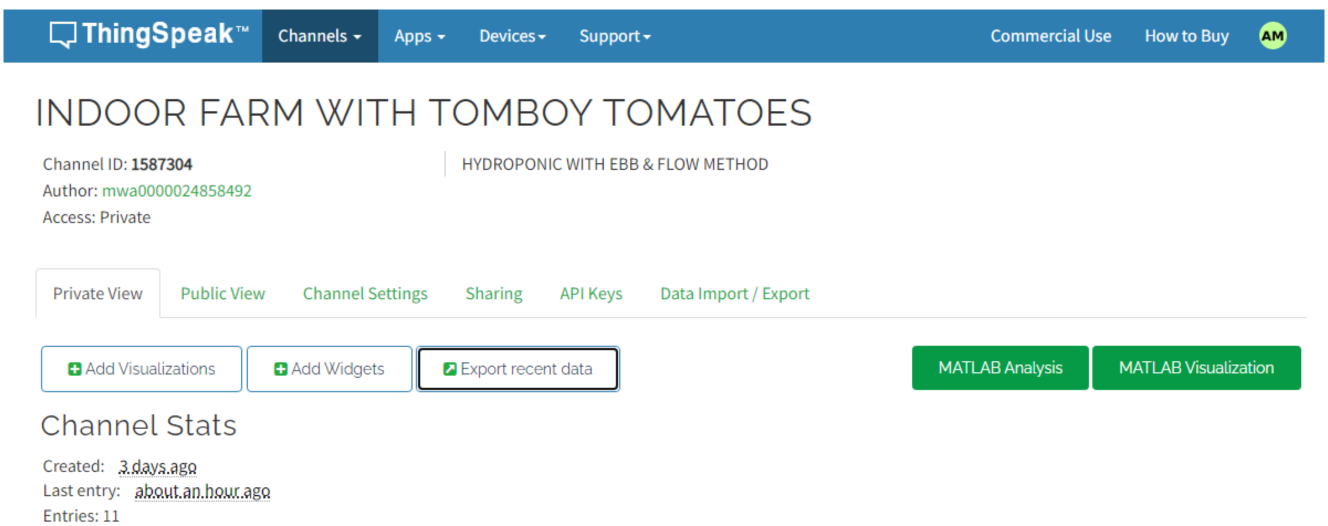


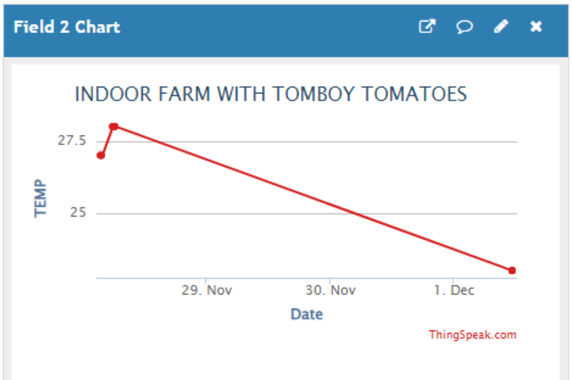

*Figure 13: ThingSpeak Channel interface*

**Source:** Internet (ThingSpeak, 2021)

Data from the farm environment are visualized by means of ThingSpeak channel with ID: 1587394. This version is free of charge as the data uploaded to it are few.

*4.2.3.2 Graphics from ThingSpeak for Humidity and Temperature Sensor*

In the following figure, Temperature and humidity from DHT11 sensor graphics are shown:



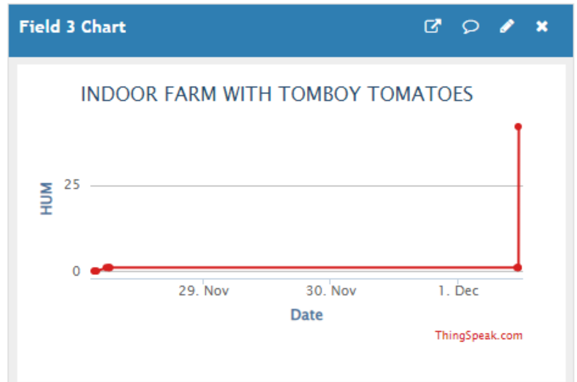




***Figure 14:*** *Data collected and stored on the ThingSpeak (ThingSpeak, 2021).*

Generated data come from Humidity and temperature sensor DHT11. The illustration labeled TEMP is the graph of data collected by Temperature sensor for 11 entries uploaded on ThingSpeak.

*Table 6: Ambient Temperature in indoor Farm*

| ENTRY ID | DATA CREATED AT | TEMPERATURE |
|---|---|---|
| 1 | 2021-11-28 11:29:35 UTC | 27 |
| 2 | 2021-11-28 11:45:10 UTC | 27 |
| 3 | 2021-11-28 11:50:35 UTC | 27 |
| 4 | 2021-11-28 13:53:46 UTC | 28 |
| 5 | 2021-11-28 14:12:32 UTC | 28 |
| 6 | 2021-11-28 14:15:33 UTC | 28 |
| 7 | 2021-11-28 14:24:24 UTC | 28 |
| 8 | 2021-12-01 19:17:48 UTC | 23 |
| 9 | 2021-12-01 19:20:49 UTC | 23 |
| 10 | 2021-12-01 19:23:49 UTC | 23 |
| 11 | 2021-12-01 19:26:49 UTC | 23 |

**Source:** Adapted from (ThingSpeak, 2021)

The above information was exported file in Excel file, and was used as a source to generate table 6 and figure 15.

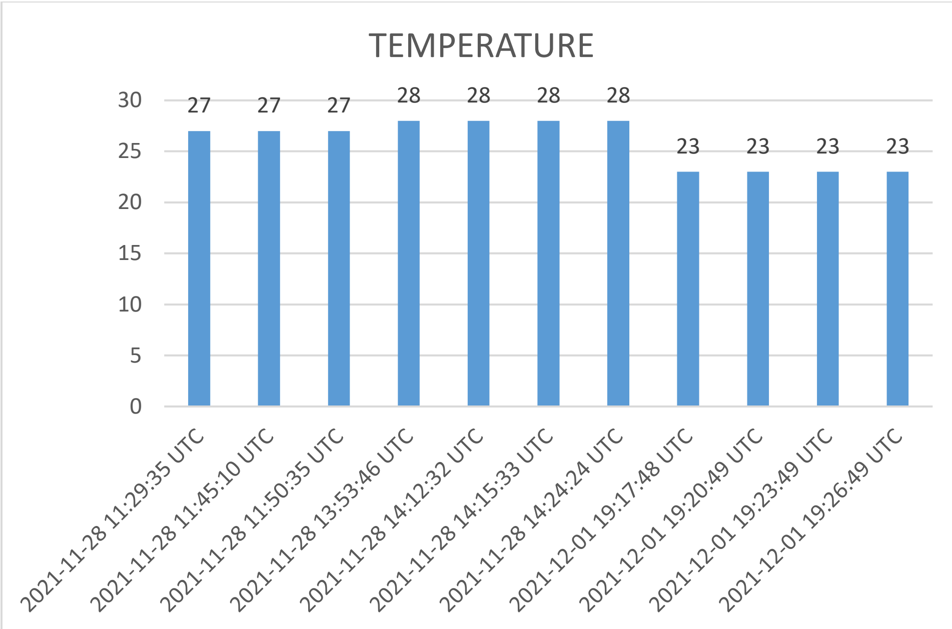



***Figure 15:*** *Graph of Ambient Temperature in indoor Farm*

**Source:** Researcher adaptation based on (ThingSpeak, 2021).

The first three entries shows that the temperature was at 27 C$^o$, this temperature raised at 28 C$^o$ in the next four entries; and that was on the same day but for different hours of the day. The last four entries were taken during the night and the temperature reduced to 23 C$^o$; that is the temperature of the grow environment. Considering the characteristics of TomBoy tomatoes, they tolerate Heat and Humidity such ambient temperature do not affect the plant. For other hydroponics, recommended temperature is between 18 C$^o$ and 26 C$^o$ .

#### *4.2.3.3 Graphics from ThingSpeak for PH Sensor*

In the literature review, factors causing the fluctuations of PH level have been summarized in Table 1, and it's suggested that PH level be regularly monitored. For indoor farms using hydroponics system, it's possible to automate that task of measuring the PH Level. The current study used PH sensor to measure PH Level, and data captured have been uploaded on ThingSpeak for further analysis.

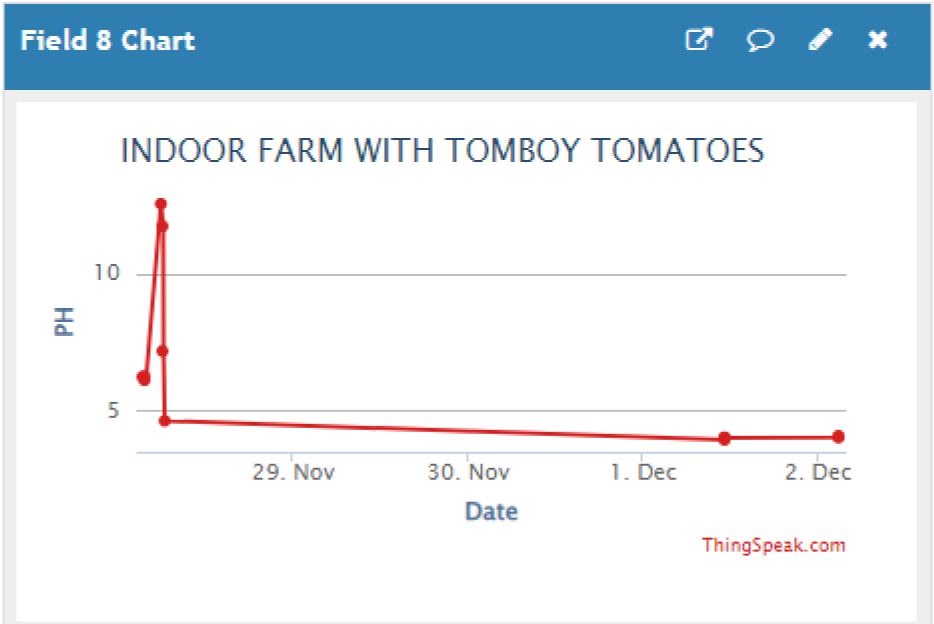



*Figure 16: PH Level of indoor nutrients reservoir*

Tomboy Tomatoes requirements suggests that the PH level for plants be maintained between 5.5 to 7 (BackyardGardener, 2021). Data collected and uploaded on ThingSpeak are as follows:

*Table 7: PH Value for indoor farm*

| ENTRY ID | DATA CREATED AT | PH Value |
|---|---|---|
| 1 | 2021-11-28 11:29:35 UTC | 6.21 |
| 2 | 2021-11-28 11:45:10 UTC | 6.24 |
| 3 | 2021-11-28 11:50:35 UTC | 6.09 |
| 4 | 2021-11-28 13:53:46 UTC | 12.55 |
| 5 | 2021-11-28 14:12:32 UTC | 11.73 |
| 6 | 2021-11-28 14:15:33 UTC | 7.16 |
| 7 | 2021-11-28 14:24:24 UTC | 4.6 |
| 8 | 2021-12-01 19:17:48 UTC | 3.9 |
| 9 | 2021-12-01 19:20:49 UTC | 4 |
| 10 | 2021-12-01 19:23:49 UTC | 3.97 |
| 11 | 2021-12-01 19:26:49 UTC | 3.98 |

The above table shows the PH values as retrieved from ThingSpeak, and they are presented in the following figure:

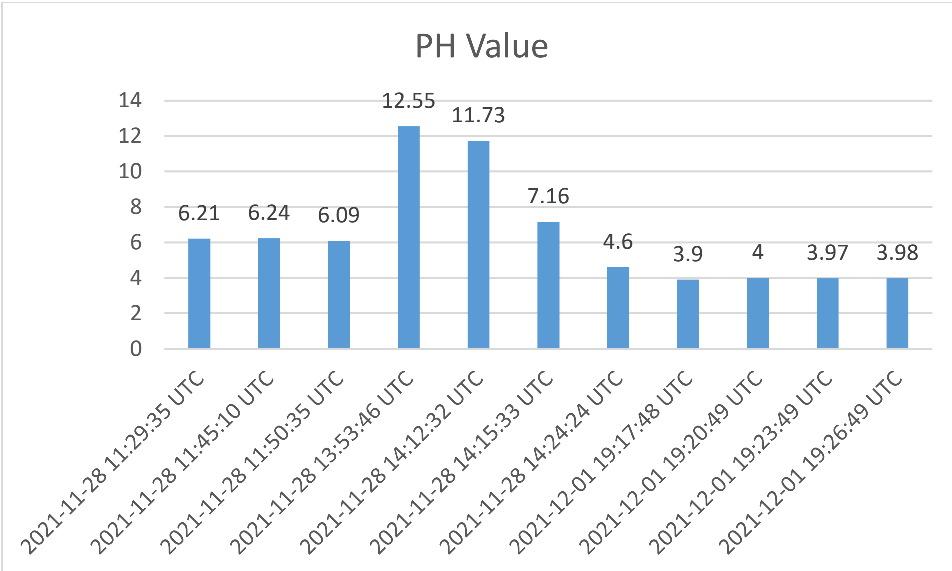



*Figure 17: PH Values*

**Source:** Researcher adaptation based on (ThingSpeak, 2021).

Data presented in the above table and figure shows that in 11 entries taken in testing phase, values in normal range of PH value for tomboy tomatoes are entry 1, 2,3 others entries are out of the range. Entries bellow 5.5 PH value indicates strong acidity, which prevents plants to get nutrients and slow their growth. Entries with PH value above 7 indicates high alkalinity this also slow plant growth. Remedy for that is to use products that adjust PH value to the required range; if it happens in real farm.

#### *4.2.3.4 Graphics from ThingSpeak for NPK Sensor*

In the research of (Malone, 2020); it was indicated that Tomatoes need three primary nutrients Nitrogen, Phosphorus and potassium and those nutrients are in most fertilizers. Polyfeed standard fertilizers was recommended by the Balton Company operating in Rwanda, with 19:19:19 ratio. Those values indicate that the nutrient solution contains 19% of nitrogen (N), 19% of phosphorus (P), and 19% of potassium (K). For this project, the graphics for NPK sensor on thingSpeak for NPK are as follows:

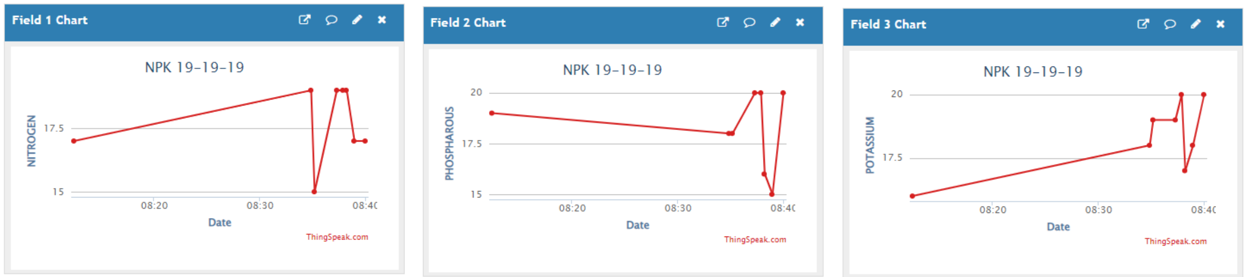



*Figure 18: Graphics for Nitrogen (N) Phosphorus (P) and Potassium (K) data uploaded on ThingSpeak*

Data related to nitrogen (N), phosphorus (P), and potassium (K) retrieved from ThingSpeak in excel format as shown in the following tables:

*Table 8: Data related Nitrogen (N) form ThingSpeak*

| ENTRY ID | DATA CREATED AT | Nitrogen Value (%) |
|---|---|---|
| 1 | 2022-01-07 08:12:25 UTC | 17 |
| 2 | 2022-01-07 08:34:50 UTC | 19 |
| 3 | 2022-01-07 08:35:09 UTC | 15 |
| 4 | 2022-01-07 08:37:15 UTC | 19 |
| 5 | 2022-01-07 08:37:50 UTC | 19 |
| 6 | 2022-01-07 08:38:11 UTC | 19 |
| 7 | 2022-01-07 08:38:55 UTC | 17 |
| 8 | 2022-01-07 08:39:58 UTC | 17 |

Data with Entry ID 2,4,5,6 are in accordance with nutrient solution's ratio for Nitrogen (N).

*Table 9: Data related Phosphorus (P) form ThingSpeak*

| DATA CREATED AT | ENTRY ID | Phosphorous (%) |
|---|---|---|
| 1 | 2022-01-07 08:12:25 UTC | 19 |
| 2 | 2022-01-07 08:34:50 UTC | 18 |
| 3 | 2022-01-07 08:35:09 UTC | 18 |
| 4 | 2022-01-07 08:37:15 UTC | 20 |
| 5 | 2022-01-07 08:37:50 UTC | 20 |
| 6 | 2022-01-07 08:38:11 UTC | 16 |
| 7 | 2022-01-07 08:38:55 UTC | 15 |
| 8 | 2022-01-07 08:39:58 UTC | 20 |

Data with Entry ID 1 are in accordance with nutrient solution's ratio for Phosphorus (P).

*Table 10: Data related Potassium (k) form ThingSpeak*

| ENTRY ID | DATA CREATED AT | Potassium (%) |
|---|---|---|
| 1 | 2022-01-07 08:12:25 UTC | 16 |
| 2 | 2022-01-07 08:34:50 UTC | 18 |
| 3 | 2022-01-07 08:35:09 UTC | 19 |
| 4 | 2022-01-07 08:37:15 UTC | 19 |
| 5 | 2022-01-07 08:37:50 UTC | 20 |
| 6 | 2022-01-07 08:38:11 UTC | 17 |
| 7 | 2022-01-07 08:38:55 UTC | 18 |
| 8 | 2022-01-07 08:39:58 UTC | 20 |

Data with Entry ID 3,4 are in accordance with nutrient solution's ratio for Phosphorus (P).

In the three tables, values, which are 19, corresponds to nutrient solution of 19% of nitrogen (N), 19% of phosphorus (P), and 19% of potassium (K). Fluctuations of values compared to the formulate ratio 19:19:19 may come from transpiration, crop differences and system size. Smaller systems fluctuate more severely than large systems (Storey, 2017). Those are some of the reasons the values are less than 19 or above 19 for the three nutrients in Polyfeed (NPK- 19:19:19 + 2MgO +TE) fertilizers which are taken into consideration in this study.

# CHAPTER FIVE: GENERAL CONCLUSION AND RECOMMENDATIONS

## 5.1 Introduction

This chapter gives the general conclusion of the work done and recommendations. It summarizes the key findings of the research project, the usefulness of the research; it acknowledges its limitation and make recommendations for future work that will be undertaken.

## 5.2 General Conclusion

In this research, the background of the study was given in the first chapter. It was stated that the traditional farming in developing countries can't alone help to meet the food demand of the increasing population. Having a focus on Kigali city, an indoor farming of tomboy tomatoes was selected as area of interest of the research with the aim of developing a related prototype.

In the review of literature, an appraisal of previous studies related to urban indoor farming was done. Technology used in indoor farms have been highlighted and the need of conducting the study highlighted.

The system was designed based on the feedback given in interview administered to urban residents practicing agriculture activities in Kigali city. The system prototype was done as an implementation part of the research project whereby a hydroponic system prototype was built.

This research study is useful in three areas, in academic it can serve as a reference for further researches. For the technical side, it shows the possibility of making prototypes for indoor farms, for the socio-economic side, it shows that it is possible to used indoor farms to increase tomatoes yield and pave ways for jobs creation.

Looking back to the general objective set of making a prototype and specific objectives set of conducting the data collection, analyzing data, writing a thesis; the research objectives have been achieved.

Though the porotype was achieved, the researcher acknowledge that not all features and functionalities of indoor farm are included due to the limit, budget and time.

## 5.3. Recommendation

- The awareness of citizens and reediness on indoor farm is limited, a sensitization campaign and incentives are recommended to be taken into account by all stakeholders in agriculture sector.

- Further researches are recommended to make indoor farming secure especially on nutrients solutions production at the local level.

- Researchers also are recommended to work on large-scale commercial indoor farms that can result in viable large businesses.

- The researcher also recommends the production of electronics components locally, as importing them add some cost on the components, a problem which can hinder the adoption of indoor farms in the future.

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# APPENDICES

## ANNEX 1: INTERVIEW QUESTIONS FOR COMPANIES INTERACTING WITH FARMERS

Respondent names:……………………….

Respondent Sector:……………………….

Respondent Cell:…………………………….

Name of Company:………………………

1. Among the services you offer to farmers, is there any service related to indoor farming? state
2. A. Do you offer plants nutrients to your customers? B. Do you sell TomBoy tomatoes seeds/Plants?
3. At which price to you sell them?
4. A. In your clients, are there some who own indoor farms? B. What is the location of the farms?
5. A. Do you offer indoor farm structures and related technology? B. State the price
6. How do you compare indoor farms adoption for urban farmers compared to countryside farmers?