Smart Agriculture as a Way of Tackling the Dual Challenge of Urban Water Pollution and Food Deficiency in Zimbabwe: An IoT Approach

HILTON CHINGOSHO[1] AND SIMBARASHE ALDRIN NGORIMA[2]

Abstract

Daily activities such as washing cars now present ethical dilemmas when considering their impact on the environment and natural resources. The use of high-end technology has made farming more productive and possible in areas not originally designed for agricultural activities. Facing the need to implement water conservation, given the context of high volumes of cars on Zimbabwe's roads and the mushrooming of unregulated car-washes that generate high amounts of waste water (causing water pollution), a specialised urban agriculture solution in the form of a hydroponics is proposed in this article to be adopted as a dual solution to water pollution and food shortages. Through a detailed analysis of car wash effluent water pollution, methods of washing options; a hydroponics system is specified that pays special attention to parameters crucial for plant growth through the use of sensors connected to a controller embedded with a wi-fi module. Crops were observed to have a higher growth rate and were generally healthier. The water and nutrient usage were observed to be less as compared to soil-based farming. The proposed system guarantees saving of natural resources and acts as a dual solution to water pollution and food deficiency.

Keywords: *sustainability, hydroponics, smart agriculture, humidity, wi-fi module.*

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[1]Department of Industrial and Mechatronics Engineering, University of Zimbabwe

[2]School of Electrical, Electronic and Computer Engineering, North-West University, Potchefstroom Campus, South Africa

INTRODUCTION

The Zimbabwean economy strongly depends on agriculture. As of 2020, the World Food Programme (WFP) has rated Zimbabwe among the top countries in food crisis with more than 4.3 million Zimbabweans being food insecure and this number has risen from 3.8 million in 2019 (WFP, 2020). Climate change effects are also seen in Zimbabwe through increase in temperatures, decrease in rainfall and it is projected that by the end of the century, average temperatures in Zimbabwe could rise by 3°C and annual rainfall is projected to decrease by between 5 to 18% (Brazier, 2015). Food insecurity, climate change effects and labour costs have motivated indoor farming methods, such as hydroponics. Also, the number of cars on the road is Zimbabwe is rising with an estimate of 1.6 million by end of 2020 (Road Transport Services and Infrastructure, 2020). This means that a lot of water is going to be wasted through car-washes. Car-washes can be combined with urban agriculture in the form of hydroponics in order to save water and also improve food security. The emergence of IoT technology has made the automation process in hydroponics farming possible. This technology involves the remote monitoring and controlling of various parameters that are crucial to plant growth in real time. Sensors and actuators are employed in the system so as to allow only the required amount of resources, thus limiting wastages and achieving Smart Agriculture.

Adding up everything from digital payment kiosks to water reclamation technology, commercial car-washes are adapting their business practices to fit modern times, thereby making a big difference. Traditionally, without water conversation equipment, car-washes use between 68 and 386 litres per vehicle. Today's versions, according to Brown, (2002), car-washes use only 36 to 318 litres per vehicle when equipped with some form of water reclamation and/or filtration technology (depending on the type of car-wash) (*ibid.*) Though water reclamation technology has been used by professional car-washes for the past 30 years, it has gained traction in the past few years as entrepreneurs aim for quality control and conservation. These reclamation systems are designed to conserve water, control water and sewer hook-up costs.

Internationally, commercial car-washes are also incorporating other technologies to make the customer experience easy and quick services, such as designing of payment portals specifically for professional car-washes that allow customers to make mobile payments and setup automated-billing and cleaning schedules (*ibid.*). Payment kiosks let consumers avoid the checkout line and many car-washes now allow clients to pay in advance online. Not only that, customers are using smart devices to locate reliable car-washes, read and write reviews online and even compare prices and specials at various car-washes (Mohammed, 2018). Car-wash companies are using software programmes that help run their businesses more efficiently, helping them perform tasks like managing inventory, allocating staff, assigning projects, scheduling meetings and running important data reports (Brown, 2002). Car-wash owners are using smartphones and tablets to change car-wash settings with a tap of their finger, troubleshoot with off-site technicians, complete chemical reporting, establish maintenance schedules and take care of various business operations.

Today's commercial car-washes use less than one percent of the water consumed in a medium or large urban area. But in times of drought, even owners of water-efficient car-washes can take additional measures to reduce the amount of fresh water their business uses. Some commercial car-wash owners are even shutting down their businesses several days a week to cut back on water usage during dry seasons, but that is not the only solution. Water conservation technology continues to be the most effective way for commercial car-washes to sustainably reduce the wash water their businesses use. With the assistance of local authorities, water reclamation is becoming more prominent, especially in locales that do not receive much rainfall, allowing businesses to recycle and re-use water. Since professional car-washes can produce a massive amount of waste, regulations and laws to reduce pollution and facilitate water conservation are in place (Brown, 2002; Mohammed, 2018).

Commercial car-washes today are thought to use less than half of the fresh water used when individuals wash their cars at home or at outdated car-washes that do not incorporate water reclamation technology. Ideally, all waste water must be sent to a sewer treatment facility that is kept separate from untreated storm sewers in most urban areas (Mohammed, 2018). The use of approved chemicals that are either treatable at these facilities or completely biodegradable are only applied in commercial car-washes that then makes these car-washes an attractive option for implementing smart urban agriculture through hydroponics and aquaponics systems. In addition, as a standard, a professional car-washing business has multiple underground tanks that isolate sediment from waste water before it is sent to a sewer treatment facility. After the tanks are filled, a company that handles hazardous materials comes to clear them out and dispose of them in a safe manner (Brown, 2002). These make commercial car-washes very ideal for setting up smart urban agriculture (UA) systems to solve the dual challenges of waste water and food shortages.

Urban agriculture in short can be defined as the cultivation of crops and the keeping of animals within urban environments (De Zeeuw and Dubbeling, 2009). UA is directly integrated into the ecological system that includes the use of urban resources, such as wastewater for supplying to the plants for growth and organic waste as a source of nutrients. Hydroponics that can be used as a form of UA has many advantages, such as more yield achieved in a short amount of time, compared to soil-based agriculture. The use of chemicals in the form of pesticides and fertilisers can be avoided, diseases that are soil borne would be avoided, quality products in terms of health and freshness can be obtained and water problems in agriculture can be overcome (Sonneveld, 2000). However, hydroponics has its limitations as follows: it requires high investment, needs constant water supply, requires constant power supply and also needs skilled technicians (*ibid.*). However, hydroponic systems can be used to grow market gardening crops such as tomatoes in an urban setting.

Tomatoes are a member of the Nightshade family, along with potatoes, peppers and eggplants (Hilhorst, Groot and Bino, 1980). The fleshy fruits come in a versatile array of yellows, browns, oranges, pinks, purples, reds and greens. They range from sweet and tart to smoky flavoured and have graced too many dishes to count. Their popularity makes them a favourite crop, especially in bucket systems and greenhouse settings (Peet and Welles, 2005). While tomatoes are incredibly common, any shopper can testify to the difficulty of finding a good-quality tomato.

Local farmers, who can get the fruit to shoppers fast after it ripens to sweetness on the vine, have a distinct advantage over larger growers in this regard. Tomatoes typically grow in one of two patterns, depending on the variety. Bush varieties are common in heirlooms and can be more difficult to manage (Hydro Systems, 2020). Bush tomatoes tend to sprawl along a greenhouse floor, making trellising difficult to impossible. As a result, growers can have trouble reaching the fruit, pruning plants and navigating the greenhouse. Vining varieties are preferable to most growers since the plants can be pruned to a single "leader" and trellised neatly above the bucket using a lean-and-lower system. This makes plants more accessible and much faster to harvest and prune (Cindy, 2016). A typical tomato setup includes two plants per bucket, with cultivars that are between 24 to 36 inches apart. If grown as single plants (such as in a slab system), tomatoes can be pruned to two leaders per plant. Ideal conditions for tomatoes are a pH range: 5.5–6.5 and temperature: 15–32^{o} Home (Hydro Systems, 2020).

Tomatoes, as a fruiting crop, are nutrient hogs. They like heat and will grow well in the same environment as crops, like okra or basil. One downside of tomatoes is that they can be vulnerable to a wide range of diseases and pests, from the common aphid and spider mites to verticillium and fusarium wilt and more specific pests, like a mosaic virus (Broadbent, 1976). Tomato life cycles vary based on the variety, but many greenhouse growers run their tomato system for 8-11 months of the year with production peaking in the summer months before tapering off (Cindy, 2016). A typical tomato life cycle may take 5–10 days to germinate, 4–6 weeks after that to reach transplanting size (about 8 inches) and anywhere from 1–2 months to start setting fruit. Because tomatoes are such a commonly grown crop, there is an abundance of data on troubleshooting and deficiencies. Common deficiencies for tomato plants are phosphorus (that shows up as stunted/slow growth and necrotic spots) and magnesium (that appears as interveinal chlorosis then necrosis around the edges of the leaf and puckering of leaf surfaces) (Winsor, 1979).

Hydroponics is the growing of plants in nutrient solutions, with or without sand, gravel or other inert media, to provide mechanical support. Nutrition is supplied by water-soluble nutrients in place of soil. Hydroponics allows for the cultivation of plants in areas where they would not typically grow. Tomatoes can be grown in a hydroponics system using mineral nutrients mixed with water, with the solution becoming the food source of the plants (Hydro Systems, 2020). The solution can be maintained to be nutrient rich by controlling parameters, such as pH concentration and electrical conductivity (EC). The EC value is an indication of the nutrient in the solution (Nursyahid, 2017). Solution volume needs monitoring in hydroponics as this indicates if the roots of the plants are continuously getting appropriate nutrient concentration or not.

The hydroponics system consists of three parts: the first is the detection part by the use of sensors that detect humidity, water temperature and water level. The second part is the controlling part by use of actuators. The third part is the notification part through the use of GSM module and Wi-Fi module. GSM notifies the farmer in case of any changes that are not normal to the hydroponics environment through a message. Recycling of the nutrient solution in hydroponics leads to sustainability. This technology eliminates the need of human monitoring as the monitoring is automated and made remotely accessible (Nalwade and Mote, 2017).

This article presents the following contributions: (1) a sensor network that tracks and gathers information of a hydroponics garden, (2) generates an analysis model that automates the hydroponics system, (3) develops a web interface that acts as the schematic and graphical access in monitoring and controlling. The rest of the article is organised as follows. Section I discusses the methodology and materials. In Section II, we discuss an overview of this hydroponics system. Section III, tests and discuses results. Section IV concludes the article. Section V consist of references.

METHODS AND MATERIALS

An audit was performed and a minimum of one week's cumulative flows of freshwater and effluent were collected for the identified car-wash site. Data related to three basic questions: the amount of water consumed per vehicle, the water loss to evaporation and potential water saving measures.

WATER CONSUMPTION

Each one of the study sites was audited for water use by cycle and for the total litres used per vehicle for each of the wash types. Numerous previous studies have used consumption estimates based upon manufacturers' specifications (Zanet, Etchepare and Rubio, 2011). This study compares water use by car-wash type and region based upon fieldwork.

EVAPORATION AND CARRYOUT

Data were also collected to determine the amount of water lost through evaporation and carryout. Carryout includes water that leaves the car-wash adhering to the surface of the car, or is blown from the car-wash bay by wind. The location, local climate, orientation to wind, size of bay, water pressure and nozzle size and orientation will all effect evaporation and carryout losses. Water loss that occurs from evaporation and carryout reduces sewer flows from the facility. This study measured actual return flows versus freshwater inflows over a week at each of the study sites and compared them to determine evaporation and carryout losses.

Conservation and Reclaim

The water audits performed at each site identified potential conservation measures. Car-wash operators have reduced their water use per vehicle washed by adjusting nozzle size, water pressure and leak detection and repair (Whatley, 1994; Mohammed, 2018). The audits identified potential conservation measures at each site and provided economic data for operators considering installing such measures. The conservation potential of water reclaim was evaluated by measuring water use in those sites where reclaim systems were installed and operating as compared to those that were freshwater use only.

Steps in a Professional Car-wash Process

The following generalised step 5 were identified for the purposes of evaluating the water balance of the car-wash process.

1. Pre-soak - An automated nozzle or hand-held spray. Not found in all car-washes.
2. Wash - High-pressure spray or cloth material with detergent solution.
3. Rocker panel/undercarriage - Cloth material or high-pressure sprays on sides and bottom of vehicle. In a conveyor, these may be operated on independent arms or carriages that spray upward from below or beside the vehicle.
4. First Rinse - High-pressure water rinse. Wax/Sealers/Polishes - An optional surface finish is sprayed on the vehicle.
5. Final Rinse - Low-pressure rinse with fresh or membrane-filtered/deionised water –Is sprayed on the vehicle.
6. Air Blowers - Air is blown over the vehicle to remove water and assist in drying.
7. Hand Drying - The vehicle is wiped down with towels or chamois cloths. In full-service and exterior washes, these are then laundered in washing machines on-site.

Hydroponic Tomatoes

Hydroponic tomatoes are grown in a nutrient solution, rather than soil, although they are typically placed in a non-soil material that can support their roots and hold the nutrients. Growing tomatoes hydroponically allows the grower to raise them in a controlled environment with less chance of disease, faster growth and greater fruit yield. There are several varieties of hydroponic systems and tomatoes can grow well in any of them. For the purposes of this research, a Nutrient film technique (NFT) was chosen as the technology of choice in that tomato plants are suspended with roots brushing against slope of trickling nutrients (Mohammed, 2018). This technology is slightly more finicky and expensive, but is usually preferred by many other commercial growers.

SEEDING

In this study, the tomato crop was used. The seed mix consist of micro and macro-nutrients that are needed for growth. The mixture was put in hydroponics medium, namely coconut coir and it was watered continuously. After 15 days, the seedlings started to show and they were transferred to the hydroponics system. Some of the seeds were transferred to the garden for comparison purposes.

HYDROPONICS SET UP

The system is designed as shown in Figure 1. The implementation of the NFT system was done using a PVC pipe. The set-up consists of sensors interfaced with the micro-controller board and these are: temperature and humidity sensor (DHT11), water level sensor, water temperature sensor (DS18SB20). Data from the sensors is captured by the NodeMCU board. NodeMCU is embedded with ESP8266 Wi-Fi module that connects to the World Wide Web directly. NodeMCU is programmed using Arduino IDE by installing the libraries for ESP8266. The humidity sensor is placed in the middle of the set-up so that it can capture the atmospheric temperature and the humidity of the environment surrounding the system. The submersible pump is placed in the reservoir to circulate the nutrients. A water temperature sensor is placed in the reservoir to continuously monitor the temperature of the solution.

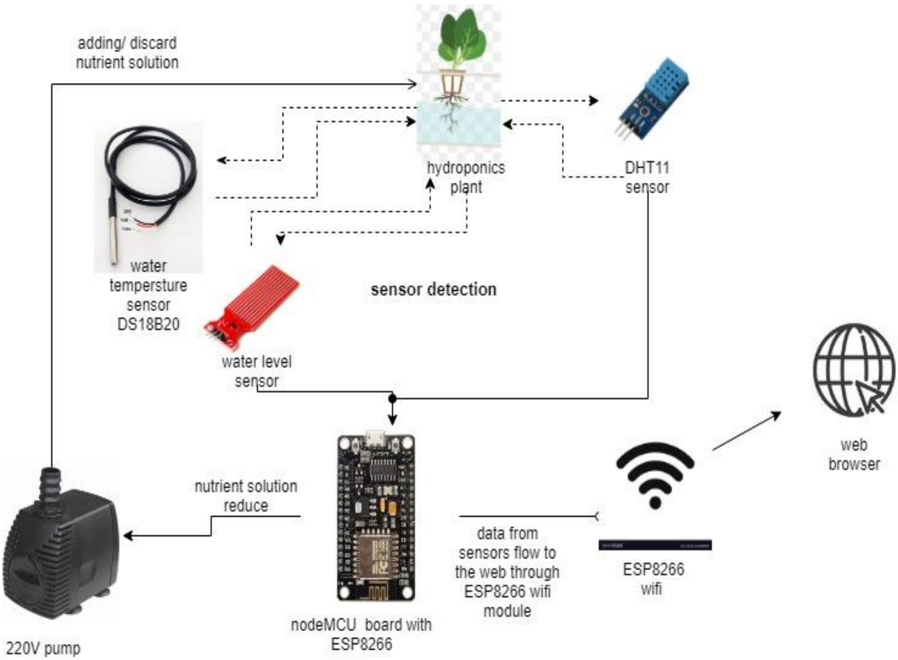

Figure 1 Architecture of Automated Hydroponics Nutrient Plant System

Each of the components in Figure 1 is described below, together with how it works

a) NODEMCU CONTROLLER

NodeMCU is a controller that can be interfaced with various sensors. It is interfaced with ESP8266 Wi-Fi module capable of transmitting the sensor data to the cloud for storage. It can be accessed remotely. Power is supplied to the nodeMCU through a USB cable.

Figure 2 NodeMCU board

b) Water level sensor

A water level sensor has 10 copper traces that are exposed, five of these are power traces and the other are sense traces. These sensing traces are interlocked to make a single trace between every two power traces. The traces are not directly connected but are bridged by the fluid when the sensor is submerged. The exposed conductors act in a similar manner in that a variable resistor, specifically called a potentiometer, acts in a manner where its resistance varies according to the level of water it is exposed to. If the sensor is exposed to more water; that means more conductivity and, therefore, less resistance. If it is exposed to less water, that means less connectivity and, therefore, more resistance. This sensor is used to make sure the plant roots always have enough nutrient supply.

Figure 3 Water level sensor

c) **DHT11 SENSOR**

This sensor measures temperature and humidity. It has two components that are a thermistor and a humidity sensing element. The humidity sensing element consists of two electrodes with a substrate that can hold moisture in between. The water vapour released is absorbed by the substrate that increase conductivity between the electrodes. As a result, change in resistance is directly proportional to the relative humidity. High relative humidity corresponds to more conductivity, therefore, low resistance whereas low relative humidity corresponds to less conductivity between the electrodes and that means more resistance. For temperature measurement, DHT11 has a NTC (Negative Temperature Coefficient) thermistor which is a component whose resistance varies inversely with temperature. More resistance means low temperature. Less resistance means high temperature. This sensor is used to estimate relative humidity and atmospheric temperature that the system is exposed to.

Figure 4: DHT11 sensor

d) **WATERPROOF TEMPERATURE SENSOR**

Figure 5 is a waterproof temperature sensor DSB18B20. This is a sensor that can measure temperature in wet environments. It has a range that starts from -55 degrees to 125 degrees Celsius. This sensor is used in this work to monitor the nutrient solution.

Figure 5: Waterproof temperature sensor DSB18B20

e) **SUBMERSIBLE PUMP**

Figure 6 shows the image of a submersible pump. A submersible pump contains a motor inside the pump's fluid when submerged in it. In this work, a submersible pump is used to circulate the nutrient solution as it is immersed in the reservoir.

Figure 6: Submersible pump

ADVANCED MONITORING SYSTEMS AND IOT

Unfortunately, a pH sensor is quite expensive, so in this project, we monitored the pH of the solution manually using a digital pH meter. The meter measures the pH effectively, although it does not support the elimination of human inference. Continuous monitoring and adjusting of pH is very important as certain pH levels can prevent proper nutrient uptake by the plants. It is recommended to use a pH and an electrical conductivity (EC) sensor to monitor the nutrient solution to continue to reduce human inference.

FORMULATION OF THE NUTRIENT MEDIUM FOR THE HYDROPONICS SYSTEM

The water used to mix the nutrients was the waste water obtained in the city. The following three nutrient mixes are important to fertilize the system:

1. N-P-K fertilizer
2. Calcium nitrate
3. Epsom salt

Crops mostly require oxygen, hydrogen and carbon. They are also called macro-nutrients and these can be obtained from water and air. The primary nutrients are nitrogen, phosphorus and potassium which can be obtained from NPK fertilizer mixture. The secondary nutrients are calcium, magnesium and sulphur and these can be found in Epsom salt. The remaining nutrients are micro nutrients that can be supplied by addressing nutrient deficiencies when encountered.

The nutrient solution was then put into a reservoir and then pumped into the nutrient film hydroponics (NFT) shown in Figure 8. By use of sensors, this nutrient solution was maintained richly through recycling (adding of more nutrients to the same solution) after some two to three weeks. The same solution can be used throughout the growth period. Therefore, water is sustainably used and not wasted, unlike in other types of farming.

GROWTH ESTIMATION

Growth rate of the plants is measured after every seven days by measuring the stem length, number of leaves and noting the leaf colour. The growth is tabulated from the hydroponics plants. Comparison with results of traditional systems is done to check if our system has made any improvement.

SYSTEM ARCHITECTURE

Figure 8 shows the architecture of the system that consists of multiple sensors, anNodeMCU board embedded with a Wi-Fi Shield ESP8266 and a web server. NodeMCU is the controller of the system that receives data from the sensors then passes it to the World Wide Web. Data from sensors is combined to one string then converted to digital. After that, the micro-controller will send that string to the server through the ESP8266 Wi-Fi module. The server is used for processing and saving all values in the database. The system mechanism is as follows; the water level sensor measures the height of the hydroponics nutrient solution (in cm) and the water temperature is measured by DSB18B20 water proof sensor. The sensor DHT11 will detect the temperature in °C and measure humidity. The NodeMCU receives signals from the sensors in the form of voltages and it compares the values with those given as threshold values by the user in the code. It then makes a decision to notify the user. Periodically, results are updated on the Web server.

PROSPECTIVE AND CRITIAL OBSERVATIONS

The prospective and critial observations presented follow a logical sequence from the evaluation of car-wash water use, waste water generation, hydroponics system performance and collectable tomatoes yields.

WATER CONSUMPTION

Three types of car-wash systems, that is self-serve, in bay and conveyor systems where evaluated. The prospective and critial observations show clear differences with respect to the amount of water consumed per vehicle and the water lost to evaporation and carryout by car-wash type. Table 1 shows average values for freshwater consumption and evaporation and carryout for the three types of professional car-washes. The prospective, critial observations and discussion begin with a comparison of water consumption and evaporation and carryout losses by car-wash type.

Table 1: Average fresh water consumption and loss by car-wash type

Average Fresh Water Consumptions and Loss at Car-washes						
	Litres per vehicle			**Evaporation and Carry out**		
	A	B	C	A	B	C
Self-Serve	62	59	48	89	129	77
In Bay	92	155	281	115	111	127
Conveyor	133	103	170	59	62	65

In most cases, in-bay automatic car-washes consumed more fresh water per average car-wash at 163 litres per vehicle. The design of some in-bay and conveyor equipment with spray nozzles mounted on rapidly moving arms made the collection of data on individual components difficult, if not impossible in several circumstances.

The customer can purchase most in-bay automatic washes without leaving their vehicle. The customer chooses their wash option and pays. The equipment is provided by the manufacturer and is designed to run optimally at certain speeds and pressure settings. The owner/operator may make adjustments to water pressure and nozzle size, but of the three types, changes that affect water consumption rates are most constrained by the equipment. Conveyor car-washes give owner/operators greater flexibility in choosing the pressure settings and nozzles sizes for each cycle of the car-wash. The speed the conveyor which moves cars through the tunnel can also be adjusted. Minor adjustments may lead to large changes in water consumption per individual wash. Water use by arches or fixtures with spray nozzles may be adjusted by changing nozzle sizes or adjusting pressures. Cloth equipment, or "mitters" need less water once they are completely wet and the car-wash has been running for a period of time. These cloth features within the conveyor are among the lowest water-using cycles of the conveyor car-washes. At some of the sites, nozzles designed to wet the brushes were left off and the water on the car was allowed to wet the cloth equipment or mitter. Car-wash personnel performed prep work with handheld spray wands and/or brushes in nine of the 10 conveyors evaluated. This also contributed to variability of water use per vehicle in the conveyor car-wash.

WASTE WATER GENERATION

Among several types of wastewater, the carwash wastewater represents one of the heavily contaminated wastes with high impurities. It was due to presence of sand and particles, oil and grease, surfactants, detergent, phosphates and hydrofluoric acid. Therefore, the direct disposal for wastewater into the drainage exacerbates natural water pollution. On the other hand, the discharge of the car-washes wastewater directly into sewerage network might affect negatively the efficiency of the treatment processes of sewage due to presence of heavy metals. At least, it represents a burden on the sewage treatment plant.

The treatment of wastewater at the resource point is considered easier and more effective. This is because, the individual treatment process will take sufficient time to remove most impurities and contaminants. Indeed, the treatment of small amount of wastewater does not require a complicated treatment system to produce high quality of treated wastewater that could then be channelled to the tomato hydroponics plant. Moreover, the simple system might be more efficient to produce good quality of treated wastewater which is suitable for car-wash again. There are no quality regulations for the water that are used for car-wash. Therefore, the wastewater generated from car-washes with high turbidity might be treated using coagulation and flocculation methods and reused. Both methods are efficient for turbidity and economic saving. To improve the water quality characteristics, an integrated treatment system might be provided.

HYDROPONICS SYSTEMS DESIGN

The use of wastewater in agriculture is common practice in order to provide a reliable source of water for irrigation and to add valuable nutrients and organic matters to soil. Where environmental standards are applied, wastewater is treated firstly before being used for urban irrigation as is the case for this tomato hydroponics system. On the other hand, untreated wastewater is widely used for irrigation and watering of agriculture lands. This is one of the most significant sources of environmental pollution that directly affects human health via crops and soil. Untreated car-wash wastewater has oil and grease that mostly contain hazardous compounds, such as arsenic, benzene, chromium, lead zinc and many carcinogenic toxic materials.

Degradation of water quality can pose serious threats due to high population growth and rapid urbanisation. Due to water scarcity, its re-use in urban agriculture is indispensable, hence the design of this tomato hydroponics system for urban farming of tomatoes. Figure 8 shows the NFT hydroponics system set up with tomato plant. The system requires materials, such as the nutrient solution, water, light, air and some human support such as monitoring and adjusting of these environmental parameters. The remote monitoring of these parameters is done successfully. Thresholds are set in the programming code and if any of the tracked parameters goes out of the safe range, i.e. the range that is most conducive for the tomato crop to grow ideally, it is seen on the web interface wherever in the world as long as the user has internet access. This system is very economical.

Figure 7: System orientation

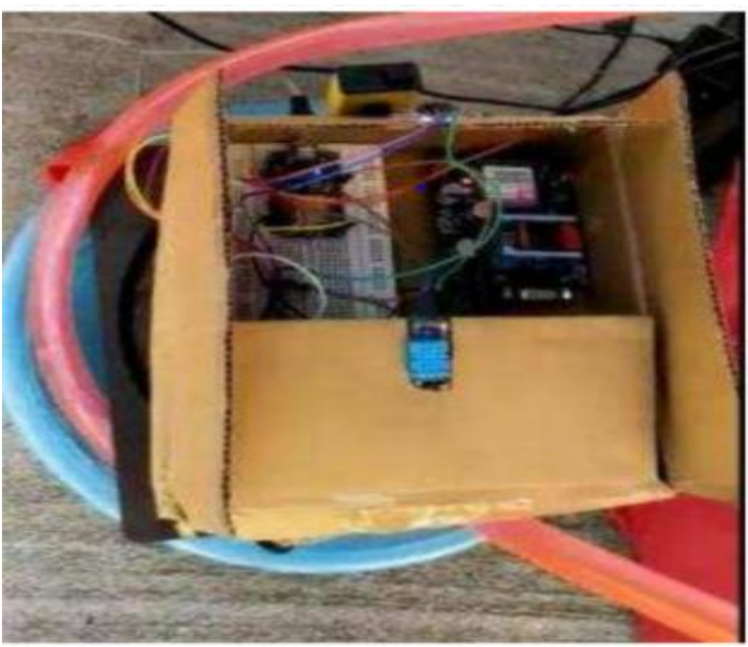

Figure 8 hardware orientation

It is then observed that the crops planted in this system grow faster and the water and nutrient usage is actually less but effective as compared to soil-based farming as it is controlled by NodeMCU.

Table 2: The Data resulted in NodeMCU and Web

Data in the NodeMCU				Data from Web		
Number of tests	**Time of the day**	**Temperature in °C**	**Height (cm) Water level**	**Temperature in °C**	**Water level (cm)**	**Delay in Seconds**
1	06.00	28,50°C	0	28,50°C	0	4
2	12.00	35,41°C	3	35,41°C	3	5
3	18.00	30,20°C	2	30,20°C	2	3
4	00.00	29,10°C	3	29,10°C	3	1
5	06.00	28,23°C	4	28,23°C	4	3

The above table shows that the information seen directly on the NodeMCU are the same with those visualised on the web interface, despite some delays. The table also indicates the average recorded temperatures at certain times of the day. The NodeMCU is programmed to notify the user on the website by changing the colour from yellow to red on the indicator wherever there are abnormal changes or when the values of any of the parameters goes out of the safe range. By so doing, the monitoring of the system is made easier and the user does not need to be always on site. Table 3 shows a comparison of the different heights of the tomato plants after 30 days in soil and hydroponics medium.

Table 3: Height of plant after 30 days

Tomato plant		**Plant height (mm)**
Planting method	Hydroponics	375
	Soil	300

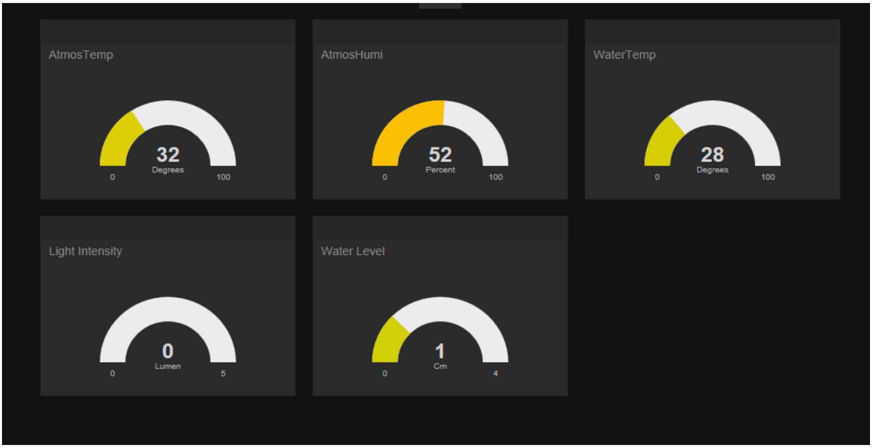

Figure 9: Data from all the sensors shown in one web page in real time

Figure 9 shows how the sensor information is displayed on the web interface. The same information can be visualised directly on the nodeMCU.

DISCUSSION

The experiment took a month and half to complete. A parallel experiment was run, consisting of tomatoes planted using the traditional soil-based farming method. The growth of the plant was measured after 30 days in both mediums and a difference is seen. The data shows clearly that the plants grown using hydroponics grew faster than the ones grown using soil-based farming. It is noticeable that the plants grown in hydroponics medium are healthier and greener. Recycling of the nutrient solution has been proved in this experiment, after every two weeks and the results in saving of water were highly commendable. In soil-based farming, watering is required by the plants and because of high temperatures, it is done twice a day. In this hydroponics plant system, it is observed that the average height of the nutrient solution in the PVC pipe is 4cm and the optimum temperature is 32 degrees.

CONCLUSION

This study brought to light a number of facts about the professional car-wash industry, water use and losses to evaporation and carryout through the use of field data. Regional differences in water consumption based on climate do not appear to be significant. This indicates that water losses due to carryout seem to take a greater part of the total losses due to evaporation and carryout. Evaporation and carryout combined appeared to be consistent across regional boundaries. IoT has been used to achieve smart agriculture using hydroponic farming as a dual solution to urban water pollution and food deficiency. The systems architecture proved to be efficient and effective in monitoring atmospheric temperature, nutrient temperature, nutrient level and humidity. Real time and remote monitoring are made possible by the IoT technology through a web interface. Finally, we conclude that smart hydroponic farming is more efficient than soil-based farming and it can save many resources, such as water, nutrients and labour that lead to a sustainable solution. Growing tomatoes hydroponically allows the grower to raise them in a controlled environment with less chance of disease, faster growth and greater fruit yield. However, hydroponic gardening is much more labour intensive and sometimes more expensive, than ordinary tomato planting.

For future research, developers must aim on introducing some intelligence, such as machine-learning to monitor systems and guide the process. Controlling of parameters such as, CO^2 should also be considered as this is very crucial for growth. Our Nutrient Film Technique system is designed on a small scale, so we expect future developers to transform it into a wider scale. In this project, we ended on the storing of data on Cloud and access of such data through a web interface. So, future researchers need to design and develop tools and system that have information panel apps that can be found on different platforms, such as IOS Android and Windows amongst others.

REFERENCES

Brazier, A. (2015). *Climate Change in Zimbabwe: Facts for Planners and Decision Makers*. Harare: Konrad-Adenauer-Stiftung.

Broadbent, L. (1976). Epidemiology and Control of Tomato Mosaic Virus. *Annual Review of Phytopathology*, 14(1), 75-96.

Brown, C. (2002). Water Use in the Professional Car Wash Industry A Report for the International Carwash Association, Inc. London: International Carwash Association

Charumathi, S., Kaviya, R.M., Kumariyarasi, J., Manisha, R. and Dhivya, P. (2017). Optimization and Control of Hydroponics Agriculture Using IOT. *Asian J. Appl. Sci. Technol*, 1(2), 96-98.

Cindy, R. (2016). Article 4-2 Home Grown Tomatoes Compliments of Homegrown Hydroponics Available online: http://www.simplyhydro.com/home_grow_tomatoes.htm. Accessed on 23 September 2020.

Crisnapati, P.N., Wardana, I.N.K., Aryanto, I.K.A.A. and Hermawan, A. (2017). August. Hommons: Hydroponic Management and Monitoring System for An IOT Based NFT Farm Using Web Technology. In 2017 5th International Conference on Cyber and IT Service Management.

De Zeeuw, H. and Dubbeling, M. (2009). *Cities, Food and Agriculture: Challenges and the Way Forward*, Leusden: RUAF Foundation.

Hilhorst, H.W., Groot, S.P. and Bino, R.J. (1998). The Tomato Seed as a Model System to Study Seed Development and Germination. *Acta Botanica Neerlandica*, 47(2), 169-183.

Homehydrosystems.com. (2020). Hydroponic Ebb and Flow, Flood and Drain Systems. Available online: http://www.homehydrosystems.com/hydroponic-systems/ebbflow_systems.html.Accessed 20 November 2020.

Mohammed, S. (2018). *Tomorrow's Agriculture: "NFT Hydroponics"-Grow Within Your Budget*. Amsterdam: Springer International Publishing.

Nalwade, R. and Mote, T. (2017). Hydroponics Farming. In: 2017 International Conference on Trends in Electronics and Informatics (ICEI).

Nursyahid, A., Wibisono, M.R., Wardihani, E.D. and Setyawan, T.A. (2017). October. Plant Age Identification System of Outdoor Hydroponic Cultivation Based on Digital Image Processing. In 2017 4th International Conference on Information Technology, Computer and Electrical Engineering (ICITACEE).

Pdf-book-search.com. (2020). Chapter 9: Road Transport Services and Infrastructure | Pdf Book Manual Free Download. Available online: https://www.pdf-book-search.com/9/chapter-9-road-transport-services-and-infrastructure.html. Accessed 30 September 2020.

Peet, M.M. and Welles, G.W.H. (2005). Greenhouse Tomato Production. *Crop Production Science in Horticulture*, 13, 257-264.

Sonneveld, C. (2000). Effects of Salinity on Substrate Grown Vegetables and Ornamentals in Greenhouse Horticulture. Available online: https://library.wur.nl/WebQuery/wurpubs/66179. Accessed on 23 September 2020.

Wfp.org. (2020). Urgent International Support Needed to Prevent Millions of Desperate Zimbabweans Plunging Deeper into Hunger | World Food Programme. Available online: <https://www.wfp.org/news/urgent-international-support-needed-prevent-millions-desperate-zimbabwe. Accessed on 23 September 2020.

Whatley Sr, W. J. (1994). *U.S. Patent No. 5,363,868*. Washington, DC: U.S. Patent and Trademark Office.

Winsor, G. W. (1979). Some Factors Affecting the Quality and Composition of Tomatoes. In *Symposium on Quality of Vegetables 93*. Available online: https://www.ishs.org/ishs-article/93_32. Accessed on 23 August 2020.

Zaneti, R., Etchepare, R. and Rubio, J. (2011). Car Wash Wastewater Reclamation. Full-Scale Application and Upcoming Features. *Resources, Conservation and Recycling*, 55(11), 953-959.