AUTOMATED IRRIGATION AND RAINWATER HARVEST FOR SUSTAINABLE COMMUNITY FARMING: A REVIEW

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ABSTRACT

Community farming is an initiative set out by the Malaysian Government to help the low-income group in reducing their household expenditure thus increasing the income of the members. The farm is cultivated in a designated land area near the residence by the community members. Although a fully automated system is available for mass plantation and agriculture industry, the same implementation in community farming is limited since community farming is relatively new and meant for sustenance rather than profit. In Malaysia recently, irrigation efficiency is approximated at 40% to 50% and becomes a challenge to water resource sustainability. It is crucial to study the feasibility of upgrading the community farming to make it more standalone, automated and easier to be cared for by the community members. The objective of this paper is to present a review on the Rainwater Harvesting System (RWHS) sustainability and automated irrigation method suitable for implementation in community farms. This paper further highlights the importance of introducing automated systems in community farms to benefit and improve the economy and social aspects of low-income group earners. The result shows the adoption of RWHS for irrigation purposes in various countries gives positive impacts on sustainability. The study also shows that various methods have been implemented in the agriculture industry in terms of irrigation including timer based, sensor based and plant based in combination with controllers such as Arduino or PIC microcontroller. Sensor based presented a precise watering system which takes into account parameters such as soil moisture, temperature, humidity and overwatering. Malaysia with high annual rainfall and installation of automated irrigation with rainwater harvesting will improve community farms which are generally located in urban areas without natural water resources. The notable contribution of this paper is highlighting the importance of improving community farms in terms of technological advancement with the implementation of automated irrigation and rainwater harvest integration. This will provide a sustainable solution for community farms in Malaysia.

Keywords: Irrigation, rainwater harvest, community farm, sustainability

INTRODUCTION

The first community farm in Malaysia is located in Presint 9, Putrajaya which was inaugurated in 2008. During the 2021 budget, the Malaysian government has allocated RM 30 million worth of fertilization kit and planting medium that is expected to benefit 60,000 community members. Community farm is cultivated by the community members in a land area of minimum 929 m^2 within a radius of 800 m from the community border. Considering many low-income group earners working multiple jobs with minimal time for maintaining the community farm, this problem can be rectified by implementing a smart system which includes the irrigation and monitoring aspect of the community farm.

Malaysia has recorded an annual rainfall of 1800 mm to 4600 mm with the highest recorded in Sarawak in 2019. To date, community farms are cultivated in Selangor and Putrajaya with an annual rainfall of 2200 mm to 3600 mm. Although water tariff in Malaysia is low averaged at RM 1.38 /m3; in recent years, water interruption is regular especially in Selangor due to pollution and maintenance work. In addition, Malaysia's domestic consumption which ranges from 209 to 228 liters per capita per day is higher compared to 165 liters per capita per day as recommended by World Health Organization (WHO).

Various irrigation methods are available namely surface, sub-surface, sprinkler and drip irrigation. For community farming which falls under small-scale farming, surface irrigation is used whereby the water is distributed to the soil by means of gravity. Surface irrigation is also the most common method which is used on 85% irrigated crop land throughout the world (Munoth et al., 2016).

In Malaysia, irrigation is traditionally done using ditch irrigation in conjunction with seasonal planting which is done during the rainy season (Toriman & Mokhtar, 2012). Ditch irrigation requires the plantation area to be located near natural water resources using a number of canals which is not feasible in community farming. Rise of awareness on sustainability issues such as water shortage and reduction of water quality have led to studies and implementation of technological innovations in water management (García et al., 2020). This includes automated irrigation and precision agriculture. Irrigation schemes for small scale agriculture have less than 40% efficiency caused by un-recycled water from the irrigation system which became a degrading factor in water sustainability (Toriman & Mokhtar, 2012).

Technical papers focusing on technology advancement in community farms around Malaysia are limited as can be shown by Table 1. Table 1 summarises the literature which discusses either community farm and community related urban farming in Malaysia within the year 2019 to 2020. Community farm is a form of urban farming which is cultivated by a group of people in a specific area whereas urban farming is the broader concept of farming and can be executed either individually or by group.

Table 1: Summary of literature discussing community farm and urban farming in Malaysia

Authors	Scope	Main Focus	Analysis			
			Technology	Economy	Social	Environment
Jamari et al (2020)	Community Farm	Automated pesticide sprayer	●			●
Sandran et al. (2020)	Community Farm	Perception of consumers			●	
Tajuddin et al (2019)	Community Farm	Communal involvement factor		●	●	
Muhammad et al. (2020)	Community / Urban Farming	Impact on community	●	●	●	
Nazuri et al. (2019)	Community / Urban Farming	Social capital of participant			●	
Hussain et al. (2019)	Community / Urban Farming	Perception and participation of community			●	
Hussain et al. (2020)	Urban Farming	Rooftop farming	●			●
Ibrahim et al. (2020)	Urban Farming	Farming framework	●	●	●	●
Kalantari et al. (2020)	Urban Farming	Vertical farming	●			●
Othman et al. (2019)	Urban Farming	Participation motivation			●	
Othman et al. (2020)	Urban Farming	Participation factor			●	

From Table 1, it can be seen that only 27% of the technical papers focus specifically on community farms and only 18% presented technology advancement for community farms. Majority of available literature considers urban farming which may not entirely be applicable to community farms. Literature which focuses on automated irrigation on community farms is quite limited which becomes the main focus of this paper to discuss. The discussion of RWHS is included with the integration of automated irrigation to enhance the sustainability aspect.

Malaysians in general have long working hours with most are dual-income families which resulted with minimal leisure time for families (Hasan et al, 2017) let alone extra hours to maintain the community farm. Thus, it is crucial to study the feasibility of upgrading the community farming making it more standalone, automated and easier to be cared for by the community members. The objective of this paper is to present a review on the Rainwater Harvesting System (RWHS) sustainability and automated irrigation method suitable for implementation in community farming. This paper further highlights the importance of introducing automated systems in community farms to benefit and improve the economy and social aspects of low-income group earners.

MATERIALS AND METHODS

This study started with literature review by analysing academic databases. The keyword-based search was performed in the main academic search engine including ISI Web of Knowledge, Scopus SciVerse and Google Scholar. The keywords used (combined with "irrigation" and "rainwater harvest" are: automation, sensors, sustainability, community farm, urban farming and agriculture. The recent publication (ranging from 2016 to 2021) comprising books, conference publications and journal articles were reviewed and selected based on preliminary skim reading of the abstracts and main body of the literature. Additionally, relevant handbooks, policies, and regulations related to the rainwater harvesting and community farming in Malaysia supply materials that could be used in the study were reviewed. The study explored current research on the automated irrigation and rainwater harvest for sustainable community farming to identify the feasibility of implementing the system in Malaysia. Analysis of the literature further discussed the working principle, types and required connections of automated systems generally used in irrigation.

RESULTS AND DISCUSSIONS

The analysis of the literature is divided into two sections. The first section examines the sustainability of the rainwater harvesting system for farming irrigation. The triple bottom line of sustainability concerning economics, environmental, and social, together with the advance technology are analysed. Meanwhile, section two focuses on the methods available in automated irrigation systems. In this section, discussion on the latest technology on automated irrigation are presented inclusive of timer, sensors, parameters measured and working principles.

A) SUSTAINABLE RWHS FOR IRRIGATION APPLICATION

Sustainable rainwater harvesting is gaining recognition for modern and urban agriculture practice, not only for large scale farming application, but small farms including community farming. Although the RWHS has utilised since ancient times, the latest technology has been developed and adopted to increase the efficiency, safety, and quality of the rainwater harvesting for water supply and irrigation without neglecting the environmental, social, and economical components (Rahman, 2017). Amos et al., (2018) emphasised that RWHS are beneficial in sustaining the food production in urban agriculture thus growing food security in a sustainable way. There is several literature addressing the triple bottom line of sustainability analysis on the rainwater harvesting system, in addition to technology advancement proposed by researchers as summarised in Table 2. Table 2 also presented the geographic location, RWHS catchment type and application in which the focus of the study was conducted.

Analysis on the economic feasibility of adopting RWHS for irrigation has been explored by researchers. The RWHS is also gaining serious consideration for irrigation of aquaponics systems that fit into the principle of circular economy for cultivation of various plants and fish species. Mao et al. (2021) suggested that rainwater catchment was preferred to use due to high quality of water and cost-effectiveness of building the system. The implementation of RWHS as alternative water resources in India shows effectiveness for farming activities and offered positive impact on farm income especially for low rainfall areas (Kumar et. al, 2016). The study also highlighted that the construction of RWHS is both capital- and labour-intensive process and capital was considered as a major constraint for the dryland farmers. Another study by Liang and van Dijk, (2016) discussed initial investment for construction of RWHS was approximately three times than annual income of the firms and the cost for operation and maintenance of the RWHS system were also high. To solve these issues, in some countries such as Beijing, subsidies were provided by the government for farmers to cover the cost of the initial investment.

In terms of social and environmental sustainability of RWHS, there were hesitation in utilising rainwater from RWHS for irrigation due to public concern that possible pollutants from the atmosphere come in the water and cause an absence of minerals especially for urban areas (Liang and van Dijk, 2016). It is important to improve confidence and awareness from the farmers and other stakeholders. Radzali et al. (2018) suggested performing a quality assessment including physical and chemical parameters of the harvested rainwater referring to the Standard Tests for Water and Wastewater. Environmental issues such as urban flooding can be mitigated with adoption of RWHS from the buildings and housing in that area (Rahman, 2017). The collected rainwater can be utilised for daily use such as toilet flushing and washing in the urban areas that have limited water supply.

Technology advancement for RWHS has been developed in various studies to fully utilise the rainwater harvesting around the world. From Table 2, there are many improvements reported in the literature regarding RWHS. The main focus of RWHS literature are rooftop catchment methods, and few studies analysed pond type catchment methods. It has been established that the rooftop catchment method has gained more reputation for modern and urban farming applications. In ensuring the collected water is safe and high quality, Mao et al. (2021) investigate the effect of roofing materials and the correlation between weather condition and water parameters in China. Meanwhile, a study on water quality for different roofing materials also has been carried out in Malaysia by Radzali et al. (2018) using remote sensing and GIS approach. Norman et al. (2019) utilised very high resolution optical remote sensing data and active systems and GIS modelling. The study confirmed that harvested rainwater quality can be affected by the quality of collected rainwater itself and the different storage media used to store rainwater. In Malaysia, Hafizi et al., (2018) suggested that utilisation of inert and environmentally friendly roof materials will result in higher water quality.

Liang and van Dijk, (2016) analysed non-technological and technological factors for RWHS for Beijing agriculture irrigation. The study discussed technical problems limiting the use of RWHS especially drip irrigation that has been implemented by farmers in Beijing. Kumar et al., (2016) accessed the potential of RWHS to improve farm production in dryland areas of India, given the accessibility of applicable technology. Hasan et al. (2019) proposed storing rainwater in ponds for irrigation for rice cultivation in Tanore, Bangladesh and Blaney-Criddle technique was utilised to calculate total consumptive use requirement of rice. Novianto et al. (2020) proposed RWHS for aquaponics irrigation. The study emphasised that aquaponics planting systems required sufficient oxygen and suitable PH for the nitrification process from the harvested rainwater in Indonesia.

Table 2: Summary of literature focusing on sustainable RWHS for irrigation application

Authors	Geographic focus	Type of RWHS catchment	Irrigation Applications	Sustainability Analysis			
				Technology	Economic	Social	Environmental
Mao et al. (2021)	China	Rooftop	Water quality	•	•		
Aleksić and Šušteršič (2020)	Various countries	-	Aquaponic		•		
e Silva and Van Passel, (2020)	Brazil	-	Aquaponics		•	•	
Novianto et al. (2020)	Indonesia	-	Aquaponic	•		•	
Clark et al. (2019)	USA	Rooftop	Irrigation for lettuce				•
Hasan et al. (2019)	Bangladesh	Ponds	Irrigation for Paddy Cultivation	•			
Norman et al., (2019)	-	Rooftop	Water quality	•			•
Amos et al. (2018)	Australia and Kenya	Rooftop	Garden irrigation		•		
Hafizi, et al. (2018)	Malaysia	Rooftop Ponds	Garden irrigation	•	•	•	•
Radzali et al. (2018)	Malaysia	Rooftop	Water quality	•			•
Mucheru-Muna et al., (2017)	Kenya	Ponds, Terraces, Pits	Dry-spell & Permanent Irrigation	•	•	•	
Rahman (2017)	-	-	-	•	•	•	•
Kumar et al., (2016)	India	Ponds	Micro Irrigation	•	•		
Liang and van Dijk, (2016)	China	-	Drip Irrigation System	•	•	•	•

B) AUTOMATED IRRIGATION METHODS

Timer based irrigation is generally accepted and is the easiest form of automated watering. Timer based may be operated without the need of an additional pump if sufficient water pressure is available. Malaysia which has equatorial climate receives 12-13 daylight hours and has high humidity (70%-90%) thus watering is generally done 2 times a day in the early morning and late evening. Montesano et al. (2016) studied the implementation of timer-based irrigation against moisture sensor-based irrigation which resulted in timer-based irrigation having less water efficiency compared to moisture-based irrigation. In Malaysia, an irrigation timer costs around RM50 – RM100 per piece and the required quantity depends on the number of available water-taps in the plantation area.

Sensor based irrigation operates by comparing a measured parameter value against a pre-determined set point before correlating the amount of watering required for the intended area. A number of parameters can be measured using sensor-based irrigation such as moisture, temperature, humidity, conductivity, salinity etc. as shown in Table 3. According to Khan et al., (2018), the most important and common parameter to be measured in irrigation is the level of moisture in the soil. Whereas for atmospheric parameters, García et al., (2020) found that air temperature is the most measured and studied parameters by most researchers. Table 3 also summarises the related controller and communication protocol/technology integrated with the sensors in order to enable automated system and seamless information transfer of the parameter being measured.

Soil can be characterized into four (4) classes namely Clay, Silt, Sand and Gravel with each having a distinctive water holding limit hence multiple techniques are available in soil moisture estimation (Khan et al., 2018). Moisture sensors can be operated using soil resistivity measurements, tensiometers, infrared moisture balance measurements and dielectric techniques (Munoth et al., 2016). A study by Montesano et al., (2016) shows that different volumetric water content treatment will result in decrease in leaf area even though the products have the same final dry weight which shows that a precise set point of the sensors need to be determined in order to produce a high-quality product. Amiri et al., (2021) conducted a study to determine the appropriate location of the tensiometers in agriculture which recommended the tensiometers to be installed at a distance of 5-20 cm horizontal to the plant and 10-20 cm depth from soil surface. The study which measured root growth and water movement was conducted in Isfahan, Iran with 151 mm annual precipitation which is 10 times less than Malaysia.

Sensor based is a precise watering system which must be coupled with water pump, motor driver, valve/actuator and programmable controller which will allow control over the amount of water to be distributed to the plant. As shown in Table 3, various programmable controller can be integrated to the sensor, namely Arduino, Peripheral Interface Controller (PIC) and etc. The programmable controller requires communication protocol/technology such as Global System Mobile Communication (GSM), Wireless Sensor Network (WSN), Zigbee, (Radio Frequency Identification (RFID) or simply using hardwire connection. Use of microcontrollers can enhance the irrigation system by including the monitoring aspect, integration with IoT as well as enabling integration with renewable energy sources such as solar panels allowing a further standalone and sustainable system. As can be seen in Table 3, any type of sensors may be coupled with any type of controller and/or communication protocol/technology.

A simplified standalone automated watering system by Adam et al., (2021) operates by sensing the humidity of the surrounding atmosphere then correlates the water flow rate required for the measured condition using Arduino controller. The study found that when temperature is high, humidity is low and vice versa. During the day, when the temperature is high, humidity is low which will initiate water flow to the crops. Humidity measurement can be obtained by measuring noticeable water vapor, measuring genuine water vapor in a predetermined air volume and measuring noticeable moisture proportion the air can hold when contrasted with extreme measure (Khan et al., 2018). In-field sensor nodes in combination with Wireless Sensor Network (WSN) enable real time information such as soil moisture and crop growth to users for better crop management (Munoth et al., 2016). This will also allow precise irrigation scheduling to be performed by comparing the measured parameters against information from meteorological data from weather stations.

Table 3: Parameters measured using sensor-based irrigation.

Authors	Sensors						Controller	Communication Protocol/ Technology
	Moisture	Temperature	Dielectric	Conductivity	Salinity & pH	Humidity		
Adam et al (2021)		●				●	Arduino	Wired
Amiri et al (2021)	●							
García et al (2020)	●	●		●	●	●		WSN, RFID, Zigbee, Z-Wave, LTE, GSM
Khan et al (2018)	●	●	●			●	Arduino PIC	GSM, WSN, Zig-bee
Munoth et al (2016)	●	●	●	●	●			GSM WSN
Montesano et al (2016)	●			●				
Amardas & Rahim et al (2016)	●					●	PIC	Wired

Another interesting approach is the plant-based method which measures the plant condition rather than the soil or atmosphere surrounding the plant. This method which uses the plant as biosensor measures also the plant physiological response to water availability apart from soil and atmospheric condition (Fernández, 2017). The common measurement includes leaf or stem water status, sap flow, trunk, stem, and fruit diameters, and leaf thickness among other variables.

In general, the studies concluded that sensor-based irrigation will generate higher efficiency in the water used and increase in profit due to higher quality of produce. Various types of sensor-based irrigations are available to be used for specific measurement. Installation of sensor-based irrigation costs approximately 70-100 % more compared to timer based since the method requires additional equipment and the quantity of sensors is usually dependent on the number of plants or crops in the allocated area.

CONCLUSION

This study presented literature review on automated irrigation with rainwater harvesting and the suitability of implementation in community farming from 2016 to 2021. The analysis of the literature shows that RWHS provides positive sustainability benefits. Nevertheless, the investment cost and public confidence on harvested rainwater might be enhanced so that the applicability of RWHS could be achieved for small-scale agriculture including community farming. Sensor based irrigation will provide precise control in terms of water efficiency, higher crop quality and lower energy consumption. However, considering the community farm is generally done for sustenance of community members rather than profit, timer-based irrigation with 50% less cost compared to sensor based is recommended for community farms.

This study contributes by highlighting the importance of improving community farms in terms of technological advancement which is beneficial to community members. In combination with the subsidies from the government, this will further improve the lifestyle and well-being of the members which are generally from the low-income group. If the approach is implemented throughout Malaysia, water sustainability issues in Malaysia may be improved with the reduction of water usage subsequently regulate Malaysia's domestic water consumption within the limit set out by WHO.

For future work, the system may be further developed to include sensors which will increase the water efficiency as well as allowing monitoring of the system. Proper irrigation and monitoring may increase production and outweigh the installation cost in long term installation. For RWHS, catchment type may be upgraded to use sustainable material which will inherently increase the water quality.

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