UNIVERSITI PUTRA MALAYSIA

# *FEASIBILITY STUDY OF UTILIZING PHOTOVOLTAIC SURFACE AS RAINWATER CATCHMENT IN AGRIVOLTAIC FARMS INFRASTRUCTURE*

NG YIEN ZER

# FEASIBILITY STUDY OF UTILIZING PHOTOVOLTAIC SURFACE AS RAINWATER CATCHMENT IN AGRIVOLTAIC FARMS INFRASTRUCTURE

NG YIEN ZER

188098

PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF ENGINEERING PROCESS AND FOOD WITH HONOURS

DEPARTMENT OF PROCESS AND FOOD ENGINEERING

FACULTY OF ENGINEEERING

UNIVERSITI PUTRA MALAYSIA

2020

**ABSTRACT**

The idea of Agro-photovoltaic or Agrivoltaic farms is on the rise due to land and food scarcity issue. Meanwhile the freshwater scarcity and urban flooding issue has catalyzed the practice of rainwater harvesting, thus the idea of rainwater harvesting on the photovoltaic surface is suggested. This study investigates the feasibility of rainwater harvesting using the surface of photovoltaic modules and propose a fertigation system using water source from both rainwater and tap water. Several difference between common rooftop and photovoltaic are discussed, the quality of rainwater harvested by the PV module is examined and compared to the National Water Quality Standards for Malaysia. Several equations on rainwater harvesting are also discussed and demonstrated to provide some insights on the system. Based on the results, the author convinced that rainwater harvesting practice are feasible on the photovoltaic surface.

## TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| FST | Fertigation solution tank |
| HAVs | Hybrid Agrivoltaic System |
| LSH | Level switch (high) |
| LSL | Level switch (low) |
| PV | Photovoltaic |
| PWST | Plain water storage tank |
| RC | Runoff coefficient |
| RWHS | Rainwater harvesting system |
| RWST | Rainwater storage tank |
| USEPA | United States Environmental Protection Agency |
| WHO | World Health Organization |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Due to the increasing awareness in renewable energy resources, solar photovoltaic (PV) technology as one of the highest priorities by the means of the energy generation. Combined with support from the Ministry of Environment, Science, Technology, Energy and Climate Change (MESTECC), numerous large-scale solar PV projects are expected to be installed in the future. Issuing both land and food scarcity, the ideology of Agrivoltaic farm is receiving more acceptance, Agrivoltaic is defined as the utilization of a land area for both agricultural and power generation from solar PV.

On the other hand, freshwater scarcity has been a long-existed global issue due to increasing population. Since the Agrivoltaic farm itself needs water resources for irrigation purpose, harvesting rainwater would aid in the self-sustainability of the farm. Designing and optimizing a rainwater harvesting system (RWHS) require preliminary study on the specific demand and rainwater available on the study location. A small-scale prototype with capacity of 10kW peak, Hybrid Agrivoltaic System (HAVs) shown in Figure 1 and Figure 2 located in Faculty of Engineering, University Putra Malaysia, is selected as location of this study.

Figure 1: Agrivoltaic farm in HAVs, Faculty of Engineering, UPM

Figure 2: Agrivoltaic farm in HAVs, Faculty of Engineering, UPM

## 1.2 Problem Statement

Performance of RWHS and the challenge associate with it had been studied extensively for both domestic and commercial buildings, however, there is some limitation on the suitability of using PV modules as Rainwater Catchment for water collection in Agrivoltaic infrastructures. Performance of rainwater capturing by solar PV are different from common roof due to its material of construction, tilt angle and geometry, these factors affect the estimation on the rainwater harvested. As the rise of solar farm and potential Agrivoltaic farms, feasibility studies must be done on the PV surface as the potential candidate for rainwater capturing.

## 1.3 Objectives

The objective of current work is to study the feasibility of utilizing photovoltaic surface as rainwater catchment in Agrivoltaic farms infrastructure. The specific objectives are:

1) To conduct feasibility study on various aspects of Photovoltaic materials and Agrivoltaic infrastructure for rainwater harvesting
2) To propose an integrated PV rainwater catchment system for herbal crops fertigation

## 1.4 Scope of study

This study is conducted on small scale Agrivoltaic farm with capacity of 1kWp to obtain and demonstrate various equations on the RWHS in order to provide basic knowledge and guidelines for the future Agrivoltaic farmers willing to install RWHS. However, the study could not perfectly depict any others Agrivoltaic farms as each farm has different water demand and capacity, different study must be done for each individual Agrivoltaic farm.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Agrivoltaic farm

Agrivoltaic also known as agrophotovoltaic is the integration between agricultural activities and solar photovoltaic farm. Generally, there are two type of agrivolataic farm: roof or pole-mounted and ground mounted. These orientation are usually depended on the crops height and the machinery used to manage them. The agrivoltaic farm in HAVs shown in Figure 1 and 2 previously are the example of ground mounting, Figure 3 below shows roof or pole-mounted agrivoltaic farms in the study done by Schindele et al. (2020) in Upper Swabia, Germany. Meanwhile, Figure 4 and 5 shows the schematic diagrams of both mounting type, adapted from (Dinesh &Pearce, 2016).

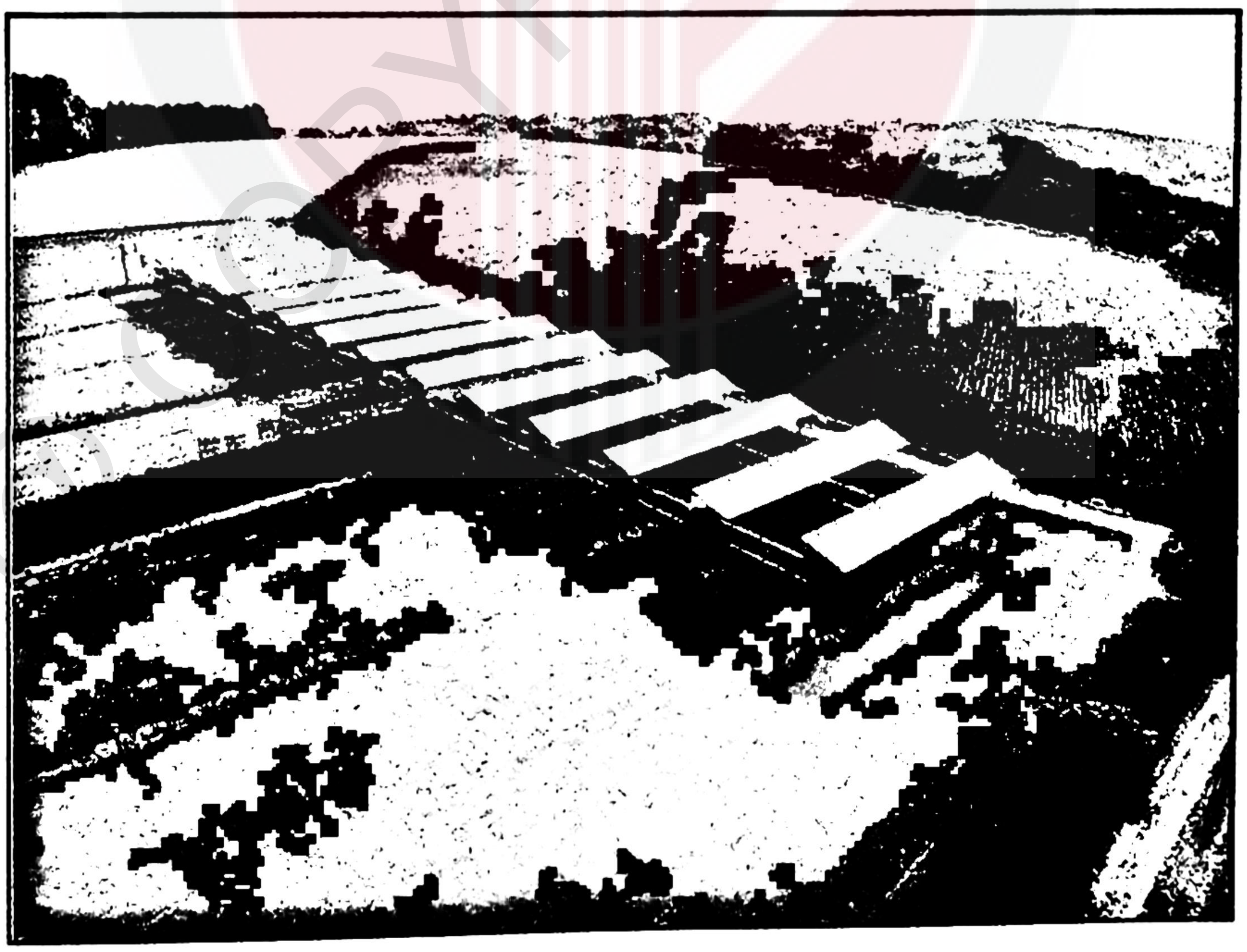

Figure 3: Agrivoltaic farm in Upper Swabia, Germany

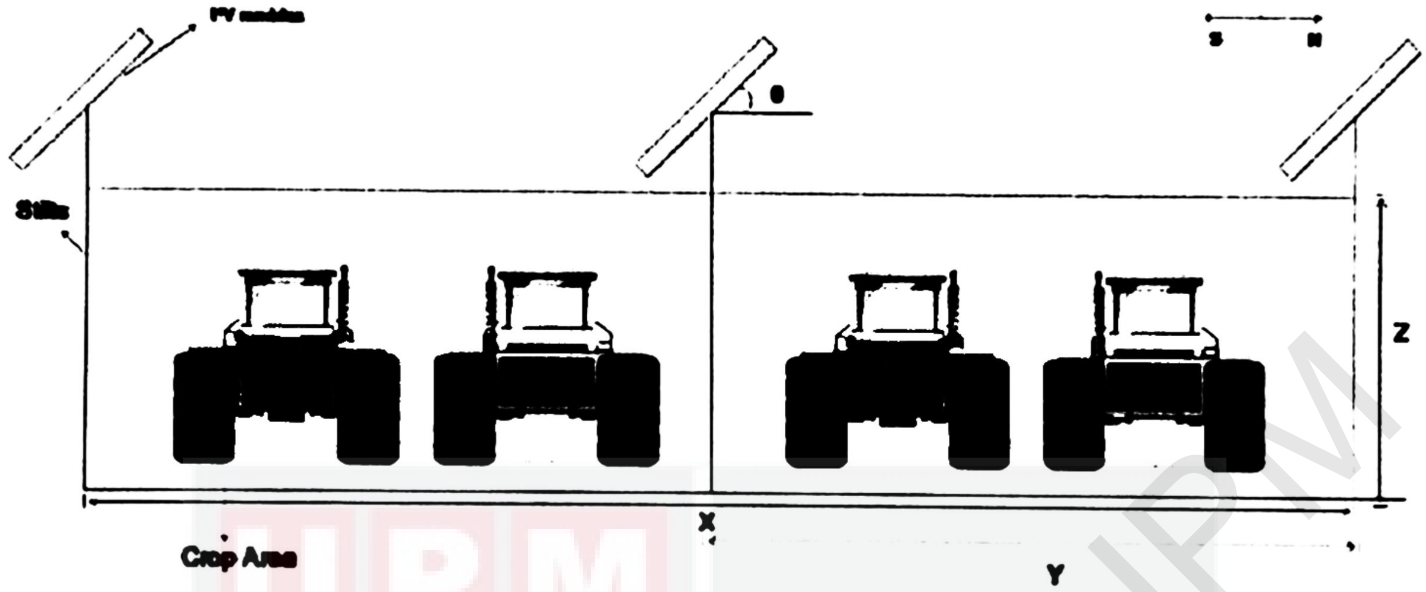


Figure 4: Schematic diagram of roof mounted agrivoltaic farm

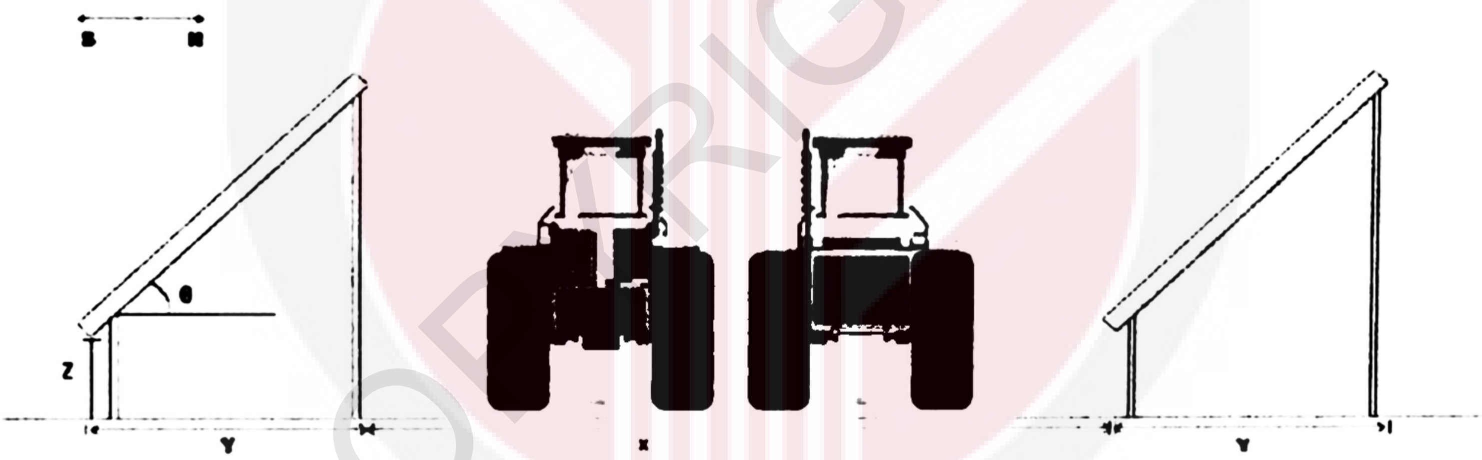


Figure 5: Schematic diagram of ground mounted agrivoltaic farm

The concept of Agrivoltaic farms has been well-accepted in the western countries, various studies on different type of crops have shown promising results. Study from Sekiyama &Nagashima (2019) using shade-intolerant crop, corn as the subject to their study, reported higher yield in low PV module density but vice versa in high module density compared to those grow without module installed overhead. Another study on maize done by Amaducci et al., (2018) found that the crop producing larger grain and more stable from those exposed in full light, this is due to the variation on soil temperature, evapotranspiration and soil water balance favoring the crop's growth. They also reported that the maize grows under PV experiencing drought stress, and thus increasing the crop's resistance to climate change.

In United State, if all 267,100 acres of conventional lettuce cultivation farms are transformed into Agrivoltaic farm, although the lettuce production is reduced by 34%, over 30% increment in overall revenue is still expected, generating 40-70 GW power at the same time (Dinesh &Pearce, 2016). Meanwhile, Malu et al., (2017) claimed that if all the existing 84,015 acres of grape farm in India convert into Agrivoltaic farm, the economic value will increase by more than 15 times and generating more than 16,000 GWh electricity annually.

All those studies conclude that Agrivoltaic farms provides better economic value compared to conventional agricultural farm.

## 2.2 Herbal crops for Agrivoltaic system

Agricultural activities are recognized as one of the National Key Economic Area (NKEA), in line with that, 16 Entry Point Project (EPP) and 11 Business Opportunities (BO) are introduced. Malaysia government had chosen the herbal industry as the first EPP, value of the industry is estimated around RM 17 billion in 2013 and projected to reach around RM 32 billion by 2020 (Mohd Hafizudin. Z., Roslina. A., Nor Amna A'liah. M.

N., 2013). Among many other herbs, *Orthosiphon Stamineus*, or commonly known as Cat Whiskers is selected and cultivated in the HAVs.

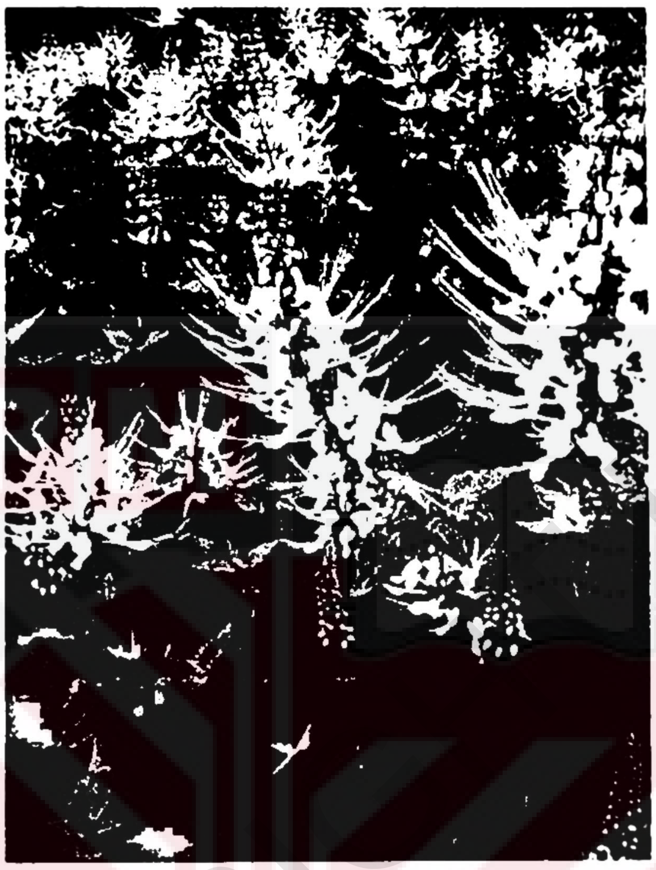

Figure 6: Orthosiphon Stamineus

The herbs can be grown during drought season (January - June) and require 40 – 50% shading (Jabatan Pertanian, n.d.), these two properties made the Cat Whiskers as one of the crop suitable to grown under solar PV. Previous study on financial analysis done by Othman et al., (2015) also verify the decision of choosing the herb as suitable crop for Agrivoltaic activity. The irrigation demand required by the herbs is one of the vital information to be known in designing the fertigation system, fortunately Yaseer Suhaimi & Abd Manas, (2016) from MARDI provided a guideline for farmers, the herbs require 3-6 times irrigation per day, consuming 150 – 250 *ml* water every times, depended on the season.

The herb is believed to exhibit antimicrobial, antioxidant, hepatoprotection, antigenotoxic, antiplasmodial, cytotoxic, cardioactive, antidiabetic, anti-inflammatory activities from various pharmaceutical studies (Ashraf, K. et al., 2018), it is believed able to treat hypertension, liver and kidney pains, and to promote excretory functions (Ariffin & Hasham, 2016). However, a study from Farhan, et al., (2012) pointed out the herbs that grown in open environment contains highest total phenolic content (TPC), gallic acid and antioxidant activity compared to those grown in shaded area. Another study done by Rahman et al., (2014) also pointed out the TPC and the antioxidant capacity of the herbs is affected by water stress, even though the yield of the leaves and stems remained unaffected. As discussed before, from the study done by Amaducci et al., (2018), Agrivoltaic activity would affect the soil water balance, and thus can contribute to the problem stated by Rahman, Shaari, Ahmad, & Mamat, (2014).

## 2.3 Rainwater Harvesting

Due to rapid urbanization and climate change, urban flash flood occurs more frequently while the other area experience draught, thus it is important to study the feasibility of RWHS to reduce the negative impacts (Yoke, Ling, Tan, &Ming, 2019). The RWHS are mainly consisted of catchment area, typically large rooftop area, rain gutter to transport the harvested water, first flush divertor/tank to capture heavily polluted water at the beginning of raining session, and a rainwater storage tank either above ground or underground, Figure 7 below shows a typical residential RWHS for both above and underground tank configuration, adapted from (Department of Irrigation and Drainage, 2012). The quality of rainwater harvested is mainly depended on the amount of pollutant existed in the rain and roof material, most of the time, the water is suitable for non-potable use but not safe enough for potable use without addition treatment (Kabbashi, Jami, Abdurahman, &Puad, 2020).

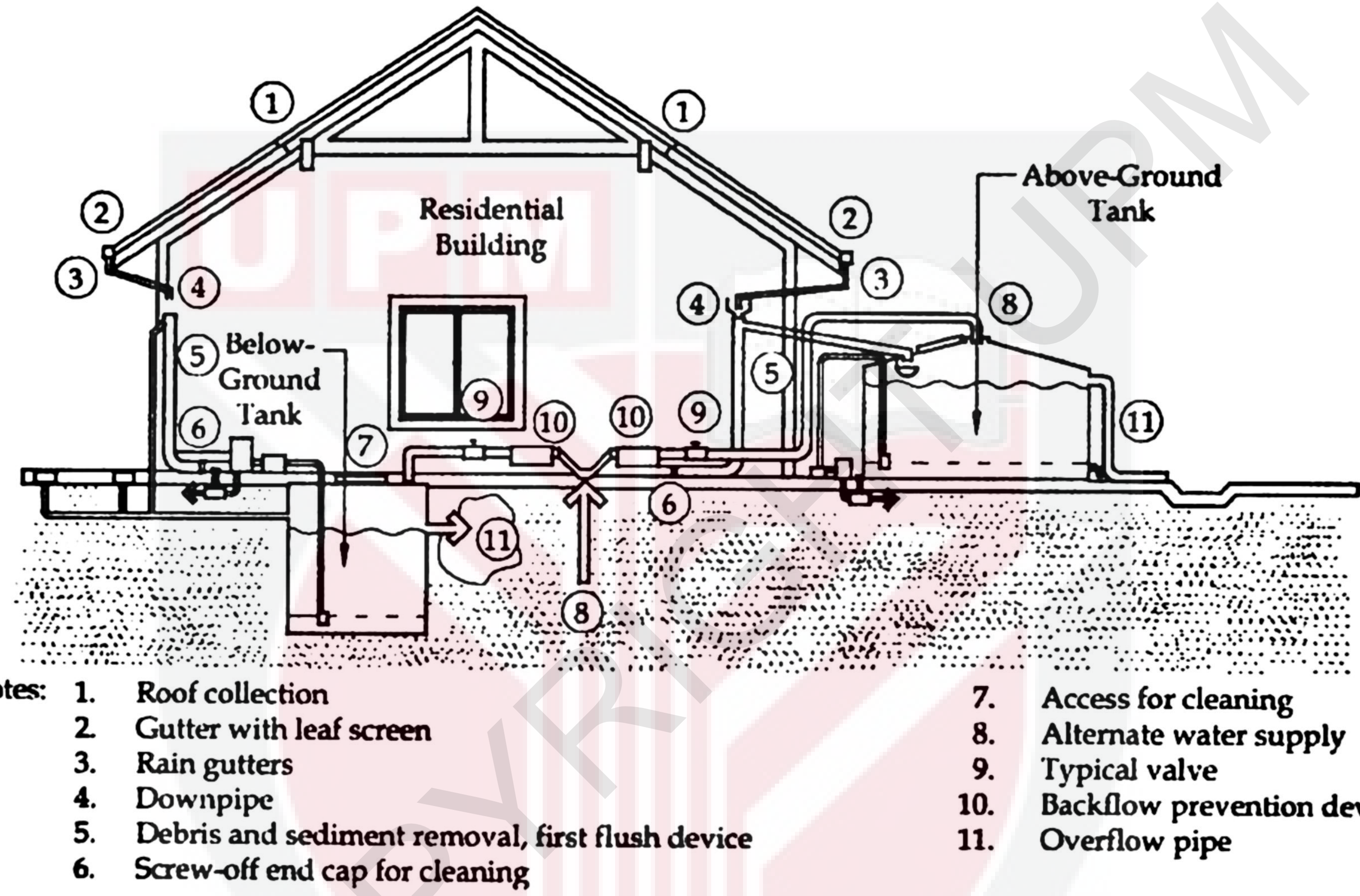


Figure 7: Typical residential RWHS

Study by Kuok &Chiu, (2020) focused on residence area in Sawarak, Malaysia where the domestic water rates are considered cheap, the authors concluded that the installation of RWHS are unlikely financial beneficial if no subsidy are provided. Despite the low acceptance of large scale RWHS in Malaysia, Lani, Syafiuddin, Yusop, Adam, &Amin (2018) found that large scale RWHS are more economic favorable over smaller scale. Meanwhile, Hamid &Nordin (2011) proposed RWHS on one of their university's residential colleges in Universiti Teknologi MARA (UiTM) Malaysia for non-potable uses, the authors estimated that RM 10,460 can be saved annually with RM 90,000 of investment. Therefore, the authors suggested that the top management of their university to consider RWHS as one of the green campus initiatives.

On the other hand, study done by Badiger (2012) focused on the implementation of RWHS among farmers found that those farmers having RWHS had increased crop yield and income, while the main barrier of keeping other farmers from implementing RWHS are high initial investment, lack of government support and fragmented land holdings. Despite of the advantages of Malaysia as tropical country with enormous rainfall and economic benefits, many property managers and residential developers still unwilling no install RWHS. Studies shown the low implementation of RWHS in Malaysia was due to insufficient financial incentive and subsidies from the government, lack of information regarding the technology, followed by environmental and health concern such as contamination of water collected and mosquito breeding in the tank and roof gutter (Mohammad, Yusof, &Musa, 2015)

Lastly, more efforts are needed to encourage the use and practice of rainwater harvesting, especially for existing houses. Incentives such as rebates or tax exemptions, education and raising awareness, guidelines, and restrictions in the usage of piped water should be introduced and implemented in order to encourage rainwater harvesting practice. To encourage public participation in rainwater harvesting practice, Government agencies and the mass media should promote the benefits and importance of rainwater harvesting and utilization through campaigns or by social media.

## 2.4 PV Catchment Mechanism

PV panel consisted of multilayer structure made from different materials, the main functioning layer is the photovoltaic cells, sandwiched by other protective layers to ensure the module survive nature weathering. Figure 8 below show the structure of the photovoltaic module.

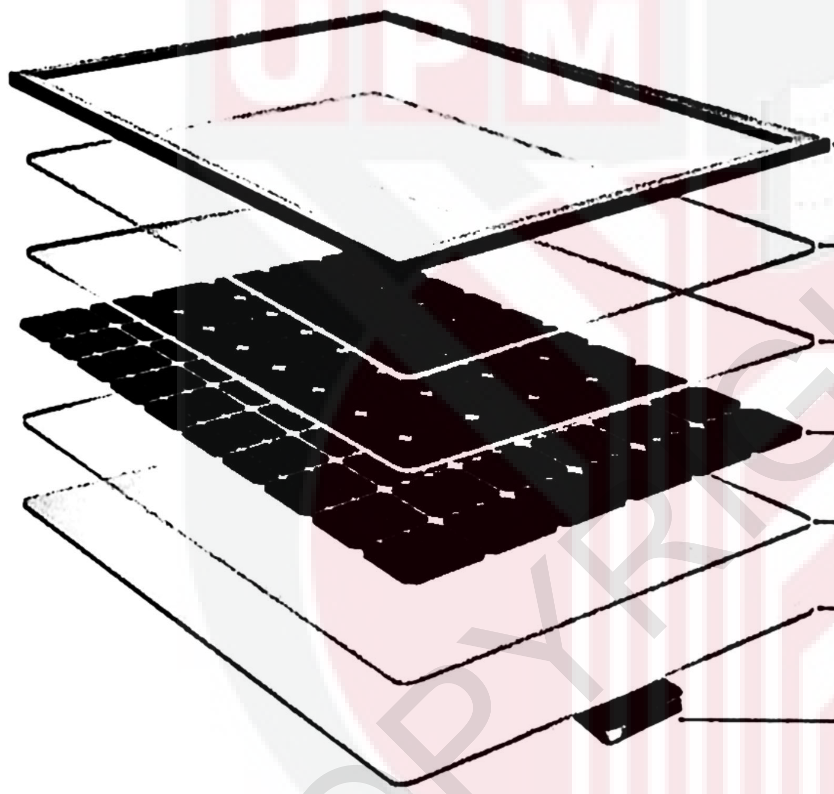


Figure 8: Structure of photovoltaic module

Studies had shown that rainwater harvested from common roof material had its heavy metal content elevated, particularly zinc and copper compared to United States Environmental Protection Agency (USEPA) water quality standards, Table 1 below shows some of the findings presented by Chang, McBroom, &Scott Beasley, (2004). Rainwater harvested also found to contains large amount of coliforms and unacceptable pH for potable use according to WHO standards (Yaziz, Gunting, Sapari, &Ghazali, 1989).

Table 1: Quality of rainwater harvested for different roof material

| Variable (*unit*) | Rainwater | Roof runoff | | | | USEPA Standard |
|---|---|---|---|---|---|---|
| | | Wood shingle | Composition shingle | Aluminum | Galvanized iron | |
| pH | 5.55 | 5.07 | 6.69 | 6.20 | 6.59 | 6.5–9.0 |
| Al (*mg/l*) | 0.354 | 0.382 | 0.495 | 0.381 | 0.435 | <0.750 |
| Mn (*mg/l*) | 0.030 | 0.044 | 0.028 | 0.015 | 0.017 | <0.050 |
| Cu (*mg/l*) | 0.043 | 0.029 | 0.025 | 0.026 | 0.028 | <0.013 |
| Pb (*mg/l*) | 0.034 | 0.045 | 0.038 | 0.037 | 0.049 | <0.065 |
| Zn (*mg/l*) | 0.139 | 16.317 | 1.372 | 3.230 | 11.788 | <0.120 |

Another study focused on the rainwater collected from organic photovoltaic cells (OPV), it is found that these cells started to fails within 6 month and emitted silver and zinc into the rainwater collected (Espinosa, Zimmermann, DosReis Benatto, Lenz, &Krebs, 2016). Similar study conducted on newly installed amorphous silicon thin film solar panel found that lead exceed the USEPA drinking water Maximum Contaminant Levels (MCLs) while cadmium barely make it through, however, none of the heavy metals exceeded the USEPA recommended limits for non-potable water reuse, and the author suggested it could be used for irrigation purposes (Gao &Kirisits, n.d.). Note that the study is done on newly installed panel, the authors did mentioned further study on degraded panel should be done as the metal are more probably to leached off due to the deterioration of the panel's protective layer.

Sinha et al. (2006) report that the accumulation of toxic metal, particularly chromium is more pronounced in leafy crops compared to fruit bearing crops. Meanwhile, presence of high concentration of lead and cadmium in soil and irrigation water had proved to reduce plant growth (Singh &Mohan, 2020). Another study revealed that the level of enzymatic and non-enzymatic antioxidants were much higher in vegetation irrigated with heavy metal contaminated waste water (Petrucci et al., 2020)(Hatamian, Rezaei Nejad, Kafi, Souri, &Shahbazi, 2020). Lastly, one study is done on the effect of lead and copper concentration in soil towards the physical and antioxidative responses of *Orthosiphon Stamineus,* the authors found that when lead is presence, leaf growth, total plant mass, catalase activity and flavonoid content is increased while phenolics contents decreased, meanwhile, presence of copper increase phenolics contents (Abd Manan et al., 2015).

To summarize, small amount of heavy metal is found leaching out into the rainwater harvested from relatively newly installed solar PV, even though the concentration is proven safe to be used for irrigation purposes, there is still no large scale studies done on the metal concentration in rainwater collected from the aged solar PV and whether it is safe to use it for irrigation purposes.

# CHAPTER 3

# METHODOLOGY

This study is done at the Hybrid Agrivoltaic system (HAVs), Faculty of Engineering, University Putra Malaysia, Serdang, Selangor. Brief discussion is done on the aspects of PV material and its structure as rainwater catchment. Quality of water harvested is assessed by comparing to the national water quality standard for irrigation purpose. The goal of this work is to study the feasibility of utilizing photovoltaic surface as rainwater catchment and thus propose a fertigation system in a 1kWp Agrivoltaic farms infrastructure.

## 3.1 Estimation of rainwater collection

The amount of rainwater to be captured can be estimated by the equation given by Cunliffe (1998) as:

$$\boldsymbol{Q = (P - L_w) \times A \times RC} \qquad \textit{Eq. 1}$$

Where:

$L_w$ is the loss associated with adsorption and wetting of surfaces, value of 2 mm per month (24 mm per year) is commonly used.

$A$ is the catchment area.

$RC$ is the runoff coefficient, which partially depends on the slope and roughness of the roof, some RC values of common roof material is shown in Table 2 below: (adapted from Farreny et al., 2011)

Table 2: Runoff coefficient (RC) estimates

| Roof | RC | Reference |
|---|---|---|
| Roofs (in general) | 0.7–0.9 | Pacey and Cullis (1989) |
| | 0.75–0.95 | ASCE (1969), McCuen (2004), Singh (1992), TxDOT (2009), Viessman and Lewis (2003) |
| | 0.85 | McCuen (2004), Rahman et al. (2010) |
| | 0.8–0.9 | Fewkes (2000) |
| | 0.8 | Ghisi et al. (2009) |
| | 0.8–0.95 | Lancaster (2006) |
| *Sloping roofs* | | |
| Concrete/ asphalt | 0.9 | Lancaster (2006) |
| Metal | 0.95 | Lancaster (2006) |
| | 0.81–0.84 | Liaw and Tsai (2004)) |
| Aluminium | 0.7 | Ward et al. (2010) |
| *Flat roofs* | | |
| Bituminous | 0.7 | Ward et al. (2010) |
| Gravel | 0.8–0.85 | Lancaster (2006) |
| Level cement | 0.81 | Liaw and Tsai (2004)) |

However, some sources does not account the $L_w$ value such as in study by Lani et al. (2018) and Kuok &Chiu (2020). Another justification to ignore the value is the top layer of solar panels are typically made of glass or plastic and it must be water-proof to protect the solar cell within, any water absorption by the top layer is not permissible, thus Equation 1 is simplified into:

$$Q = P \times A \times RC \qquad \textit{Eq. 2}$$

## 3.2 Estimation of water demand

### 3.2.1 Demand for irrigation

Irrigation water demand as the main water consumption in an Agrivoltaic farm, annum demand is calculated as:

$$D_i = Q_i \times f_i \times n_p \times 365\ d/y \qquad \textit{Eq. 3}$$

Where:

$Q_i$ is the volume of irrigation water required per plant per irrigation.

$f_i$ is the irrigation frequency per day.

$n_p$ is the total number of plants in the farm.

### 3.2.2 Demand on panel cleaning/ loss on first flush system

Deposition of dust and other undesired particulate such as bird droppings on the are known to reduce the panel's efficiency, affecting the quality of rainwater harvested at the same time. These problems can be countered by actively cleaning the panel or passively cleaned using first flush technology, both actions require water to execute, causing some water loss from it.

For active cleaning, most panel manufacturers recommend cleanings are done at least twice a year (Laura, 2018). Meanwhile, Santra et al. (2017) estimated that about 20,000 litter of water is required to clean every 0.5 MW block, the authors did mentioned the water used here could be recycled for irrigation purpose, thus it is assumed no water is used for active cleaning of the panels.

Next, for passive cleaning, by the means of first flush system, several sources presented the first flush volume as 10 gallon per 1,000 square feet or about 0.41 litter per square meter (Texas Water Development Board, 2003)(University of Hawaii, n.d.). However, Texas Water Development Board (2003) further explain the value is a general guideline, precise value can be obtained after study on the dust deposited on the roof, which is related to the number of dry days, amount and type of debris, tree overhang, and season.

Equation 2 is then can be modified to account water loss from first flush:

$$\boldsymbol{Q = [P - FF(f_{FF})] \times A \times RC} \qquad \textit{Eq. 4}$$

Where:

*FF* is first flush volume per area, 0.41 litter per square meter or 0.41 mm.

$f_{FF}$ is the annum first flush frequency, presuming first flush is done at any rainfall day. From figure 3 (adapted from Weather Atlas (n.d.)), the average annum rainfall day is 210, thus $f_{FF}$ = 210 day/year.

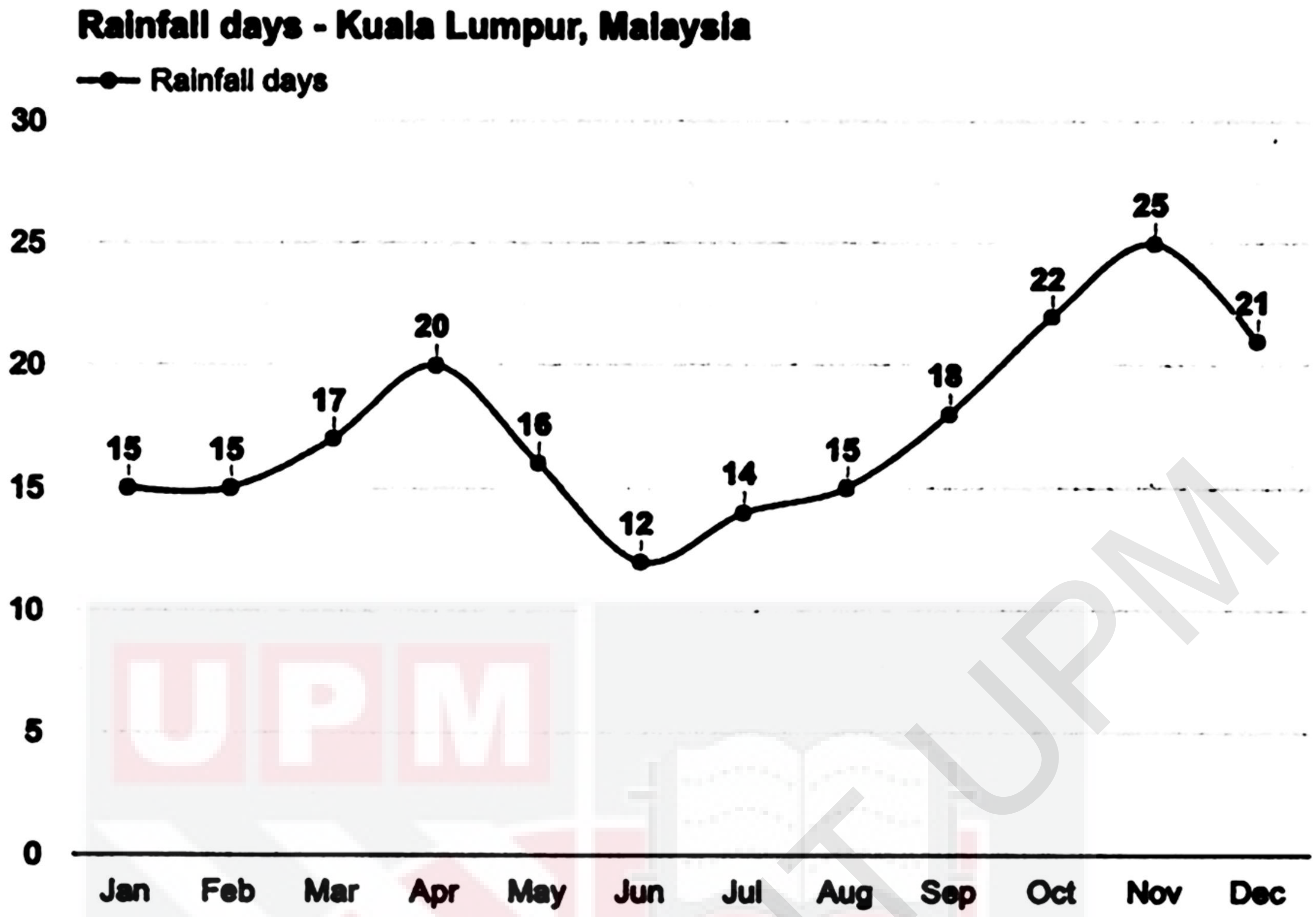


Figure 9: Average rainfall days data for Kuala Lumpur, Malaysia.

## 3.3 Sizing of rainwater storage tank

The main purpose of rainwater storage tank is to have sufficient water supply to meet the demand, since the demand is constant while the water source is based on the rainfall, the storage tank should be able to provide continuous water supply even though there is no rain fall for consecutive days, thus volume of rainwater storage tank is calculated using equation given in Kabbashi et al. (2020):

$$V = D_t \div 365\ d/y \times DP \qquad Eq. 5$$

Where:

$D_i$ is annum irrigation water demand

DP is the dry period, where the amount of consecutive days with no rainfall, data obtain from Subang Airport, Selangor, Malaysia, lasting from 1960 to 2011, the observed DP is about 20 days (Muhammad, Julien, &Salas, 2016). It is worth mention that the data covered 50 years period, taking DP as 20 days might have overshoot and high chance of oversizing the storage tank, thus 15 days of DP is presumed from the data shown in figure 3.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Rainwater harvesting in Agrivoltaic farms

### 4.1.1 PV material and structure

When investigating the feasibility of PV modules as rainwater catchment, the first aspect is the material of construction, the construction of PV module had shown in Figure 8 previously, the top layer which directly contact with the rain is made of glass. Comparing to other common roof material, glass can be considered as inert and does not absorb water, thus increasing its credibility as a rainwater catchment material.

There are two type of glass are commonly used as the top layer of PV module: tempered glass and flat plate glass. High quality monocrystalline and polycrystalline panels use tempered glass, while lower quality and most amorphous panels uses flat plate glass. Tempered glass is stronger and more durable than plate glass, providing long term protection against natural elements. Proper constructed PV should have passed various testing and in line with the International Electrotechnical Commission (IEC) standards IEC61730 and IEC61215.

Another aspect to be considered is the tilt angle, as general rule of thumb, PV modules are tilted based on the latitude of the location. In Malaysia, the optimum tilt angle is reported as 0° to 15°, while common roof pitch start from 15° to 60°, depended on the climate (Fadaeenejad, Radzi, Fadaeenejad, Zarif, &Gandomi, 2015). Aside from that, rather than having wave-shape like common roof, surface of PV panels is flat. This property might reduce the efficiency of the rainwater catchment, as wavy shape helps direct rainwater to the gutter.

As shown previous in equation 1 in Chapter 3, volume of rainwater collected depended on the runoff coefficient, while the coefficient depended on both climatic and architectural factors (Farreny et al., 2011). The difference between PV and common roof in both material of construction and structural aspects proves that further study on the coefficient must be done to provide more accurate estimation.

### 4.1.2 Rainwater quality and national standard

The quality of rainwater harvested from any roof surface is depended on many factors, such as the air pollution level of the area and the material construction of the roof. The quality rainwater harvested will deviate from location to location as the atmospheric pollutant content deviate. Fortunately, previous study done by Ya'acob, Salmiaton, Farid, &Othman (2016) at current study location reported the rainwater quality harvested from PV. Table 2 below summarize and comparing their finding to the National Water Quality Standards for Malaysia provided by Ministry of Natural Resources and Environment Malaysia, (2014), the full entry of the standard is attached in Appendix A. From Table 3, the concentration of copper exceeds the standard requirement by fivefold, while the fluoride concentration and pH values are barely passed the requirement. In general, elevated copper content can be toxic to certain plant. Study by Abd Manan et al., (2015) reported that *Orthosiphon Stamineus* is able survive even the copper concentration in soil as high as 5 mg/l and it adapt to metal stress by physical change and produce antioxidant compounds. Even so, first flush diverter is proposed in attempt to reduce the concentration of the copper in the harvested rainwater.

Table 3: Comparison of measured water quality and the standard

| Parameter (*unit*) | Measured | Standard |
|---|---|---|
| Phosphorus (*mg/l*) | 0.17 | No specify |
| Potassium (*mg/l*) | 0.46 | No specify |
| Calcium (*mg/l*) | 3.2 | No specify |
| Magnesium (*mg/l*) | 0.33 | No specify |
| Sodium (*mg/l*) | 0.83 | 3 SAR |
| pH | 5.1 | 5.0 - 9.0 |
| Fluoride (*mg/l*) | 1.0 | 1.0 |
| Chloride (*mg/l*) | 3.7 | 80 |
| Ammonium (*mg/l*) | 0.82 | No specify |
| Nitrate (*mg/l*) | 1.4 | 5.0 |
| Sulphate (*mg/l*) | 8.0 | No specify |
| Copper (*mg/l*) | 1.0 | 0.2 |
| Zinc (*mg/l*) | 0.11 | 2.0 |

## 4.2 Calculations and estimations

### 4.2.1 Estimation of rainwater collection

The precipitation data in Malaysia is shown in Figure 10 below (adapted from (Tan, Ibrahim, Duan, Cracknell, &Chaplot, 2015), the study location, Selangor is indicated by the red circle. The average annual precipitation in the study location is about 2500 mm/year.

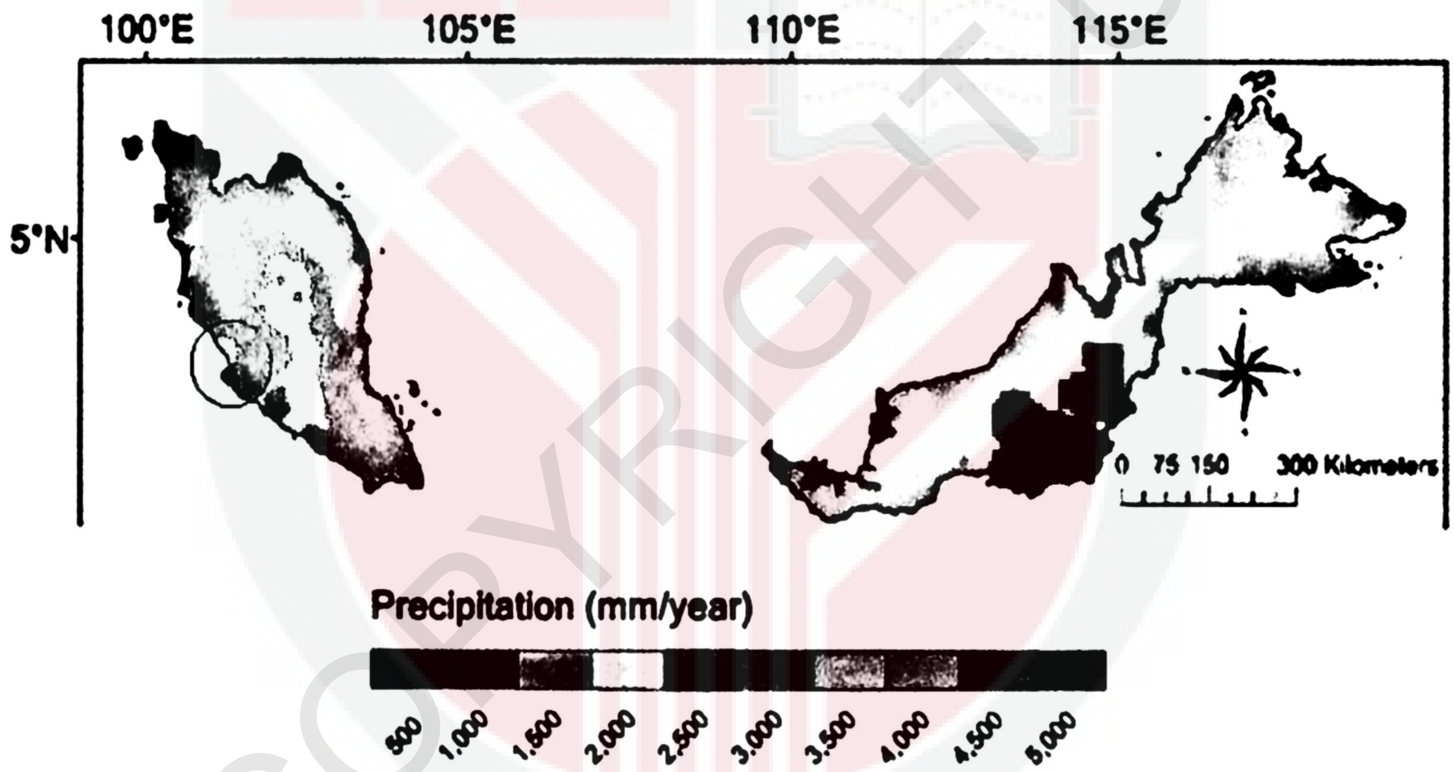


Figure 10: Annual rainfall intensity map over Malaysia

The runoff coefficient for glass material is not provided in Table 1, since the coefficient for most material ranged from 0.7 to 0.9, it is assumed to be 0.85. Lastly, the catchment area of the 1 kWp PV array is 11.632 $m^2$ (3.24 m * 3.59 m). Thus, by using Equation 4, the expected rainwater harvested is about 23,865 litter per year, after accounting loss from first flush.

### 4.2.2 Estimation of water demand

Currently, there are 70 units of *Orthosiphon Stamineus* being cultivated underneath the 1 kWp PV array. As discussed previously in section 2.2, the crop requires 3-6 times irrigation per day, consuming 150 – 250 *ml* every time. By taking average of 200 *ml* for 5 times per day, the water demand for the 70 plants is about 25,550 litter per year.

When comparing to the volume of rainwater harvested in previous section, the RWHS unable to fulfil the irrigation demand of 70 plants. By using the known values and equations, a maximum of 65 plants is proposed based on the volume of rainwater harvested. The proposed plant numbers are based on the following assumptions:

1. No addition water supply is available, and
2. All rainwater harvested is fully utilized, i.e. no overflow occurs in the rainwater storage tank.

### 4.2.3 Sizing of rainwater storage tank

Based on the Equation 5, the proposed tank size is 1050 litter. Based on 50 years of historical data in Selangor, the longest dry period on record is 20 days, thus the tank is designed to be able to fulfil all the irrigation demand for 70 plants even when there is no rainfall at all for 15 consecutive days. Since there is no data on average dry period, this estimation has a high chance to oversize the tank.

Another equation presented in Urban Stormwater Management Manual for Malaysia provided by Department of Irrigation and Drainage, (2012) to estimate rainwater storage tank size is given as:

$$V = 0.01A \qquad \textit{Eq. 6}$$

Where $V$ is tank size in $m^3$, and $A$ is catchment area

From this equation, the tank size is calculated as 0.12 $m^3$ or 120 litter, this tank size is unable to fulfil current irrigation demand if there is no rainfall for 2 days when there is no addition water supply available.

Thus, if addition water supply is available, smaller tank size can be used; vice versa, if no addition water supply is available, reliability study on the rainwater storage tank should be done to identify optimal tank size. Since the study location located in populated area where water supply is readily available, the reliability study is not necessary in this case, unless the Agrivoltaic farmer has the mean to only utilizing the rainwater harvested.

## 4.3 Proposed PV rainwater catchment system for herbal crops fertigation

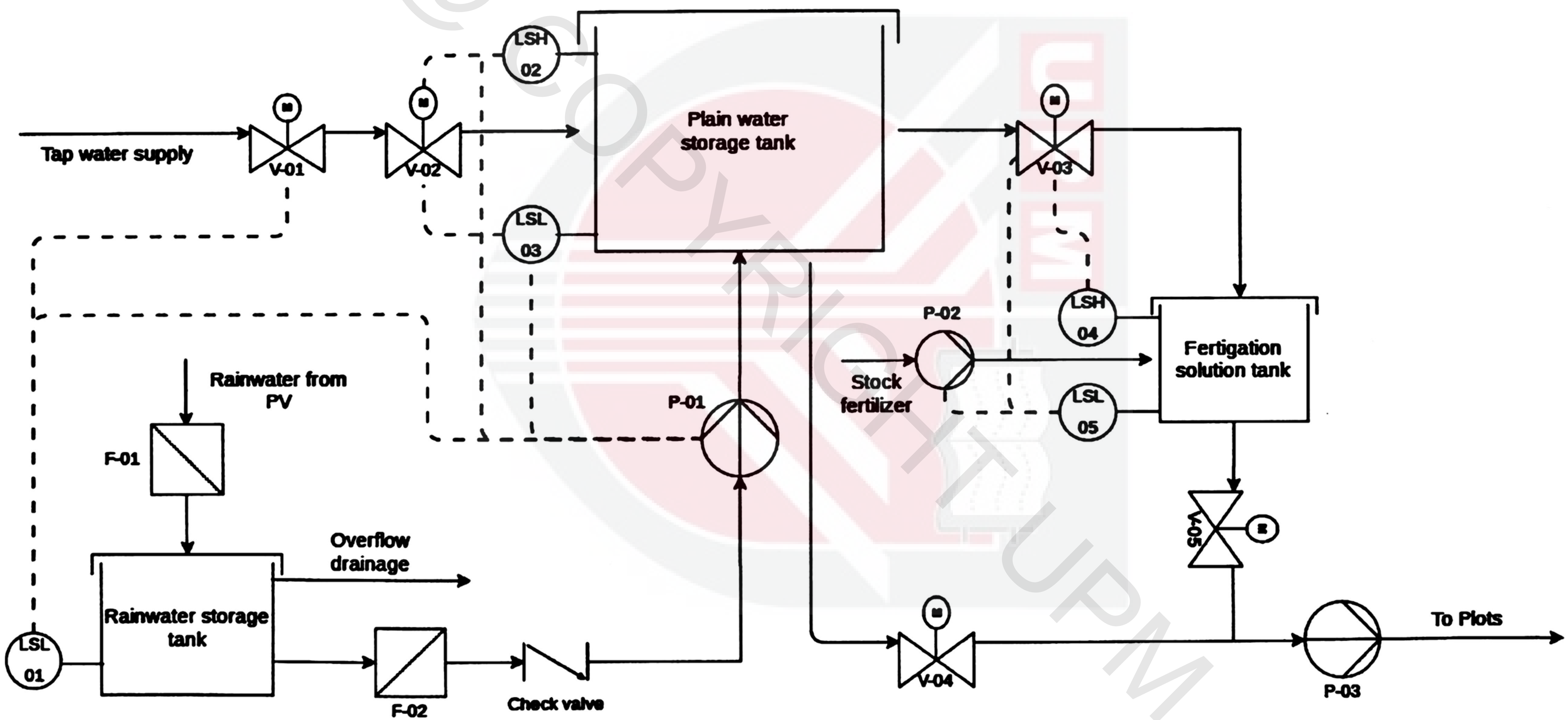


Figure 11: Piping and instrumentation diagram of proposed fertigation system

The fertigation system shown in Figure 12 utilizing rainwater collected from PV while provide sufficient irrigation for the crop in the Agrivoltaic farm. It is designed to be fully automated, provided there is enough of stock fertilizer to produce fertigation solution. In addition, tap water also connected to the system to act as alternative in case of the RWHS fails or no rainfall for more than 15 days.

Rainwater harvested by PV is filtered by strainer F-01 to remove unwanted materials such as leaves before entering the underground rainwater storage tank (RWST). The tank has a level switch (LSL 01) installed, when low water level is detected, it will turn on valve V-01. On the other hand, plain water storage tank (PWST) has both level switch (LSH-02 and LSL-03) installed to detect high water level and low water level respectively. When LSL-03 detected low water level, centrifugal pump (P-01) is turned on, rainwater from RWST is filtered again by strainer F-02 to remove potential sand or gravel to protect the pump. Since the pump work against gravity, check valve must be installed to prevent back flow. Moreover, if LSL-01 detected low water level in RWST, the pump is shut downed regardless the LSL-03 signal, this act as the other initiative to maximize the pump's lifespan.

When both RWST and PWST has low water level, both valve (V-01 and V-02) will opens to allow tap water to flow into PWST and V-02 will closes once the tank is full. Next, the fertigation solution tank (FST) holds the fertigation solution to be applied directly to the crops, when LSL-05 detected low water level, valve (V-03) opens to allow water from PWST flow in, the PWST is slightly elevated to allow gravity flow. At the same time, dosing pump (P-02) is activated for a fixed duration to pump in stock fertilizer, the operation of the pump is controlled by a timer, the time is depended on the capacity of the pump and the concentration of nutrient in the fertigation solution needed. Once LSH-04 detected high water level in the FST, V-03 is turned off. Lastly, the fertigation solution is pumped to the crops by centrifugal pump (P-03), the operation of the pump and both valve (V-04 and V-05) is controlled by timer, the operation time is depended on the pump capacity, fertigation frequency and fertigation volume needed. Table 4 below shows the operation summary for the whole system.

Table 4: Operation summary of the system.

| Case | Action | Consequence |
|---|---|---|
| RWST = 1<br>PWST = 1 | None | Excessive rainwater drained through overflow drainage. |
| RWST = 0<br>PWST = 0 | V-01 and V-02 opens<br>P-01 turned off | Tap water flows into PWST until it full. |
| RWST = 0<br>PWST = 1 | V-01 opens<br>P-01 turned off | None |
| RWST = 1<br>PWST = 0 | P-01 turns on | Stored rainwater pumped into PWST. |
| FST = 0 | V-03 opens<br>P-02 turns on | Water from PWST flows into FST.<br>Desired amount of stock fertilizer pumped into FST. |
| FST = 1 | V-03 closes | Water from PWST stop flowing into FST. |

*Remarks: 0 = low water level, 1 = high water level*

Centrifugal pump (P-01) is receiving 3 input from LSL 01, LSH 02 and LSL 03. To avoid complication, hereby discussing the operation of the pump given different input. LSL 01 and will overwrite input from LSL 03, the pump should only operate when low water level is detected in PWST and sufficient rainwater is presence in RWST. Figure 13 below shows the logic circuit of the design and Table 5 shows the truth table showing its operation. Note that input from both LSH 02 and LSL 03 cannot coexist as it indicates water level in PWST are both at low and high level, thus excluded in the truth table.

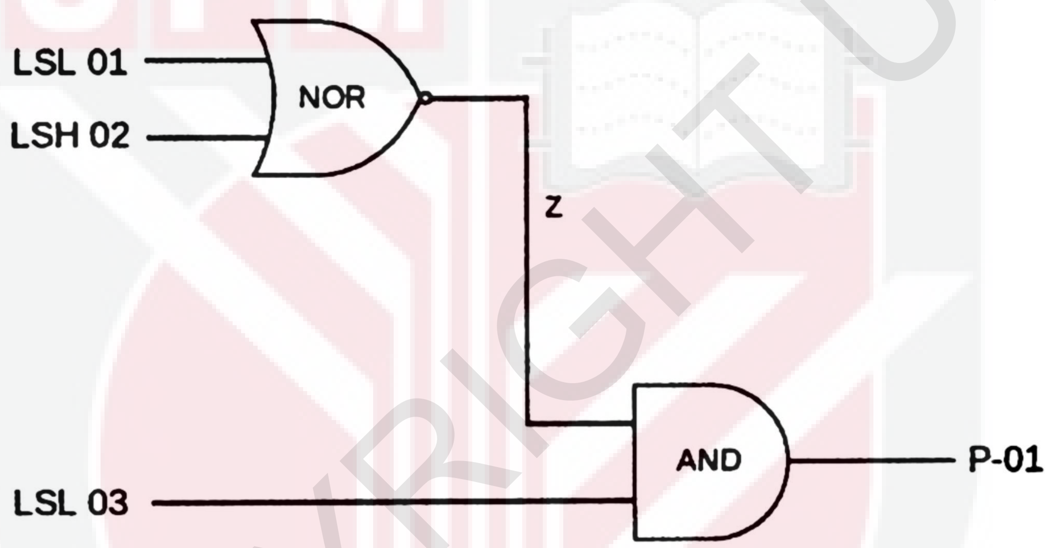


Figure 12: Logic circuit of the P-01 operation

Table 5: Truth table of P-01 operation condition.

| Input (LSL 01) | Input (LSH 02) | Input (LSL 03) | Intermediate (Z) | Output (P-01) |
|---|---|---|---|---|
| 0 | 0 | 0 | 1 | 0 |
| 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 | 1 |

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATION

As the conclusion, glass layer on the top PV module is suitable candidate as rainwater harvesting surface due to its inert properties. The occurrence of heavy metal in the rainwater harvested from PV surface can be great concern to health, future study on the treatment of the water should be done to produce water with higher quality.

On the other hand, it is estimated that a 1kWp PV array with area of 11.6 $m^2$ is able to collect about 23,865 litter of rainwater annually, fulfilling fertigation demand for as much as 65 herbal crop *Orthosiphon Stamineus* in an Agrivoltaic farm.

It is found that there are several method and guidelines to estimate the size of rainwater storage tank. When there is no addition water supply available, it is suggested a reliability study should be done to identify the optimum tank size.

The ideology of rainwater harvesting using PV surface is still new and very limited study is done. Future study could be very useful for researcher, such as study on the runoff coefficient on PV surface at different tilt angle, large scale case study and reports on the existing PV RWHS could provide guidelines and insights for those whom concern.

## REFERENCES


Abd Manan, F., Chia, W. H., Othman, N. F. A., Mamat, D. D., Chong, C. S., Samad, A. A., &Chai, T. T. (2015). Physical and antioxidative responses of Orthosiphon stamineus towards various copper and lead concentrations. *Chemical Speciation and Bioavailability*, *27*(3), 106–111. https://doi.org/10.1080/09542299.2015.1095656

Amaducci, S., Yin, X., &Colauzzi, M. (2018). Agrivoltaic systems to optimise land use for electric energy production. *Applied Energy*, *220*, 545–561. https://doi.org/10.1016/j.apenergy.2018.03.081

Ariffin, N. H. M., &Hasham, R. (2016). Potential dermatological application on Asian plants. *Biotechnology and Bioprocess Engineering*, *21*(3), 337–354. https://doi.org/10.1007/s12257-015-0750-4

Ashraf, K., Sultan, S., & Adam, A. (2018). Orthosiphon stamineus Benth. is an outstanding food medicine: Review of phytochemical and pharmacological activities. *Journal of Pharmacy And Bioallied Sciences*, *10*(3), 109. https://doi.org/https://doi.org/10.4103/jpbs.jpbs_253_17

Badiger, R. (2012). *An Economic Analysis of Rainwater Harvesting in North Karnataka*. Retrieved from http://krishikosh.egranth.ac.in/handle/1/5810102743

Chang, M., McBroom, M. W., &Scott Beasley, R. (2004). Roofing as a source of nonpoint water pollution. *Journal of Environmental Management*, *73*(4), 307–315. https://doi.org/10.1016/j.jenvman.2004.06.014

Cunliffe, D. a. (1998). Guidance on the use of rainwater tanks. *National Environmental Health Forum Monographs Water Series No 3*, *5210*, 1–29.

Department of Irrigation and Drainage. (2012). *Urban Stormwater Management Manual for Malaysia*.

Dinesh, H., &Pearce, J. M. (2016). The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *54*, 299–308. https://doi.org/10.1016/j.rser.2015.10.024

Espinosa, N., Zimmermann, Y. S., DosReis Benatto, G. A., Lenz, M., &Krebs, F. C. (2016). Outdoor fate and environmental impact of polymer solar cells through leaching and emission to rainwater and soil. *Energy and Environmental Science*, *9*(5), 1674–1680. https://doi.org/10.1039/c6ee00578k

Fadaeenejad, M., Radzi, M. A. M., Fadaeenejad, M., Zarif, M., &Gandomi, Z. (2015). Optimization and comparison analysis for application of PV panels in three villages. *Energy Science and Engineering*, *3*(2), 145–152. https://doi.org/10.1002/ese3.52

Farhan, M., Abdul Razak, S., Pin, K. Y., &Chuah, A. L. (2012). Antioxidant activity and phenolic content of different parts of Orthosiphon stamineus grown under different light intensities. *Journal of Tropical Forest Science*, *24*(2), 173–177.

Farreny, R., Morales-Pinzón, T., Guisasola, A., Tayà, C., Rieradevall, J., &Gabarrell, X. (2011). Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water Research*, *45*(10), 3245–3254. https://doi.org/10.1016/j.watres.2011.03.036

Gao, Q., &Kirisits, M. J. (n.d.). The Effect of Photovoltaic Nanomaterial Roofing on Harvested Rainwater Quality. *USGS 104b Research Grant*, 1–15.

Hamid, T. A., &Nordin, B. (2011). Green campus initiative: Introducing RWH system in kolej perindu 3 UiTM Malaysia. *3rd ISESEE 2011 - International Symposium and Exhibition in Sustainable Energy and Environment*, (June), 135–138. https://doi.org/10.1109/ISESEE.2011.5977121

Hatamian, M., Rezaei Nejad, A., Kafi, M., Souri, M. K., &Shahbazi, K. (2020). Interaction of lead and cadmium on growth and leaf morphophysiological characteristics of European hackberry (Celtis australis) seedlings. *Chemical and Biological Technologies in Agriculture*, *7*(1), 1–8. https://doi.org/10.1186/s40538-019-0173-0

Jabatan Pertanian. (n.d.). Panduan menanam misai kucing. Retrieved from http://www.terengganu.gov.my/maxc2020/appshare/widget/mn_img/76682file/mis ai kucing.pdf

Kabbashi, N. A., Jami, M. S., Abdurahman, N. H., &Puad, N. I. M. (2020). Rainwater harvesting quality assessment and evaluation: IIUM case study. *IIUM Engineering Journal*, *21*(1), 12–22. https://doi.org/10.31436/iiumej.v21i1.1139

Kuok, K. K., &Chiu, P. C. (2020). Optimal rainwater harvesting tank sizing for different types of residential houses: Pilot study in Kuching, Sarawak. *Journal of Engineering Science and Technology*, *15*(1), 541–554.

Lani, N. H. M., Syafiuddin, A., Yusop, Z., Adam, U. binti, &Amin, M. Z. bin M. (2018). Performance of small and large scales rainwater harvesting systems in commercial buildings under different reliability and future water tariff scenarios. *Science of the Total Environment*, *636*, 1171–1179. https://doi.org/10.1016/j.scitotenv.2018.04.418

Laura, D. (2018). Solar Panel Cleaning: Why, How, and How Often? Retrieved from Solar website: https://www.solaralliance.org/solar-panel-cleaning/#:~:text=It's a good idea to check them periodically%2C especially if,at least twice a year.

Malu, P. R., Sharma, U. S., &Pearce, J. M. (2017). Agrivoltaic potential on grape farms in India. *Sustainable Energy Technologies and Assessments*, *23*, 104–110. https://doi.org/10.1016/j.seta.2017.08.004

Ministry of Natural Resources and Environment Malaysia. (2014). National Water Quality Standards For Malaysia- Annex. *National Water Quality Standards for Malaysia- Annex*. Retrieved from http://www.wepa-db.net/policies/law/malaysia/eq_surface.htm

Mohammad, M. F., Yusof, M. R., &Musa, M. F. (2015). The Awareness Among Developers on Rainwater Harvesting System (RWHS). *International Colloquium on Science and Technology 2014 (ICOST 2014)*, *2014*(Icost), 6. Retrieved from https://www.researchgate.net/publication/274314402_The_Awareness_Among_Developers_on_Rainwater_Harvesting_System_RWHS

Mohd Hafizudin. Z., Roslina. A., Nor Amna A'liah. M. N., N. R. N. O. (2013). *Malaysian Herbal Industry Malaysia is one of the largest contributors to the world ' s biodiversity . According to a report released by the Malaysian Biotechnology Corporation ( 2009 ), Malaysia ranked 12 th in the world and the fourth in Asia as a divers. 2050*(2008), 1–7.

Muhammad, N. S., Julien, P. Y., &Salas, J. D. (2016). Probability Structure and Return Period of Multiday Monsoon Rainfall. *Journal of Hydrologic Engineering*, *21*(1). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001253.

Othman, N. F., Ya'acob, M. E., Abdul-Rahim, A. S., Shahwahid Othman, M., Radzi, M. A. M., Hizam, H., …Jaafar, H. Z. E. (2015). Embracing new agriculture commodity through integration of Java Tea as high Value Herbal crops in solar PV farms. *Journal of Cleaner Production*, *91*, 71–77. https://doi.org/10.1016/j.jclepro.2014.12.044

Petrucci, G., DeBondt, K., Claeys, P., Sinha, S., Gupta, A. K., Bhatt, K., …Fai Chow, M. (2020). Roofing as a source of nonpoint water pollution. *IOP Conference Series: Materials Science and Engineering*, *636*(1), 1–8. https://doi.org/10.1109/ISESEE.2011.5977121

Rahman, A. A. A., Shaari, A. R., Ahmad, S., &Mamat, A. S. (2014). Water stress affecttotal phenolic content and antioxidant capacity of Orthosiphon Stamineus leaf and stem. *Advances in Environmental Biology*, *8*(22), 82–86.

Santra, P., Pande, P. C., Kumar, S., Mishra, D., &Singh, R. K. (2017). Agri-voltaics or solar farming: The concept of integrating solar PV based electricity generation and crop production in a single land use system. *International Journal of Renewable Energy Research*, *7*(2), 694–699.

Schindele, S., Trommsdorff, M., Schlaak, A., Obergfell, T., Bopp, G., Reise, C., …Weber, E. (2020). Implementation of agrophotovoltaics: Techno-economic analysis of the price-performance ratio and its policy implications. *Applied Energy*, *265*(October 2019), 114737. https://doi.org/10.1016/j.apenergy.2020.114737

Sekiyama, T., &Nagashima, A. (2019). Solar sharing for both food and clean energy production: Performance of agrivoltaic systems for corn, a typical shade-intolerant crop. *Environments - MDPI*, *6*(6). https://doi.org/10.3390/environments6060065

Singh, J., &Mohan, D. A. (2020). Effect of Heavy Metal Contaminated Waste Water Irrigation on Enzymatic and Non Enzymatic Antioxidants in Some Selected Vegetables. *Journal of Physics: Conference Series*, *1531*(1). https://doi.org/10.1088/1742-6596/1531/1/012093

Sinha, S., Gupta, A. K., Bhatt, K., Pandey, K., Rai, U. N., &Singh, K. P. (2006). Distribution of metals in the edible plants grown at Jajmau, Kanpur (India) receiving treated tannery wastewater: Relation with physico-chemical properties of the soil. *Environmental Monitoring and Assessment*, *115*(1–3), 1–22. https://doi.org/10.1007/s10661-006-5036-z

Tan, M. L., Ibrahim, A. L., Duan, Z., Cracknell, A. P., &Chaplot, V. (2015). Evaluation of six high-resolution satellite and ground-based precipitation products over Malaysia. *Remote Sensing*, *7*(2), 1504–1528. https://doi.org/10.3390/rs70201504

Texas Water Development Board. (2003). The Texas Manual on Rainwater Harvesting. *Austin, Texas, USA*. Retrieved from https://www.twdb.texas.gov/innovativewater/rainwater/doc/RainwaterHarvestingManual_3rdedition.pdf

University of Hawaii. (n.d.). *First-Flush Diverters*. 2. Retrieved from https://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Urban_Runoff/First-Flush_diverters.pdf

Weather Atlas. (n.d.). Monthly weather forecast and climate Kuala Lumpur, Malaysia. Retrieved from https://www.weather-my.com/en/malaysia/kuala-lumpur-climate

Ya'acob, M. E., Salmiaton, A., Farid, M., &Othman, N. F. (2016). DEVELOPMENT OF PV CATCHMENT MECHANISM FOR. *The IIER International Conference*, (April), 2–5.

Yaseer Suhaimi, M. &, &Abd Manas, M. (2016). Planting cat's whiskers using fertigation system. *Buletin Teknologi MARDI*, *9*, 41–46.

Yaziz, M. I., Gunting, H., Sapari, N., &Ghazali, A. W. (1989). Variations in rainwater quality from roof catchments. *Water Research*, *23*(6), 761–765. https://doi.org/10.1016/0043-1354(89)90211-X

Yoke, B. W., Ling, L., Tan, W. L., &Ming, F. C. (2019). COMMUNITY RAINWATER HARVESTING FINANCIAL PAYBACK ANALYSES - CASE STUDY in MALAYSIA. *IOP Conference Series: Materials Science and Engineering*, *636*(1). https://doi.org/10.1088/1757-899X/636/1/012019

# APPENDIX A

## NATIONAL WATER QUALITY STANDARDS FOR MALAYSIA

| PARAMETER | UNIT | CLASS | | | | |
|---|---|---|---|---|---|---|
| | | I | IIA/IIB | III# | IV | V |
| Al | mg/l | ↑ NATURAL LEVELS OR ABSENT ↓ | - | (0.06) | 0.5 | ↑ LEVELS ABOVE IV ↓ |
| As | mg/l | | 0.05 | 0.4 (0.05) | 0.1 | |
| Ba | mg/l | | 1 | - | - | |
| Cd | mg/l | | 0.01 | 0.01* (0.001) | 0.01 | |
| Cr (VI) | mg/l | | 0.05 | 1.4 (0.05) | 0.1 | |
| Cr (III) | mg/l | | - | 2.5 | - | |
| Cu | mg/l | | 0.02 | - | 0.2 | |
| Hardness | mg/l | | 250 | - | - | |
| Ca | mg/l | | - | - | - | |
| Mg | mg/l | | - | - | - | |
| Na | mg/l | | - | - | 3 SAR | |
| K | mg/l | | - | - | - | |
| Fe | mg/l | | 1 | 1 | 1 (Leaf) 5 (Others) | |
| Pb | mg/l | | 0.05 | 0.02* (0.01) | 5 | |
| Mn | mg/l | | 0.1 | 0.1 | 0.2 | |
| Hg | mg/l | | 0.001 | 0.004 (0.0001) | 0.002 | |
| Ni | mg/l | | 0.05 | 0.9* | 0.2 | |
| Se | mg/l | | 0.01 | 0.25 (0.04) | 0.02 | |
| Ag | mg/l | | 0.05 | 0.0002 | - | |
| Sn | mg/l | | - | 0.004 | - | |
| U | mg/l | | - | - | - | |
| Zn | mg/l | | 5 | 0.4* | 2 | |
| B | mg/l | | 1 | (3.4) | 0.8 | |
| Cl | mg/l | | 200 | - | 80 | |
| $Cl_2$ | mg/l | | - | (0.02) | - | |
| CN | mg/l | | 0.02 | 0.06 (0.02) | - | |
| F | mg/l | | 1.5 | 10 | 1 | |
| $NO_2$ | mg/l | | 0.4 | 0.4 (0.03) | - | |
| $NO_3$ | mg/l | | 7 | - | 5 | |
| P | mg/l | | 0.2 | 0.1 | - | |
| Silica | mg/l | | 50 | - | - | |
| $SO_4$ | mg/l | | 250 | - | - | |
| S | mg/l | | 0.05 | (0.001) | - | |
| $CO_2$ | mg/l | | - | - | - | |
| Gross-α | Bq/l | | 0.1 | - | - | |
| Gross-β | Bq/l | | 1 | - | - | |
| Ra-226 | Bq/l | | < 0.1 | - | - | |
| Sr-90 | Bq/l | | < 1 | - | - | |
| CCE | µg/l | | 500 | - | - | - |
| MBAS/BAS | µg/l | | 500 | 5000 (200) | - | - |
| O & G (Mineral) | µg/l | | 40; N | N | - | - |
| O & G (Emulsified Edible) | µg/l | | 7000; N | N | - | - |
| PCB | µg/l | | 0.1 | 6 (0.05) | - | - |
| Phenol | µg/l | | 10 | - | - | - |
| Aldrin/Dieldrin | µg/l | | 0.02 | 0.2 (0.01) | - | - |
| BHC | µg/l | | 2 | 9 (0.1) | - | - |
| Chlordane | µg/l | | 0.08 | 2 (0.02) | - | - |
| t-DDT | µg/l | | 0.1 | (1) | - | - |
| Endosulfan | µg/l | | 10 | - | - | - |
| Heptachlor/Epoxide | µg/l | | 0.05 | 0.9 (0.06) | - | - |
| Lindane | µg/l | | 2 | 3 (0.4) | - | - |
| 2,4-D | µg/l | | 70 | 450 | - | - |
| 2,4,5-T | µg/l | | 10 | 160 | - | - |
| 2,4,5-TP | µg/l | | 4 | 850 | - | - |
| Paraquat | µg/l | | 10 | 1800 | - | - |

Notes :
* = At hardness 50 mg/l $CaCO_3$
# = Maximum (unbracketed) and 24-hour average (bracketed) concentrations N = Free from visible film sheen, discolouration and deposits

# NATIONAL WATER QUALITY STANDARDS FOR MALAYSIA (cont.)

| PARAMETER | UNIT | CLASS | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | IIA | IIB | III | IV | V |
| Ammoniacal Nitrogen | mg/l | 0.1 | 0.3 | 0.3 | 0.9 | 2.7 | > 2.7 |
| Biochemical Oxygen Demand | mg/l | 1 | 3 | 3 | 6 | 12 | > 12 |
| Chemical Oxygen Demand | mg/l | 10 | 25 | 25 | 50 | 100 | > 100 |
| Dissolved Oxygen | mg/l | 7 | 5 – 7 | 5 - 7 | 3 - 5 | < 3 | < 1 |
| pH | - | 6.5 - 8.5 | 6 – 9 | 6 - 9 | 5 - 9 | 5 - 9 | - |
| Colour | TCU | 15 | 150 | 150 | - | - | - |
| Electrical Conductivity* | μS/cm | 1000 | 1000 | - | - | 6000 | - |
| Floatables | - | N | N | N | - | - | - |
| Odour | - | N | N | N | - | - | - |
| Salinity | ppt | 0.5 | 1 | - | - | 2 | - |
| Taste | - | N | N | N | - | - | - |
| Total Dissolved Solid | mg/l | 500 | 1000 | - | - | 4000 | - |
| Total Suspended Solid | mg/l | 25 | 50 | 50 | 150 | 300 | 300 |
| Temperature | °C | - | Normal + 2 °C | - | Normal + 2 °C | - | - |
| Turbidity | NTU | 5 | 50 | 50 | - | - | - |
| Faecal Coliform** | count/100 ml | 10 | 100 | 400 | 5000 (20000)[a] | 5000 (20000)[a] | - |
| Total Coliform | count/100 ml | 100 | 5000 | 5000 | 50000 | 50000 | > 50000 |

**Notes :**

**N** : No visible floatable materials or debris, no objectional odour or no objectional taste
* : Related parameters, only one recommended for use
** : Geometric mean
**a** : Maximum not to be exceeded

# WATER CLASSES AND USES

| CLASS | USES |
|---|---|
| Class I | Conservation of natural environment.<br>Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species. |
| Class IIA | Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species. |
| Class IIB | Recreational use with body contact. |
| Class III | Water Supply III – Extensive treatment required.<br>Fishery III – Common, of economic value and tolerant species; livestock drinking. |
| Class IV | Irrigation |
| Class V | None of the above. |