MAKING AN AQUAPONIC SYSTEM SUITABLE FOR KAMPUNG MELAYU

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ABSTRACT
In Semarang lies kampung Melayu. This kampung has a lot of issues relating to water management. To find a way to deal with these issues, research has been conducted at a different kampung: Kampung Kandri. In Kandri, an aquaponic system was implemented. This system brings certain economic, social, spatial and climate benefits. These benefits all fulfil certain needs of kampung Melayu, except the water relating needs. However, this system has a potential to fulfil water treatment functions. By preventing evapotranspiration, adding a reliable water supply, a final treatment to get higher quality water, increasing the storage potential and providing a reliable source of energy, this system can be part of the solution to the issues kampung Melayu is facing.

KEYWORDS: Aquaponics, Hydroponics, Water treatment, drinking water, clean water, water storage, water supply, evapotranspiration, water pumping systems, Melayu, Kandri.

I. INTRODUCTION

This paper is initiated by a design study of which the location is set in kampung Melayu, an old neighbourhood in the Indonesian city of Semarang. Semarang is facing many problems relating with water. To give some examples: sewage and garbage is flowing untreated into the rivers, causing the rivers and the sea to be polluted and heavy rainfall causes flash floods, bringing even more pollutants to the river and causing houses and roads to be flooded.

Many of the problems are related with how water is being supplied to the houses and released to the river. This research paper will address the issues relating to clean water and drinking water supply in kampung Melayu. To understand this, the definition of “clean water” and “drinking water” have to be given. This paper uses the definition “clean water” as water that is of a quality that it can be used for everything in a normal household except that is not safe to drink. “Drinking water” has the same properties as clean water but is safe to drink.

One of the sustainability goals of the United Nations is to *“achieve universal and equitable access to safe and affordable drinking water for all”* (United Nations Sustainability Goals, goal No.6)[1]. Right now, this is not the case in kampung Melayu.

To understand the issues regarding clean water and drinking water supply, it is needed to know how the situation is right now. In figure 1 the water supply is shown graphically. Drinking water comes from two possible sources: bottled mineral water bought from a store or company, which causes pollution due to single use plastic and is very expensive, or it is made by boiling clean water for a couple of minutes. The problem with the bottled water is that it needs a lot of plastic and the waste treatment system in Semarang functions badly: a lot of trash ends up in the river, which leads to the ocean. Causing the ocean to be contaminated with plastic.

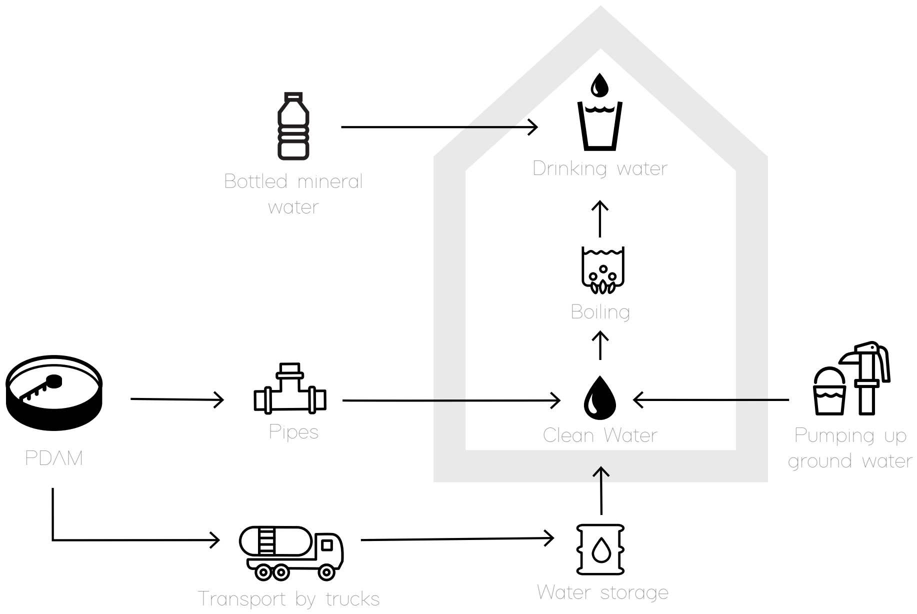

Figure 1 Schematic impression of water supply. Everything within the grey line is what mainly happens indoors.

Clean water in kampung Melayu has two known sources: It comes from the local water treatment plant (PDAM in Indonesian), which delivers the water through pipes or delivers it by truck to a tank in which the water is stored. The problem with PDAM is that the 50% of the water in the pipes is lost through leakage. Another issue is their unreliability: they cannot supply enough water during the peak of dry season, nor when it rains too much during rainy season.

The second source is from a well, where water is pumped from the ground. This practice is not sustainable in the way that the aquifer is depleting faster than it is being refilled and the amount in which the water is being pumped up causes the land in Semarang to subside, increasing the problems with flash floods.

Seeing how chaotic the water supply is, raises the question on how this problem needs to be faced. Putri and Moulaert[2] discuss in their paper different spatial practices and forms of institutionalization in the water and water sanitation sector in Jakarta, which can be considered similar to the situation in Semarang. They mention how the informal actors should be involved: *"Considering that neither the state nor the corporate market sector alone can meet, or even properly identify, the needs and institutional relations among the urban poor in the global South, desperately needed institutional reforms to solve water-related problems should also involve so-called informal actors and their networks."* In Semarang these informal actors and their networks can be seen as the kampungs. A kampung is a *"typical spatial enclave in Indonesian cities in which informality takes on different yet articulated institutional and spatial forms"* Putri and Moulaert (2017)[3]. Possible solutions have to be seen within the context of Semarang and its many kampungs. Everyday life is organized in a de-centralized manner, where people work together with their kampungs to provide services which in a western civilization are mostly organized in a centralized manner. Plans which are based on a centralized system have a harder time to be implemented than small scale kampung oriented plans.

To find possible kampung-based solutions for a new water supply system for kampung Melayu, research was done at different kampungs. One of which involved the implementation of aquaponic systems in Kampung Kandri. This system seemed very promising to implement in kampung Melayu. The case of kampung Kandri will be thoroughly discussed in paragraph 2. The system was an inspiration to look at water management in a different way and forms the basis for this paper.

However, its primary function was not to treat water. In paragraph 3 will be discussed what the shortcomings are of this system. In paragraph 4 the possible necessary additions are for this system will be discussed and the focus will lay on what the spatial and social consequences are for the kampung when these additions are implemented.

By researching this system and looking for possible additions this paper hopes to answer the question: *"How can the aquaponic system in kampung Kandri be improved in a way that it fulfills the needs of kampung Melayu?"* Thereafter, this paper hopes to answer the question: *"What are the consequences of the improvements?"*

Figure 2 Location of kampung Kandri on the outskirts of Semarang

II. Kampung Kandri

2.1. Introduction

Kampung Kandri lies in the outskirts of Semarang (see figure 2). The kampung is small, but very dense (see figure 3). In 2017, small aquaponic systems were implemented in the kampung. This was initialized by Syaffei Hassanudin, a local resident. The system was based on Syaffei's interest in aquaponic farming and not so much on water treatment.

To understand how aquaponics works and how it is implemented in kampung Kandri, it is important to know how an aquaponic system works. Therefore, the systems will be explained first. After that, the effect of the system on kampung Kandri will be explained.

Figure 3 Kampung Kandri as seen from above. Source: Google Earth Pro

2.2 Aquaponic system

Aquaponics can be seen as a combination of two systems: hydroponics and aquaculture. These two systems will be briefly explained as well as how these systems are combined.

Hydroponics

According to Woodford (2019)[4] the word hydroponic means to grow plants with water, but because you can grow plants without actually standing them in water, most people define the word to growing plants without using soil. However, the definition this paper uses is to grow plants with a water based nutrient solution. This can be seen in figure 4.

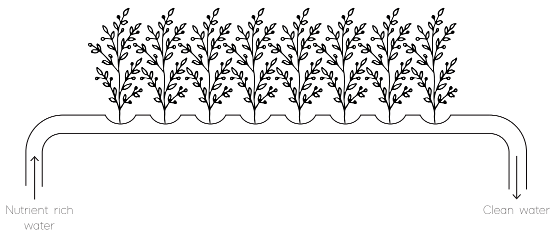

Figure 4 Schematic rendition of hydroponics. Nutrient rich water enters the system, clean water comes out.

Some disadvantages with a hydroponic system for small-scale users are that maintenance can take a lot of time , because it needs to be monitored on a daily basis and it requires more energy than conventional agricultural methods. Some advantages with hydroponics are that it takes much less water to grow fruits and vegetables and the yield per m^2 is much larger than if conventional agricultural methods would have been used.

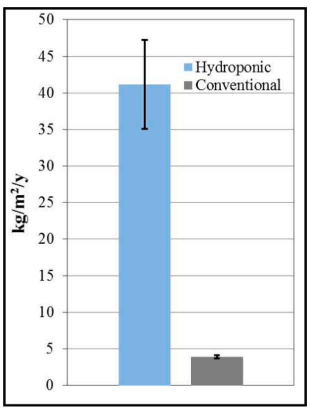

Figure 5 Modeled annual yield in kilograms per square meter of lettuce grown using hydroponic vs. conventional methods. Source: Barbosa et al. (2015)

In the research paper of Barbosa et al (2015)[5] they compare conventional agriculture with hydroponics. They found out that the yield of lettuce with a hydroponic system was 41 $kg/m^2/y$ (kilograms per square meter per year), while the yield of lettuce using conventional methods only was 3.9 $kg/m^2/y$ (figure 5). Additionally, the amount of water used per kg lettuce per year with a hydroponic system was 20 L/kg/y, while the amount of water using conventional methods was a staggering 250 L/kg/y (figure 6). However, the amount of energy use was found to be much higher with a hydroponic system. 90.000 kJ/kg/y was needed for a hydroponic system, while conventional methods only required 1.100 kJ/kg/y (figure 7). But when looking at the way the energy is used, it can be seen that most of the energy of the hydroponic system went to artificial lighting and heating/cooling. When implemented in a stable, warm and humid climate the demand for lighting and heating/cooling should go down.

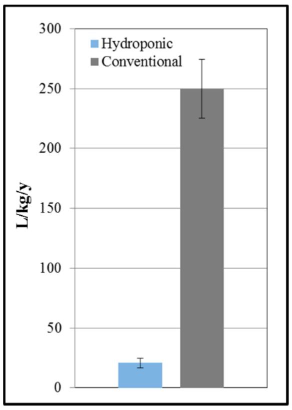

Figure 6 Modeled annual water use in liters per kilogram of lettuce grown using hydroponic vs. conventional methods Source: Barbosa et al. (2015)

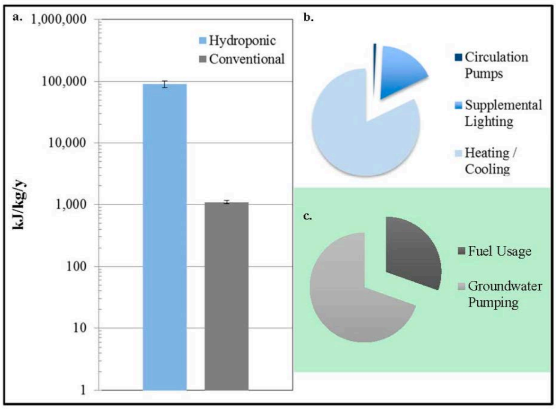

Figure 7 (a) Modeled annual energy use in kilojoules per kilogram of lettuce grown using hydroponic vs. conventional methods; (b) The energy use breakdown related to the hydroponic production of lettuce; (c) The energy use breakdown related to the conventional production of lettuce. Source: Barbosa et al. (2015)

Aquaculture

According to the American National Ocean Service[6], aquaculture is the breeding, rearing and harvesting of fish, shellfish, algae and other organisms in all types of water environments. For the definition this paper uses this is done in a basin, where clean water is added, and contaminated water is being removed (figure 8). The contamination of the water consists in the form of nutrients. These nutrients come from the feces of the fish, this is being filtered out to make the water clean again and reuse it in the basin.

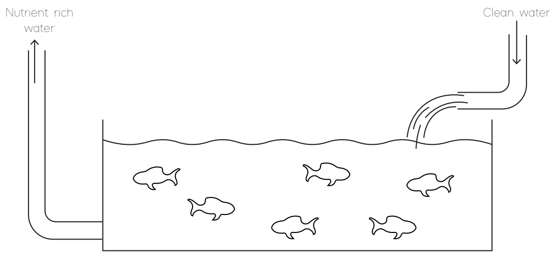

Figure 8 Schematic rendition of aquaculture. Clean water enters the system, nutrient rich water comes out.

Aquaponics

By combining hydroponics and aquaculture, a circular process is created as seen in figure 9. Hydroponics works in this process as a filter, cleaning the "contaminated" water and providing clean water for the fish. Aquaculture works in this process as a feeding system for the plants, providing nutrients to the water for the plants to eat. This is the basis of aquaponics and this process is used in the system in kampung Kandri.

2.3 Implementation in Kandri

As mentioned in the introduction, the aquaponic system was initialized by Syaffei Hassanudin. In a personal interview, he was asked how it started. *"It began in 2010 where I just experimented with it myself and told my neighbors about it. And then in 2017, the head of our neighborhood community (RW) agreed to make it as a neighborhood program. In our district, each RW has their own theme: culinary, cave recreation, batik art, and so we made ours an aquaponic tourism village. We introduce it to social media in 2017, making the village famous as an ecotourism destination. Only then we start to acknowledge the zero-waste and circular economic aspects of it, slowly."*[7]

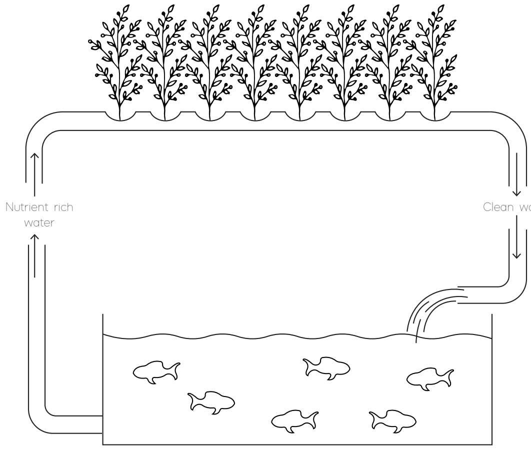

Figure 9 Schematic rendition of aquaponics. The water circulates through the system.

The system started off due to personal interest of Syaffei, but for the implementation it relied heavily on the neighbourhood community. In Indonesia this is called an *"Rukun Warga"* or RW in short. *"In principle, all of the households in the area become members of their RT/RW, and the neighbourhood association manages various community matters comprehensively. These include: maintaining an hygienic environment; preventing crime; holding events; marriage ceremonies or funerals; collecting membership fees and other dues from people; taking measures for the relief of the poor; promoting peace in the neighbourhood; registering or making a record of residents; cooperating with the census and helping in the execution of general elections"* Dwianto (2003)[8]. Due to these responsibilities and the normality of being member, the social structure of an RW is very strong and when implementing an aquaponic system throughout the kampung, the RW is a crucial partner to make this happen.

2.4 Benefits

Even though it started off as a personal experiment, the system was eventually implemented kampung-wide and brought benefits with it. These benefits can be categorized as economic, social and spatial. The benefits will be explained according to these categories.

Economic benefits

People in kampung Kandri can produce any plants they want. What was seen, was that a lot of people preferred to grow herbs and small vegetables with the system. This was harvested for themselves to consume. This way, they had to buy less products on the market, since they produced it themselves.

Because of the direct benefit of food production, the inhabitants seem to take care of the system quite well. It could be assumed that because of the direct benefit in the form of food, the motivation to take care of the system is increased. When implemented as a water treating mechanism this benefit might be of great importance as people could literally eat the fruits of their labour, giving them a second direct benefit of the system instead of only clean water.

Social benefits

Installing an aquaponic system in kampung Kandri enabled the possibility of increasing the amount of nature and biodiversity in the kampung. A lot of research has been done on the social benefits of increased access to nature in neighbourhoods. According to Anderson and Minor (2017)[9] exposure to nature and real or perceived biodiversity may provide many benefits to people, including improved psychological well-being, physical health, and cognitive function.

When aquaponics is implemented as a community garden project it can gain even more social benefits. According to Macias (2008)[10] , who researched the social impact of community-based agriculture, social integration in a community garden is high, it *"includes a wide range of participants who share tools and*

Figure 10 Facade of one of the dwellings in kampung Kandri. Completely green with help of the aquaponic system.

Figure 11 One of the streets in kampung Kandri. Most houses have an aquaponic system in front of their house.

responsibilities; relationships are fostered gradually over time" . Macias also mentions a high natural human capital: *"Gardeners learn from each other and from direct experience how to grow their own food."* However, in kampung Kandri, the system is not implemented as a single community garden, but people do work together to maintain the systems in a similar manner as would be the case in a community garden.

Spatial and climate benefits
One kind of benefit has not been addressed up till now: the fact that increased greenery in a neighbourhood has an aesthetic value as well. As can be seen in figure 10 and 11, kampung Kandri has a green appearance resulting in a pleasant outside space.

Another benefit of this system is the improved indoor climate. Because of the vertical way the system is implemented (figure 10), the system can be considered as a green wall. In the paper of Haggag et al. (2014)[11] the reduced heat gain through green facades in a high heat load climate was researched. It was concluded that there could be achieved a decrease of 5 degrees in the indoor temperature caused by: the blocking of incident radiation by the leaves, soil mass and the assembly carrying the plants; the evaporative cooling caused by the irrigation water to the plants; the heat resistance due to low thermal conductivity of the plants acting as heat insulators to the ambient heat gain by the wall. The system in Kandri has not been measured, but due to the way the system is implemented in some of the cases a similar decrease in indoor temperature seems possible.

III. System improvement

3.1 Introduction
The system in Kandri brought a lot of benefits to the neighbourhood. These benefits match some of the needs of kampung Melayu, but to apply the aquaponic system of Kandri in Melayu as a system to provide clean and dining water a lot of adjustments have to be made. To see what has to be adjusted, the needs of Melayu will be discussed. Based on these needs, the shortcomings of the system in Kandri will be assessed. After which, the necessary additions and consequences of those additions will be discussed. This way, there will be a proposal for an improved aquaponic system suitable for kampung Melayu.

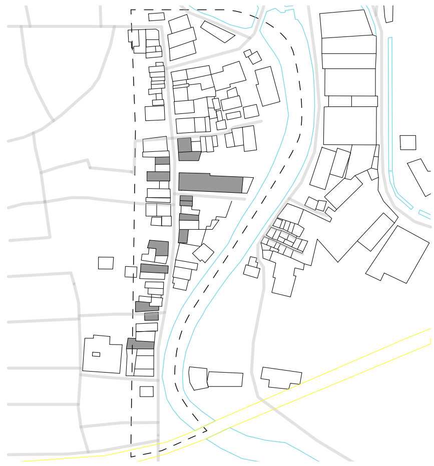

Figure 12 Map of places that show abandonment (grey) within kampung Melayu

3.2 Needs of Melayu
To understand the needs of Melayu, the same structure as paragraph 2.4 will be used. The focus lies on the economic needs, social needs and spatial needs. Because the water related problems in this area are enormous, a group of needs is added under the name "water related needs". The needs of kampung Melayu will be discussed in this paragraph, as well as how an aquaponic system like in kampung Kandri could help to cover these needs.

Economic needs
Kampung Melayu is not home to a lot of economic activity. When visiting the site, it was observed that most activity seemed to look informal of nature. There seemed to be some small-scale waste collection industry, but it is not clear what the income model is. The inhabitants could use an extra source of income.

Figure 13 Schematic map visualizing the urban space (grey) and the unused space (green)

The kampung itself has a lot of possibilities for economic activity. Its location is in between and close to two main train stations of Semarang, connecting it to the rest of Java. There is also a lot of undeveloped land in the kampung, which could house new economic activities.

As mentioned in paragraph 2.2 a hydroponic system can have a yield of 41 kg/m^2/y. With the right number of square meters, an aquaponic system like in kampung Kandri could start up new economic activities in kampung Melayu. Aquaponics can be used to provide food and vegetables like it happens in kampung Kandri. If implemented well, these products can be the base of a food-economy in Kampung Melayu.

Social needs
Kampung Melayu has suffered from an outflow of residents, causing buildings to be abandoned and to decay. Right now, a major part of Melayu is empty as can be seen on figure 12. Because the inhabitants are leaving, the social structures that once were there are starting to decay. The kampung is in need of an influx of new inhabitants and proper social structures fitting a normal kampung in Indonesia.

The communal work of implementing and maintaining an aquaponic system helps to revive the social structure of the kampung. If the aquaponic system is implemented as a community garden, the benefits as explained in paragraph 2.3 can become a new reality for kampung Melayu.

Spatial & climate needs
Right now, kampung Melayu has two main structures forming the kampung: a hard urban street were a lot of traffic passes through and an empty, mostly unused stroke of land next to the river filled with trash (figure 13, 14 and 15).

The street is dense and has not a lot of green elements. This causes an urban heat island effect in this kampung. Implementing an aquaponic system in a vertical manner, forming a green façade helps to solve this problem.

The land next to the river is undeveloped but filled with trash. It is green and a lot cooler but needs to be developed in a way that it will not be used as a landfill but will remain its green identity. An aquaponic system can be of help to give this place a function within the kampung.

Water related needs
As mentioned in the introduction Semarang has many issues related with water: sewage and garbage is flowing untreated into the rivers, causing the rivers and the sea to be polluted and heavy rainfall causes flash floods, bringing even more pollutants to the river and causing houses and roads to be flooded.

Kampung Melayu is no different in this regard and many of the needs mentioned before, can be traced back by the water related issues. Ground water being pumped up underneath Semarang is causing the land to subside in Melayu as well as in other parts in Semarang, resulting in damage to the buildings and more severe flooding. This causes houses to be abandoned, as it gets harder to keep living in these circumstances.

Figure 14 Riverside of Melayu. Mainly empty, trash on numeral places, but also with a green character

Figure 15 Main street of Melayu. Dense urban character, without a lof green elements.

Another need of this area (as well as other parts of Semarang) is a working sewage system. Right now, the sewage is flowing into the river, causing the river to pollute. This causes numerous problems: it makes the water from the river unusable when it could be useful during the dry season, it makes the area around the river harder to live because of the smell and it kills a lot of the aquatic life in the river.

In kampung Melayu there is a need for access to clean water and drinking water. Right now, there is a tank in the kampung where clean water is being stored from PDAM. A few people bring the water by bike in jugs to the inhabitants of the kampung. This can work is a burden during the day, when temperatures can rise to extreme heights. The system itself is unreliable as well, having to depend on a steady flow from PDAM as this company has trouble to supply clean water during the peak of dry season and during heavy rainfall in the rainy season.

The aquaponic system of Kandri does not fulfil this need in kampung Kandri. However, the system has the capability to treat water to a level where it becomes clean water. When the system is altered, it can drastically improve the living quality in Melayu. The next paragraph will explain what the shortcomings of the system in Kandri are, if it needs to satisfy the needs of Melayu.

3.3 Shortcomings in Kandri

The aquaponic system in kampung Kandri works fine for Kandri. However, it has certain shortcomings if it is implemented in kampung Melayu as a water treatment system. This paragraph will explain five known problems the system is facing now or might face when it is implemented in Melayu: Evaporation and transpiration, problems with water supply, water treatment, storage of clean or drinking water and energy demand.

Evaporation and transpiration

The aquaponic system in kampung Kandri makes use of an open basin of water for the fishes. Because it is open, it is prone to evaporation. That is not the only place water is lost. Plants transpire an amount of water as well. The combination of evaporation and transpiration is called evapotranspiration. The amount of evapotranspiration that takes place depends on a lot of factors. In the article of Wati et al (2019)[12] the water evaporation and transpiration in Java and Bali are calculated and measured. To calculate the evaporation and transpiration the following equation is used:

$$ETo = Eo \times Kp$$

ETo is the amount of evapotranspiration.
Eo is the panned evaporation. "*Pan evaporation is one of the methods for measuring open water evaporation, the use of US Class A pan has found widely around the world and Indonesia"* Wati et al (2019).
Kp is the correction factor which values a range from 0.35 to 0.85. This factor depends on the prevailing upwind fetch distance, average daily wind speed, relative humidity conditions and other factors relating to the site location.

For Java and Semarang this results in a calculated average *ETo* of 150 mm per month. When measured in reality, the average *ETo* in Java and Bali is 103 mm per month. However, the paper of Wati et al suggests to use the calculated 150 mm per month when assessing water storage. Where the panned evaporation is a fixed number, the correction factor (*Kp*) can be influenced. When implementing this system in the future, all the factors forming the *Kp* have to be taken into account to ensure that this number is as low as possible. This way a low amount of evapotranspiration can be achieved and less water will be lost.

Even though this equation is very simple, it shows the amount of possible evapotranspiration at a certain place. But to go more in depth and show how many factors influence the amount of evapotransporation another equation will be given. This equation shows the evaporation rate in an open water surface. The equation is found in the paper of Rosa-Clot et al (2017)[13]:

$$R_{evap} = \frac{1}{\lambda} \times \left\{ \frac{\Delta_w (Q^* - N) + 86400 \rho_a C_a (e_w^* - e_a)/r_a}{\Delta_w + \gamma} \right\}$$

λ is the latent heat of vaporization
Δ_w is the slope of the water vapour curve for temperature saturation
Q^* is the net radiation
N is the change in heat storage in the water body
ρ_a is the air density
C_a is the specific heat of the air
$e_w{}^*$ is the saturated pressure at water temperature
e_a is the vapour pressure at air temperature
r_a is the aerodynamic resistance
γ is the psychometric constant

As is clear, evaporation depents on a lot of factors. Many of these factors cannot be easily influenced. However, some factors can be easily influenced. These factors will be explained, as alteration of these factors will lower the evaporation rate.

Q^* is the net radiation, which translates to the amount of sunlight on the water surface. Lowering the amount of sunlight can lower the amount of evaporation. N is the change in heat storage in the water body and can be influenced by changing the volume of the water body. r_a is the aerodynamic resistance and is directly related to the windspeed and surface area. This means by adding shade, having a small surface and large volume of water and low windspeed a lot of evaporation can be prevented.

Problem with water supply
When asked what the challenges were of the aquaponic system Syaffei answered that *"many parts of this subdistricts have no clean water pipes installed yet from PDAM. Hence, they obtain water for the aquaponics from the adjacent compounds which do have pipes installed. This would be a problem during the dry season as the water on the fishponds may evaporate."[14]* During a visit of kampung Kandri, it became clear that some of the systems were not functioning anymore. This was because of the supply issue. It seems that a steady water supply is necessary to maintain this system.

Water treatment
When implemented in a proper way, it is possible to get clean water out of the system when it is taken out after it has been through the hydroponic part of the system. However, the ultimate goal in this system is to get drinking water from it. The system needs to have an additional filter to treat the bio-based pollutants that are still left. According to Syaffei UV-treatment or boiling the water would get it to the quality of drinking water.

Storage
One shortcoming of the system is the lack of water storage. The system itself can be seen as a way of storing water. Because of the fishes and the plants, the water maintains a constant quality. However, the water can only be taken out on a certain place for the highest quality, this is right after the hydroponic part, where the plants do their cleaning. If there is a need for a large amount of water, it needs to come out of this part of the system, and it would be very useful that a large quantity of water is available in this stage of the system. Right now, the main water basin is the fish tank. This is inconveniently also the part of the system with relatively the lowest quality of water. A small basin after the hydroponic part would be a proper addition to the system.

Energy demand
In kampung Kandri the water is pumped through the aquaponic system by electrical pumps. This requires a certain amount of energy, which can make the system costly. To make the system more economically viable it would be wise to find out whether the water can be pumped around without the need of external energy provision.

IV. SYSTEM ADDITIONS AND CONSEQUENCES

4.1 Introduction
Some small additions and recommendations have already been mentioned in the previous paragraph. In this paragraph, these additions and their consequences will be discussed.

4.2 Evapotranspiration
As mentioned in paragraph 3.3 evapotranspiration can cause a lot of water to go to waste. However, circumstances can be created where the amount of evapotranspiration is lowered. The factors that can be most easily influenced are wind (r_a), amount of direct sunlight (Q^*) and the relation between volume and surface of the water body (N and r^a).

Wind
Wind is a critical factor for the amount of evaporation. By lowering the wind speed the evaporation rate can be significantly lowered. According to a study of Youssef and Khodzinskaya (2019)[15] water reservoirs wich are sheltered against the wind can have reductions of evaporation of 28% compared to reservoirs without shelters.

The water basin with the fishes that forms the aquaculture part should be protected against large wind speeds to mitigate the amount of evaporation. This can be done by placing the basin between wind breaking structures or finding a place within the design where the wind speed is the lowest or non-existing.

Shading and covering
To mitigate the effects of evapotranspiration on open water bodies, covering or providing shade can have a significant effect. As shown in the formula of Rosa-Clot et al (2017)[16] lowering the amount of net radiation (Q^*) has a direct effect on the amount of evaporation. Providing shade will be necessary to keep as much water as possible available.

In a study of Alam and AlShaikh (2012)[17] the effects of palm fronds as shaded cover for water storage was examined. It was concluded through experiment that a reduction in evaporation of 47% could be achieved using a single layer of cover and 58% when it was a double layer. However, the use of open water can be a valuable design tool, covering up the water might not be desirable for the eventual design.

Covering (part of) the water with plants can be more desirable. Even though plants are a cause of transpiration, certain plants can help to mitigate the effects on open water bodies. In a study of Sherwood (1980)[18] the effects of lily pads on evaporation is examined. They concluded that when the water is covered with lily pads, could lead to 16% less evaporation. Of course, this is less than the palm frond cover method but it is a more subtle design tool.

Planting trees to provide shadow over the water body can have a significant effect as well as it lowers the direct radiation. This method also faces loss through transpiration, but this could be mitigated. In the research paper of Kelliher et al (1993)[19] the evaporation and canopy characteristics of coniferous forests and grasslands is researched. Even though this was researched in different climatic conditions, some of the conclusions can be applied on this situation as well. Kelliher et al say that *"evaporation rate is determined by the balance between atmospheric demand on the canopy and supply of water by the roots. It is the functional balance between roots and shoots that allow plants to cope with soil water deficits."* And "Below a critical soil water content, the evaporation rate decreases sharply with decreasing soil water content." This means that transpiration can be kept low if the water supply to the trees is kept low. To achieve this, a strict separation of stored water and water for the trees should be maintained as is shown in figure 16. This way the water loss through transpiration can be managed and kept low.

Volume and surface
The contact surface with open air of the water body is of direct influence for the evaporation rate of an open water body. By adjusting the relationship between volume and contact surface with open air the evaporation rate can be lowered. This means that an open water body should deep and have a small contact surface with open air.

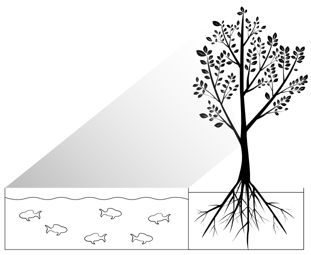
Figure 16 Trees provide shade and use little water due to the seperation between storage and roots.

Tegal Mulyo
To give an example where evapotranspiration caused problems the case of Tegal Mulyo will be shown. Tegal Mulyo is a small village on the slope of the Merapi volcano near Yogyakarta. Because the village is located far away from any city and located on a high altitude, it does not have a continuous water supply. The people used to depend on rainwater collection from rooftops or it was delivered by large trucks. Some time ago a large water basin was built to store clean water flowing down the volcano (figure 17 and 18).

During field work, it was discovered to be almost empty and not functioning. This was at the end of the dry season. It seems there was not enough water stored to cover the complete dry season. As can be seen in figure 17 and 18, it is likely that a lot of water is lost through evaporation. Firstly, the altitude of the basin and how it is not sheltered, gave free way for the wind to speed up the evaporation process. Secondly, the basin is not covered or shaded causing the sun to speed up the evaporation process even more. Thirdly, there is a relatively small volume against a large contact surface with the open air.


Figure 17 Water basin in Tegal Mulyo. Looking away from the Merapi vulcano


Figure 18 Water basin in Tegal Mulyo. Looking towards the Merapi vulcano

4.3 Supply
For the system to work, there is a need for a steady supply of water. Melayu has certain possibilities that might fulfill this need: collect rainwater, collect water from the river or reuse wastewater.

Rainwater
Rainwater meets the requirements to fulfil as clean water according to the definition given in the introduction. Therefore, it is a possible source of supply with a high quality.

Semarang endures on average 4000 mm rainwater per year (climate-data.org)[20]. When collected, this can be enough to meet the needs of the inhabitants of Melayu. However, the amount of rain during the year differs as can be seen in figure 19. During the months June -September there is hardly any rain. This means rainwater needs to be stored to be able to supply during these months. According to the UN[21], each individual should have access to 50-100 litre of clean water per day. For the months June – September (122 days) this results in 6-12 m3 per person. This means the system should be able to store this amount of water per person. For collecting 12 m3 water, at least 3 m2 of collection surface per person per year is necessary. For a full year this will be 18 – 36 m3 water per person, resulting 4,5 – 9 m2 of collection surface per person.

By knowing how much collection surface is needed per person, the maximum number of inhabitants who solely depend on rainwater can be calculated. For this calculation an area of Melayu between the road and the river is taken as shown in figure 21. This area consists of 22.165 m2. By dividing this with the necessary collection surface, the maximum number of inhabitants is calculated. This means that this area can maintain

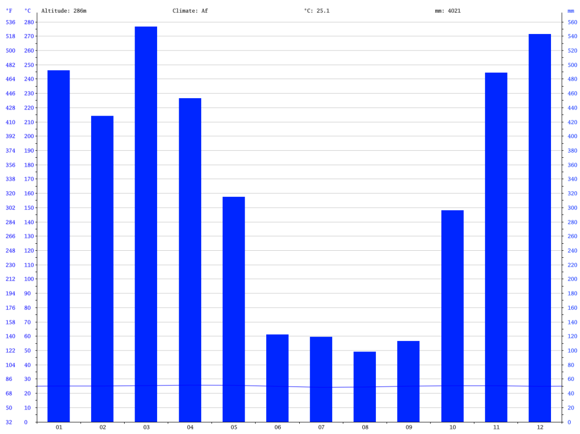

Figure 19 Avarage rainfall per month in Semarang. Source: en.climate-data.org

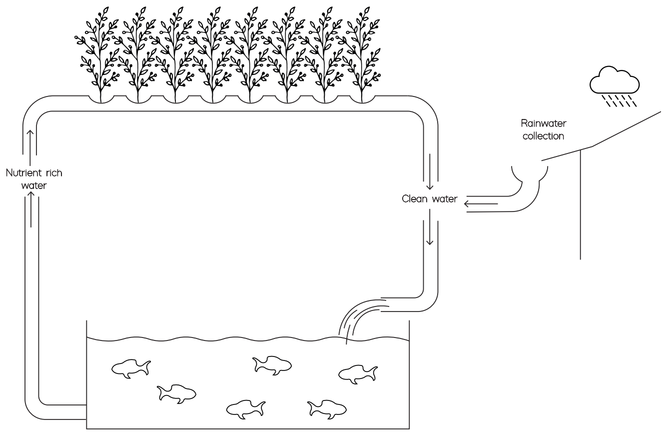

Figure 20 Rainwater is collected and enters the system immediately. The system itself functions as storage

between 22.165 / 9 = 2463 and 22.165 / 4,5 = 4925 inhabitants, when they use 50-100 litre of water per day and solely depend on rainwater. The storage potential necessary during dry season for this number of people would be approximately 2463 x 12 = 29.556 m3.

To achieve the necessary storage potential, it is possible to add an extra basin to store rainwater. The water in this basin needs to flow on a regular basis through the system to keep it clean. A more logical approach would be to use the system itself as rainwater storage, where an influx of rainwater is a possibility (see figure 20). The fish tank would serve in this case as the storage basin and will have to be made bigger to achieve the necessary storage potential.

Figure 21 Reference area in Melayu. Source: Google Earth

River collection

A second option for water supply is to collect water from the river. However, this water is extremely polluted. Not all the contaminations in the river are known, therefore it is not wise to use this water at this point of time. It is mentioned, because this might be a possibility in the future but will require further research.

Reuse water

The last way to collect water is to reuse the water of the inhabitants. Right now, the wastewater is being dumped into the river, further contaminating the river. Using the water from the river would be unwise but collecting it directly from the houses, where the contaminations (faeces and urine) are known, might provide a better option.

S. Rana et al (2011)[22] research whether it is possible to treat domestic wastewater by hydroponics (the water treatment part of aquaponics). They conclude that the water can be treated up to the level that it can be used for agriculture and aquaculture, however the crops produced by the process do not require the minimum level for consumption. To make this supply a possibility, the water

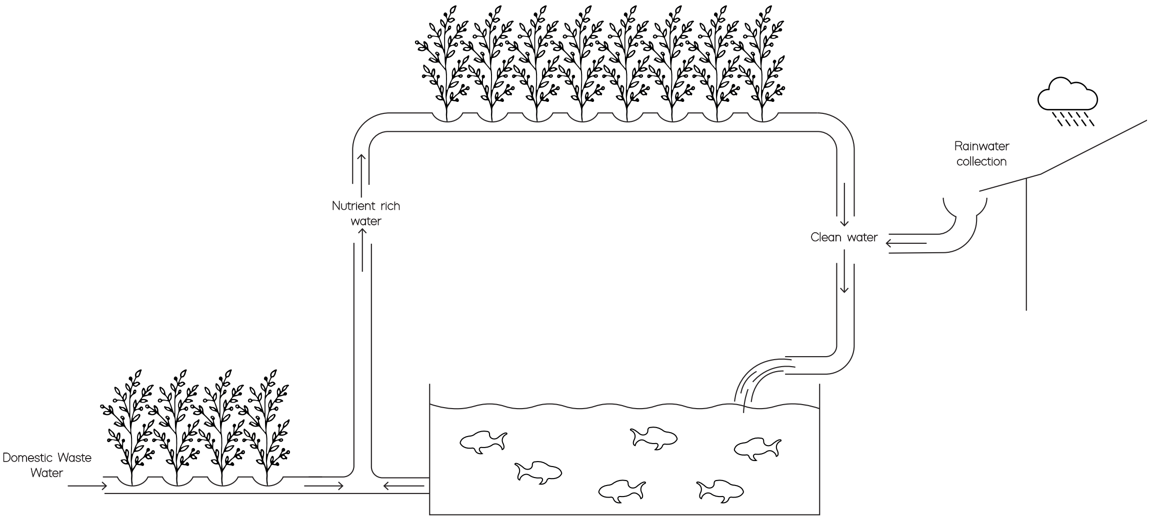

Figure 22 Domestic waste water is added on the left. It goes through a singular hydroponic system without food production, to get to a cleaner level. The hydroponic system could also be replaced with a helophyte filter.

needs to flow through a hydroponic system, in which no food is produced, before it can enter the system (figure 22).

Another option can be a combination of sedimentation tank and a helophyte filter. In the sedimentation tank the solid waste sinks to the bottom and can be harvested for anaerobic fermentation. This way the human waste can provide energy. More on this subject will be explained in paragraph 4.6. In Handboek Groene Waterzuivering Spoelstra and Truijen (2010)[23] explain different ways of natural water treatment. They give an in-depth explanation of helophyte filters (see figure 23): *"Sedimentated water enters through the inflow and flows slowly through the filtration bedding in an almost horizontal passage untill the end of the bedding. Here the water reaches a collection point and goes through the drainage. During the passage of the waste water through the helophytes it makes contact with a network of aerobic, anoxic and anaerobic zones."* When the water is treated it can access the aquaponic system and be further treated or used.

By reusing wastewater, there is less need of an external source as water supply. Only the loss through evapotranspiration will have to be accounted for.

Kampung Naga

To give an example of smart water usage with rainwater as a supply, Kampung Naga will be discussed. Kampung Naga is a traditional village in Indonesia that maintains old and strict customs, especially when it comes to taking care of their environment. This results in an interesting way of managing water, which is comparable to aquaponics.

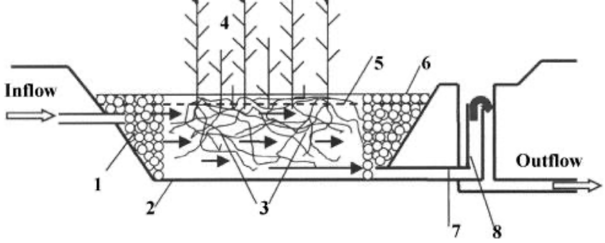

Figure 23 Schematic display of a horizontal helofyte filter. 1. Distribution zone with large rocks, 2. Waterprfoof underground, 3. Filtration medium (gravel, sand), 4. Vegetation, 5. Waterlevel in bedding, 6. Collection point with large rocks, 7. Drainage piping, 8. Exit, designed to keep the waterlevel in the bedding high. The arrows show a general pattern of flowing. Source: Spoelstra and Truijen (2010)

In figure 24 is shown how the water flows through Kampung Naga. The water comes from a spring on the hill near a sacred forest. From here the water flows through bamboo pipes to a fishpond (1). A washing platform is placed above the fishpond. The waste from washing forms food for the fish. After this, the water flows to the rice fields (2), where it is used for growing rice crops. After the rice fields, the water flows through the village, where rainwater can be added (3). The water is again collected in a fish-pond (4), where toilets, washing huts and places to wash dishes are situated. The waste is again

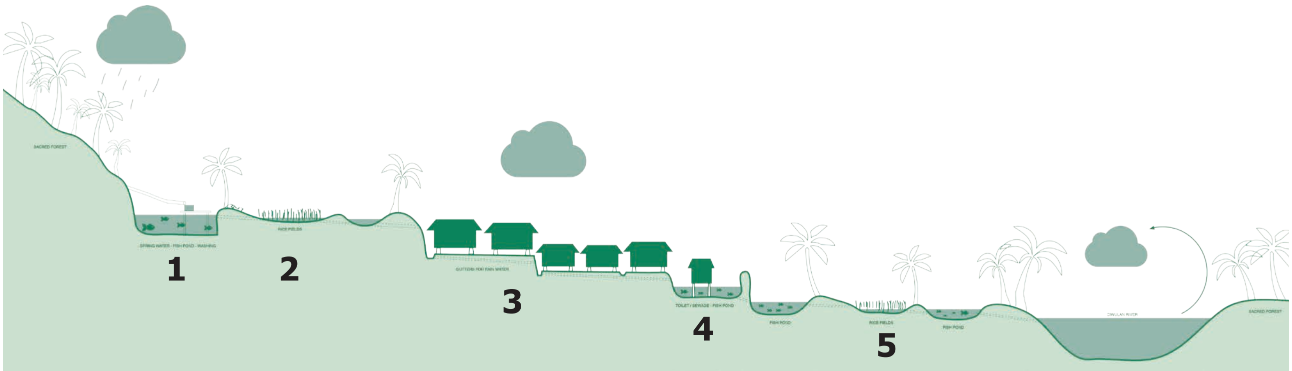

Figure 24 Schematic rendition of Kampung Naga. Source: Hegeman, S (2019). The numbers have been added. Larger version added in apendix.

used as food for the fishes. This water is led through several fishponds and rice fields (5), before it is disposed to the river. This way the water is given back relatively clean.

Like in aquaponics there is a relationship between plants and fish. They work together and provide food for each other, while cleaning the water. It shows how it is possible to make full use of the water that is available.

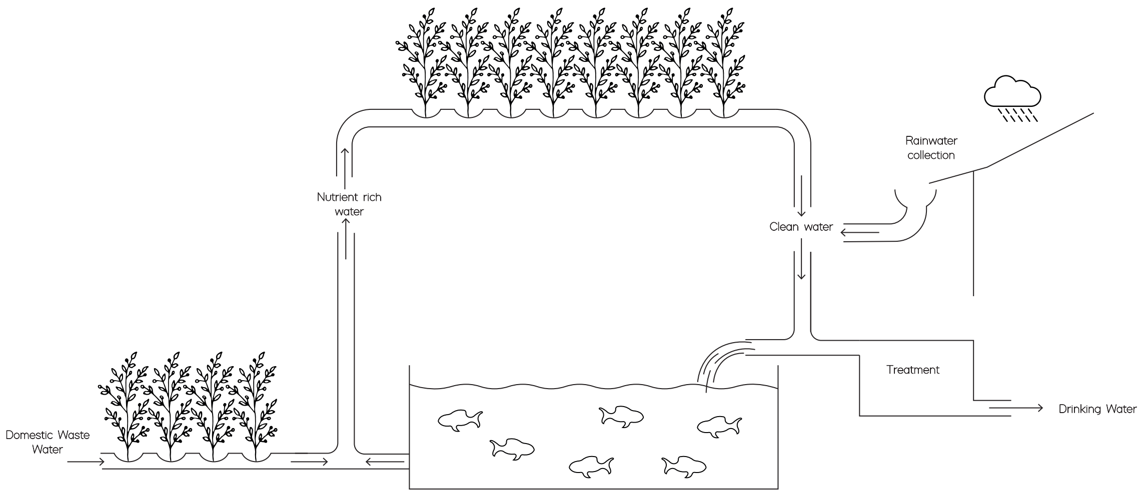

Figure 25 Clean water is being distracted on the bottom right. To get drinking water it needs either UV treatment or it needs to be boiled.

4.4 Water treatment

To get drinking water quality, additional treatment needs to be added at the end of the line (figure 25). Known possibilities for treatment are UV treatment, boiling the water and collecting evapotranspiration.

Boiling

Through personal observation it was found out that a lot of the people obtain drinking water by boiling clean water. This is still possible with this system, although it demands a small amount of daily labour. Whether this is a desirable situation is debatable. A solar boiling system could be the answer in the way that people don't have to actively boil it.

UV treatment

UV treatment is a plausible solution for kampung Melayu. Right now, there are small shops where solar treated water is sold through Semarang (see figure 26). When an aquaponic system is built kampung-wide, it

Figure 26 A store in kampung Kandri where water is being treated with UV radiation to be of drinking water quality.

might be economically feasible to set certain points in the kampung where the water is UV treated in such manner.

A different method which is based on UV treatment is a SODIS method. This method is very low-tech and cheap, but it requires some manual labour. "Transparent containers are filled with contaminated water and placed in direct sunlight for at least 6 hours, after which time it is safe to drink. Solar disinfenction containers (reactors) can be glass or plastic (usually polyethylene-terephthalate – P.E.T.) – even plastic bags have been used." McGuigan et al. (2012)[24]. To implement this system in a way where there is no need for people to manually refill bottles, but to keep the advantages of it being low-tech and cheap further research is recommended.

Evapotranspiration catchment

As mentioned in paragraph 4.2 evapotranspiration can cause the water storage to deplete. However, it can bring an interesting advantage. When the evapotranspiration is caught and turned back to water, drinking water is obtained. The water is so clean that minerals have to be added before humans can drink it. When this method is used no liquid water will have to be taken out of the aquaponic system. Only gaseous water which escaped the system will be collected. This system can provide drinking water and decrease overall water loss.

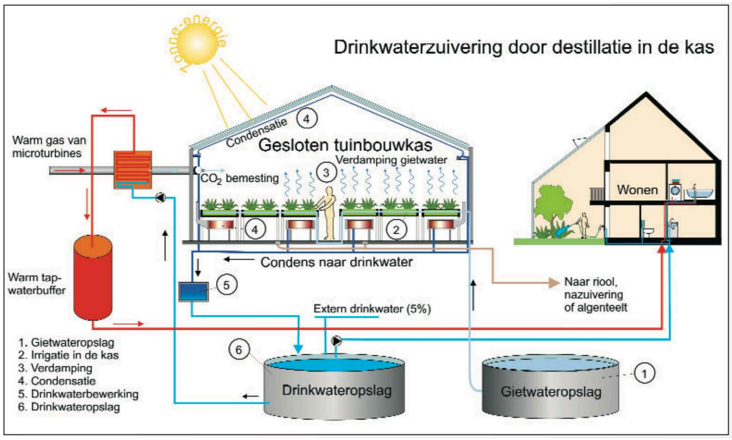

Figure 27 Schematic figure of drinking water treatment in the "zonneterp". Source: http://www.zonneterp.nl/zonneterp.pdf

An example of this system can be seen in figure 27. This project is called the "zonneterp" and provides drinking water by collecting evapotranspiration (3) of plants in a greenhouse. This is done by the process of condensation (4) against a glass roof. After this the water is altered by adding minerals (5) after which it can be stored (6) and used.

4.5 Clean water storage

To maintain a proper amount of clean water available, a storage basin where the clean water is collected might be necessary. The hard part in this, is to keep the water clean. Water will stay clean, if it keeps flowing in the system. Therefore, the storage basin needs to be integrated in the system, so the water keeps flowing (see figure 28). This way the water will stay clean.

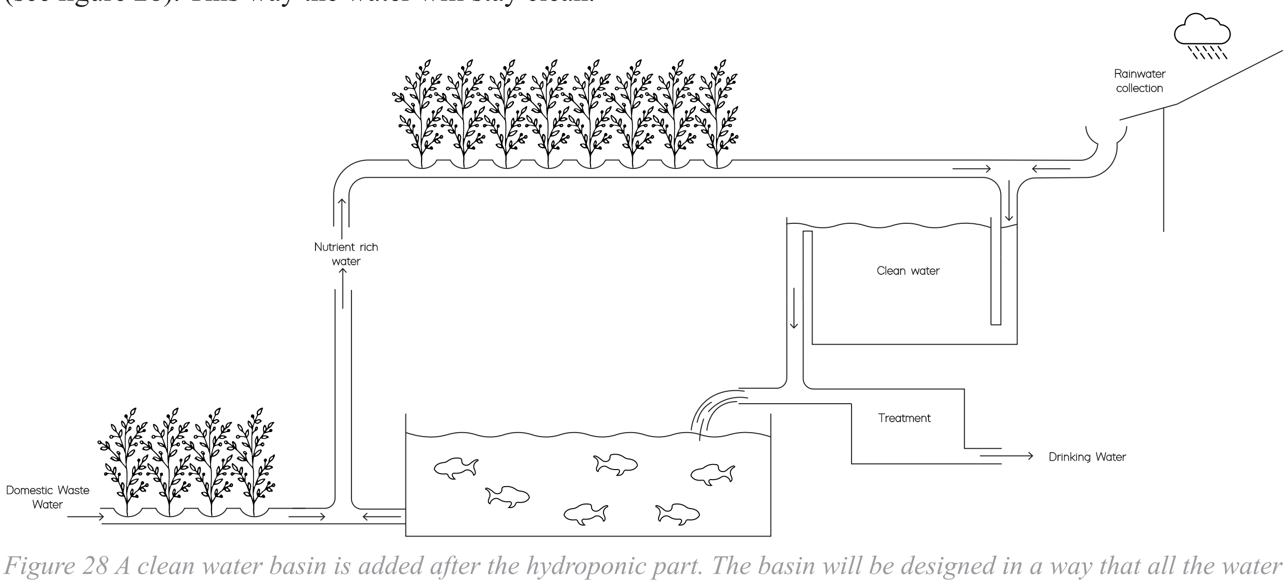

Figure 28 A clean water basin is added after the hydroponic part. The basin will be designed in a way that all the water will continuously be refreshened through the system.

4.6 Energy demand

When the system is implemented, the water is pumped around on a regular basis. This requires energy. This energy can be bought (as electricity), but for economic gain and environmental reasons it is more desirable to find a renewable source to provide this energy. In the paper of Gopal et al (2013)[25] renewable energy sources for water pumping systems for irrigation are researched. According to this paper there are four main renewable water pumping systems: solar powered water pumping systems (SPWPS), solar thermal water pumping systems (STWPS), wind energy water pumping systems (WEWPS) and biogas water pumping systems (BWPS).

With SPWPS electricity generated with solar panels is used to pump the water around (figure 29). Depending on the system design it requires batteries. When it is installed without batteries it is cheaper and it requires less maintenance. However, the water can only be pumped during the day. PV panels have to be installed near the project to provide the electricity. In tropical countries direct solar radiation may reach up to 1000 W/m2. To give an example: a small pump of 400 W can pump up 7500 liter per hour (Powerplus PO-WEW67904 Dompelpomp). With 1 m^2 of PV-panels at least 15000 can be pumped around every hour.

STWPS (figure 30) use solar thermal energy and convert it into mechanical energy. The main advantages of STPWS are their low cost and that they are maintenance free and without mechanical moving components. However, the amount of water being pumped per m^2 of solar collector is significantly lower than with SPW-PS. With a flat-plate collector of 1 m^2 700-1400 liter per day can be pumped around.

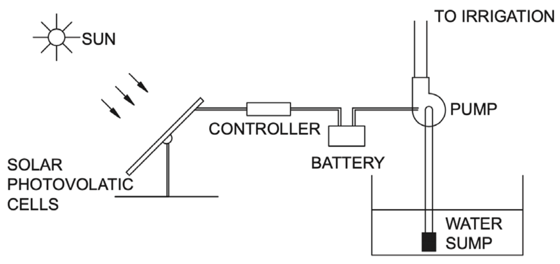

Figure 29 Schematic layout of SPWPS. Source: Gopal et al (2013)

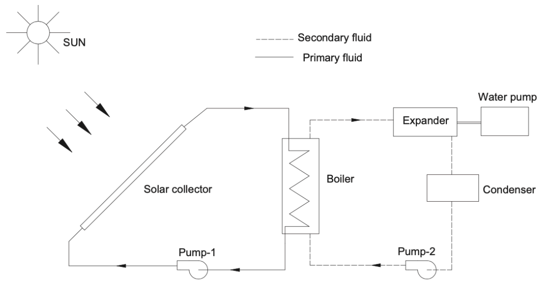

Figure 30 Schematic layout of STWPS. Source: Gopal et al (2013)

WEWPS use wind power to pump the water around (figure 31). A wind powered rotor is coupled to a generator which convert the wind to electrical energy. This energy is used for an electrical pump to pump the water. The amount of pumped water depends on the amount of energy generated with the wind turbine. To get the amount of electricity as high as possible, a large tall wind turbine has to be installed. Therefore, this method can be seen as less desirable.

BWPS consists of a biomass gasifier and a dual fuel engine (figure 32). It uses a combination of 30% diesel and 70 % biogas. This means that a certain amount of fuel still needs to be bought. However, it is also possible to convert the biogas into electricity in a gas generator and use an electrical pump. This would require no diesel, but energy is lost due to the conversion of chemical energy to electrical energy.

To create biogas, organic material is needed. This is available in the form of human fecal waste, urine and waste provided by the hydroponic system. However, to convert this into biogas, a lot of time and a large amount of organic waste is needed. In the research paper from Akpojaro et al. (2019)[26] the possibilities of biogas created from cow dung are researched. They found out that with 40 kg of cow dung, 1,53 m3 of purified biogas could be created. This was converted into electricity using a low-pressure gas generator. This resulted in 2,28 kWh. However, the total possible amount of energy stored in 1,53 m3 of biogas is 8,26 kWh. This means that there is only an efficiency of 35%.

One of the systems proposed above has to be added to the aquaponic system. To choose which one is most suitable, depends on the specific location in which it is implemented. With a lot of hours of sun SPWPS and STWPS can be more suitable for instance. Each of the systems has its advantages and disadvantages, but all of them could be a solution.

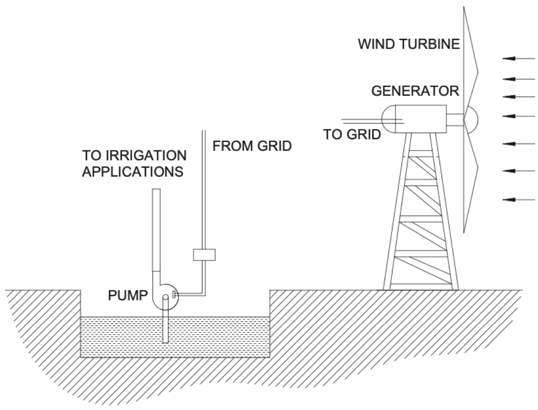

Figure 31 Schematic layout of WEWPS. Source: Gopal et al (2013)

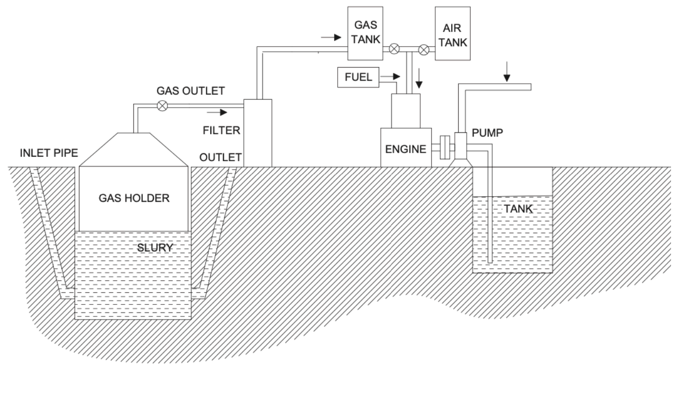

Figure 32 Schematic layout of BWPS. Source: Gopal et al (2013)

V. Conclusion

An aquaponics system like the one in kampung Kandri can bring a lot of economic, social, spatial and climate benefits to kampung Melayu. However, certain adjustments have to be made to make this system suitable for the clean and drinking water demand of Melayu. The system has to be altered to function as a water supplier. These alterations can be seen in figure 33.

Evapotranspiration causes a lot of water to go to waste. To mitigate the effects of evapotranspiration exposure to winds of a large speed has to be prevented, the open water bodies have to be shaded and/or covered and the basins need to have a relatively small contact surface with open air compared to its volume.

For the system to work, there is a need for a steady supply of water. This is done in the form of rainwater collection and the reuse of waste water in the community. If the system would fully depend on collecting rainwater, volumes of 18 -36 m^2 per person have to be reserved. This means that with the area of kampung Melayu 2463 - 4926 people can live from rainwater collection. If 100% of the wastewater can be reused, the rainwater would only have to account for the loss through evapotranspiration.

There is also a necessity to add a final step of treatment to upgrade the clean water to that of the quality of drinking water. This is done by boiling the water, applying UV treatment or by catching evapotranspiration.

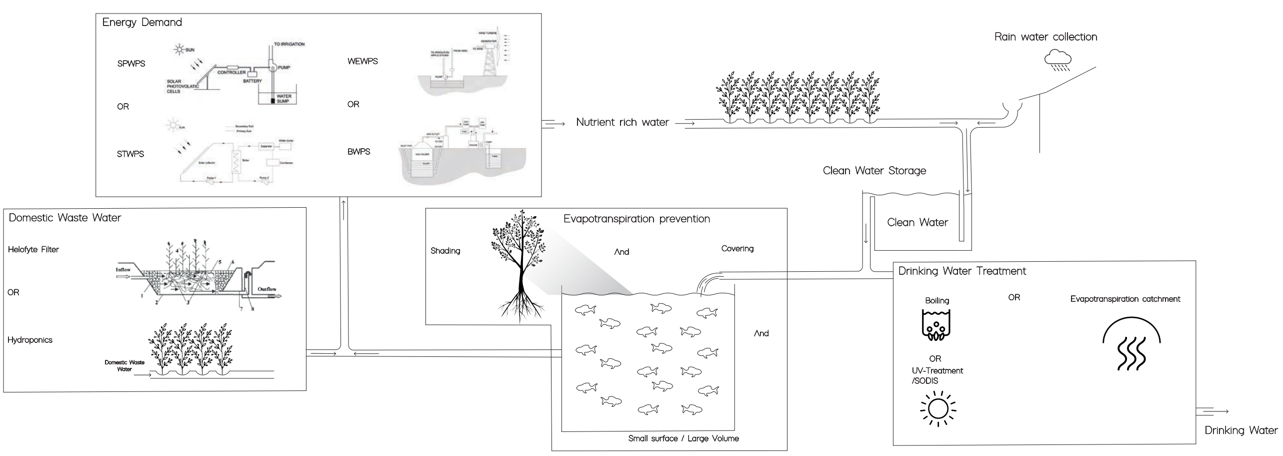

Figure 32 Aquaponics system with the proposed additions. Larger version added in Appendix C.

Another necessary addition to the system would be that of adding a storage basin for the clean water. The difficulty in this would be that the basin needs to be part of the system to keep the water clean.

Finally, there is a need for energy to keep the water pumping around in the system. There are multiple possibilities to provide energy for the pumps: SPWPS, STWPS, WEWPS and BWPS.

By applying these additions to the aquaponic system it can now function as a clean water and drinking water supplier for kampung Melayu.

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APPENDIX A

Interview with Syaffei Hassanudin, a resident of Kandri and the person who implemented aquaponics in his kampung.

1. What are your backgrounds?
I did not go to higher education, but my parents are both farmer. But I like to explore new things on the internet, until one day I came across aquaponic. For someone who have been raised farming on land, aquaponic became a wander to me. How can we practice agriculture not on soil itself? From that on, I started researching and did some experiments myself. Until I found myself one day in national aquaponic community.

2. When and how did you introduce aquaponic to the first time?
It began in 2010 where I just experimented it myself and told my neighbors about it. And then in 2017, the head of our neighborhood community (RW) agreed to make it as a neighborhood program. In our district, each RW has their own theme: culinary, cave recreation, batik art, and so we made ours an aquaponic tourism village. We introduce it to social media in 2017, making the village famous as an ecotourism destination. Only then we start to acknowledge the zero-waste and circular economic aspects of it, slowly.

3. Could you explain a bit of how it works?
Made a sketch

4. What are the types of plants and vegetables that people grow on their aquaponics?
They are mostly vegetables or spices, such as mustard greens, leek, celery, kale, grapes, etc.

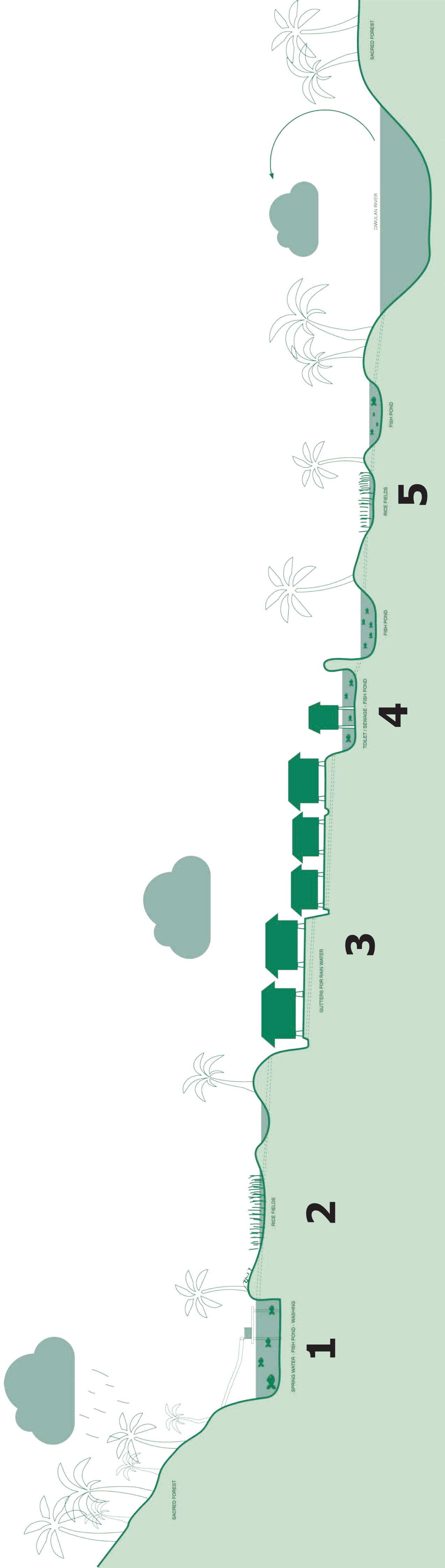
5. Is it economicaly viable?
It only takes about 100.000 rupiah (5 euro) to install a minimal set up. I would say it is very viable as you can harvest some spices for ingredients. It is just the maintenance cost that you need to be aware afterwards, but still, it is not that much. I only clean this set-up every four months.

6. Has it reduce people's need to go to the market?
Yes, and they could also trade their harvests.

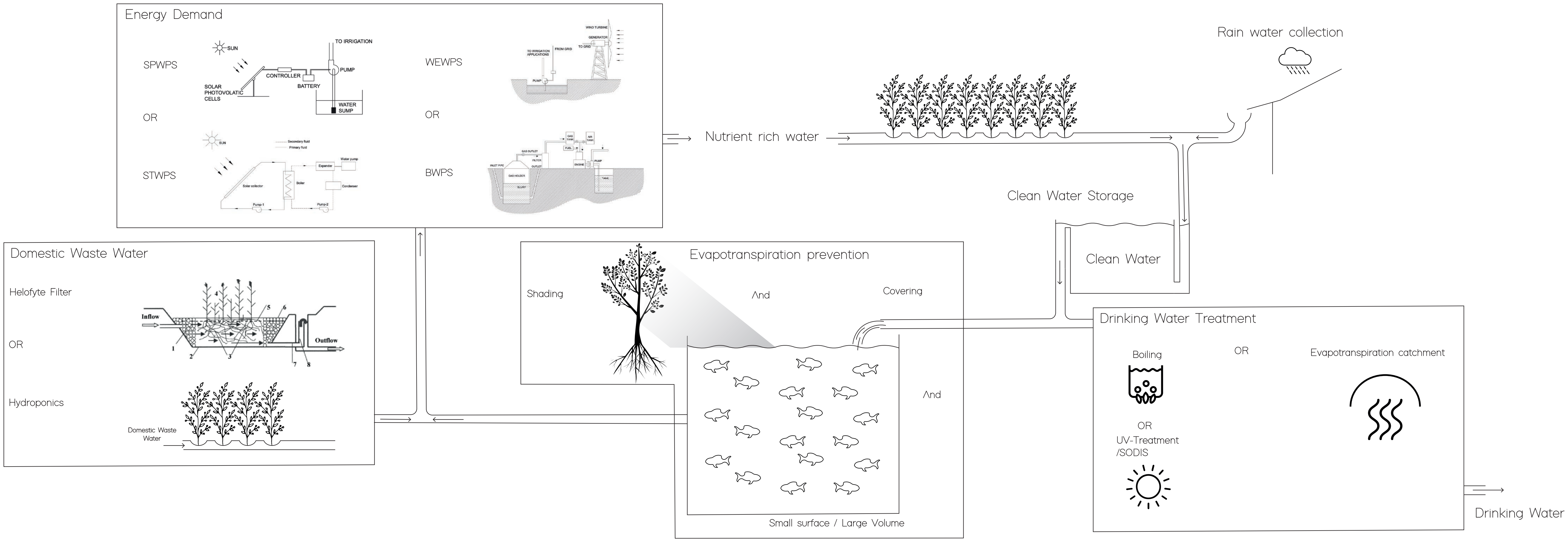
7. What are the challenges so far?
It would be to keep the consistency of people as well as the clean water access. Many parts of this subdistricts have no clean water pipes installed yet from PDAM. Hence, they obtain water for the aquaponics from the adjacent compounds. This would be a problem during the dry season as the water on the fish ponds may evaporate.

8. What your future hopes on this project?
We need a empty land for the aquaponic waste treatment--processing it to be food for the worms, worms for the fishes, and the fish waste for the aquaponic fertilizers. If this treatment process could be aided by the government it will be very helpful. We also hope that bigger institutions would be able to support us in terms of networking and innovative technology research so this project would non be stagnant.

APPENDIX B


SACRED FOREST
1
SPRING WATER - FISH POND - WASHING
2
RICE FIELDS
3
GUTTERS FOR RAIN WATER
4
TOILET / SEWAGE - FISH POND
FISH POND
5
RICE FIELDS
FISH POND
CIWULAN RIVER
SACRED FOREST

APPENDIX C



Energy Demand
SPWPS
OR
STWPS
WEWPS
OR
BWPS
Nutrient rich water
Rain water collection
Clean Water Storage
Clean Water
Domestic Waste Water
Helofyte Filter
Inflow
Outflow
OR
Hydroponics
Domestic Waste Water
Evapotranspiration prevention
Shading
And
Covering
And
Small surface / Large Volume
Drinking Water Treatment
Boiling
OR
Evapotranspiration catchment
OR
UV-Treatment
/SODIS
Drinking Water