THE OUTLOOK OF RURAL WATER SUPPLY IN DEVELOPING COUNTRY: REVIEW ON SABAH, MALAYSIAS

Rosalam Sarbatly1, Farhana Abd Lahin2*, Chel-Ken Chiam3

1, 2, 3 Membrane Technology Research Group, Material and Mineral Research Unit, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA

Email: 1rslam@ums.edu.my, 2*farhana.abdlahin@ums.edu.my, 3chiamchelken@ums.edu.my

ABSTRACT. This paper reviews the challenges in the water supply provision, water source availability and quality and the distribution approaches in rural Sabah. The main challenges to provide potable water in Sabah is the variance in terrain and geographical distance between populated regions. Review reveals that other than the river water, average annual precipitation of 3000 millimetres (mm) could be harvested for domestic and agricultural purposes. Numbers of aquifer uncovered in the eastern and western region of Sabah with underlying sandstone and Quaternary Alluvium have significant potential for groundwater reservoirs. Aquifer along the coastal areas and islands around Sabah also gives sufficient potable water supplies. Minimal pollutant content was found in all water sources and acceptable under the National Water Standard of Malaysia, except for contaminants coming from septic tanks and agricultural activities. A decentralized water system is more beneficial for Sabah’s rural areas. Smaller scaled plants are flexible to collect from any water sources and treat at the point of use. Expenditure is significantly decreased by a shorter distribution network and lower installation and maintenance cost. Nonetheless, the treatment utilized may be limited to a simpler process as semi-skilled or un-skilled personnel will be required to operate and maintain the system.

KEYWORDS: Groundwater, Malaysia, rainwater, rural area, surface water, water supply

INTRODUCTION

Water scarcity has long been a pressing issue, affecting almost every country in the world albeit more significant for some than others (Distefano and Kelly, 2017). Statistics show that 183 million of the world’s population lacked basic drinking water (UNICEF and WHO, 2017). Beyond just drinking needs, water is important for many human activities such as basic sanitation and hygiene, crop watering, and livestock, irrigation, energy production, transportation, recreation, and industrial application (Davis and Cornwell, 2013). As such industrial development, climate change, increase of population and change in water consumption patterns exasperates the gap between water demand and supply; thus intensifying the issue on water scarcity. (Zhou, Deng, et al., 2017). Water scarcity essentially affects the economic growth of a country (Distefano and Kelly, 2017), food security (Wang, Li, et al., 2016), socio-economy (Zhou, Deng, et al., 2017) and even more so on human health (Nyemba, Manzungu, et al., 2010). Inaccessibility to water leads to a lack of clean drinkable water and proper sanitation (WHO and UNICEF, 2014). The concept of water scarcity is defined as the inaccessibility to safe and affordable water for livelihood within a significant duration (Rijsberman, 2006). It considers not only the availability of water but also the quality of water (Liu, Liu, et al., 2016; Zeng, Liu, et al., 2013).

Though it may be less obvious, Malaysia also experiences water scarcity. As a developing country, Malaysia’s continuous growth in population, urbanization, industrial, and agricultural expansion has put an immense pressure on its water supply industry. This phenomenon has greatly increased the demand for water, while subsequently polluting its water resources (DID, 2009). Consequently, authorities have put great efforts to expand and improve the existing water service.
Nonetheless, the development of water supply service in Sabah has been rather uneven. Urban and semi-urban areas have developed water supply systems, whereas rural populations struggle to get access to clean water for domestic and non-domestic usage. Sabah comprises a number of rural regions that suffer from low water quality, water interruption, with some areas even facing the absence of treated water. Rural communities in some parts of the state have to rely on rainwater or surface water (pond/river) for daily water use (Zin, SabaiAung, et al., 2015).

Previous researchers have studied the condition of water quality from several rivers and lakes in Sabah and compared it to the Malaysia Interim National Water Quality Standards of Malaysia (INWQS). These studies have found that while some of the rural water intakes in Sabah are well under the standards, other parameters such as the chemical oxygen demand (COD), ammonia-nitrogen (NH₃–N) and total suspended solids (TSS) exceed the standard (Harun and Fikri, 2016; Harun, Dambul, et al., 2014; Heng, Chu Kong, et al., 2006; Aris, Lim, et al., 2014; Cleophas, Isidore, et al., 2013). These pollutants are mainly due to septic tank leakage and under-maintained wastewater treatment, mill discharges and industrial effluents (Kadhum, Ishak, et al., 2015; Ariffin and Sulaiman, 2015; Liew, Kassim, et al., 2014). Rainwater as a source of water for potable and non-potable uses has been considered by some researchers (Ayob and Rahmat, 2017; Che-Ani, Shaari, et al., 2009; Lee, Mokhtar, et al., 2016; Ani, 2009; Kasmin, Bakar, et al., 2016; Appan, 1997). Studies have found that rainwater treatment is required in order to remove heavy metals and pathogenic content in water (Leong, Oh, et al., 2017; Ahmed, Gardner, et al., 2011; Kasmin, Bakar, et al., 2016). However, these researches suggest rainwater for individual domestic use; and have not considered rainwater as a large or mid-scale water resource. Groundwater resources on the other hand, have mainly been studied on island areas (Kura, Ramli, et al., 2015; Isa, Aris, et al., 2014; Praveena, Lin, et al., 2010; Aris, Abdullah, et al., 2007; Abdullah, Musta, et al., 1997) since groundwater is the main freshwater source in those areas. The inland studies focus only on the areas with severe water supply problems such as Selangor and Kelantan (Sefie, Aris, et al., 2015; Suratman, Tawnie, et al., 2011; Ismail, 2009). As such, information on the availability and quality of groundwater in Sabah is still limited.

Several researchers have evaluated the effects of privatization on water services in Malaysia which conclusively showed the affordability of water utility yet with no dramatic improvement to the access of treated water (Tan, 2012; Lee, 2011). With regards to policies, researchers acknowledged the inaccessibility of treated water, and the lack of development of treated water supply in the country, suggesting that better policies and resource management should be in place to protect the various social, political, and economic levels (Saimy and Yusof, 2013; Padfield, Tham, et al., 2016). However, these studies have focused on Malaysian governance in general and which mainly refer to federal legislation. This may not necessarily be applicable for all states, as the water service in Sabah is governed by the state government and may differ from that in other states in the peninsular region. Furthermore, a generalization of the water supply for urban, sub-urban and rural areas may not be the most efficient approach, especially in Sabah, as the physical and socio-economic conditions differ greatly.

Presently, no study has been conducted on reassessing the underlying issues of rural water supply in Sabah in the attempt to propose a universal solution to the problem. In this paper, we aim to fill the gap and present a comprehensive review on the status of water resources and supply strategies in Sabah. This paper proceeds as follows: firstly it describes the nature of Sabah, as the case study area, while highlighting the reoccurring issues with regards to water supply. The paper later reviews the available water resources in Sabah, the potential and quality of each water resource. The next section reviews the potential of decentralized water networks for rural water supplies and finally concludes the findings of the study.
Case Study Location and Climate

Malaysia is located in South East Asia and therefore experiences equatorial climate with a mean temperature of 22 to 32 degrees Celsius. The average annual rainfall is 3,000 millimetres, seasonally distributed throughout the year. Generally, Malaysia experiences four monsoon seasons, influenced by the periodic changes in the wind flow. The Northeast Monsoon occurs from November until March. During this season, the east coast of Peninsula Malaysia, and some parts of western Sarawak and Sabah’s northeast coast regions experience heavy rainfall. Two Inter-Monsoons March to May and October until mid-November bring in convectional rain. Whereas during the Southeast Monsoon around May or June ending in September causes relatively dry weather except for Sabah (Malaysian Meteorological Department, 2017). Sabah’s specific rainfall patterns are discussed further in Section 0.

![Figure 1: Locality of Sabah, Malaysia](image)

Sabah’s Water Supply Issues

In Malaysia, water is generally supplied through water distribution networks operated by the government; as well as some privatized organizations (Lee, 2011; Tan, 2012). Water distribution networks are managed centrally in major towns and cities. Meanwhile, regional water networks are applied in smaller townships. The development of water supply networks is however seen to be unevenly developed throughout the country. In the more urbanized states, universal access is available to the public, while the rural populations continue to struggle with access to treated water (Lee, 2011). This situation is especially apparent in Sabah. National comparison (Figure 2) shows that rural Sabah is among the lowest having access to treated water.
A majority of the rural communities still struggle with water supply issues; by either having low water quality; which is frequently interrupted or the complete lack of water supply, forcing communities to seek alternative water supply themselves. The following are examples of situations faced by the rural populations in Sabah based on the author’s observation and experience:

**Banggi Island**, the biggest island in Malaysia is inhabited by roughly 20 thousand residents, most of whom work as fishermen and farmers. Being in a secluded part of Sabah (northeast of Kudat), the development in Banggi Island is far behind, including the water supply system. Almost 70% of the locals live in the absence of clean water supply. The locals have to depend on river water, rainwater, and groundwater through manually dug wells. The lack of supplied potable water results in proper basic sanitation such as functioning indoor toilet and solid waste disposal system. Utilization of polluted surface and groundwater will lead to disease outbreaks among the locals. Despite having a newly operating water treatment plant on the island, most locals are unable to benefit from the facility due to costly meter connection and pipe mounting to the current main network.

**Mabul Island**, a small, densely populated island, is one of the tourist attractions in Semporna, in the east of Sabah. Locals of Mabul Island are supplied with improved water, treated via reverse osmosis method. Unfortunately, the treatment is not adequate, resulting in significant brackish water, forcing the locals to use a more conventional water supply of rain water for potable uses.

**Ranau** is the highest contributor for agriculture as well as tourist income for Sabah. Consequently, the demand for water in the district is high. However, treated water has always been an issue for the locals. In Ranau, water supply complications occur during the rainy season. Heavy water flows in the Liwagu River are causing the intake point to be flooded by mud, increasing the sedimentation loading in the water, as a result, this exceeds the allowable level for the treatment plant. This causes water treatment suspend its operation resulting in disruption of water supply. Moreover, waste from upstream such as broken tree bark and branches will obstruct the inlet and aggravate the situation further.

**Beaufort** has continually struggled with water inconsistency. In spite getting the highest annual rainfall among the regions and regular amount of water source from Padas River, the fundamental reason for lack of water supply is poor management of treatment and distribution. A steady increase in residential with a recorded population over 66 thousand in census 2010 has created a rapid increase in need for treated water. Operating water treatment plant has seen incapable to meet these demands of 40 million liters daily. Fast track development on the upper part Padas River has resulted in elevated

![Figure 2: Status of pipe water access in each state for 2014 and 2016](image)
sedimentation and erosion of soils particularly during the monsoon. Increase in turbidity hinders the treatment plant to operate efficiently, which finally cause turbid water to be distributed.

**Distribution Pipelines**

Within 73,619 Kilometres Square (km$^2$) of land area, Sabah’s population is sporadically scattered into a total of 23 districts. The significant distance between residential areas together with the physical land condition of undulating terrains have proven that constructions, operation and maintenance of water supply network to be an overly expensive undertaking. The mountain range of Sabah demands extended pipeline networks and an overwhelming pumping energy necessity. To date, the water network has stretched to nearly 10,500 km supplying water to 99.8% urbanised areas and 69% rural areas in Sabah.

Sabah’s pipeline network is comprised of several materials as listed in Table 1. In the early years, asbestos cement pipes were frequently used and due to ageing, these pipes are beginning to rupture. These decomposing pipes are unable to cater the demand for high pressure flow thus in severe need for replacement. Nonetheless, constraints faced such as inadequate manpower and competent personnel hinder from upgrading these networks and instead easy repairs such as replacement of bursting pipes and faulty end-point meter only. Furthermore, lack of complete statistics on the current network and incomplete plotting has made upgrading of the system to be even more challenging (Salleh and Malek, 2012).

**Table 1:** Pipeline material and length in Sabah (Salleh and Malek, 2012)

<table>
<thead>
<tr>
<th>Material</th>
<th>Length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbestos Cement (AC)</td>
<td>2,345</td>
</tr>
<tr>
<td>Mild Steel (MS)</td>
<td>2,622</td>
</tr>
<tr>
<td>Unplasticized polyvinyl chloride (uPVC)</td>
<td>1,620</td>
</tr>
<tr>
<td>High-density Polyethylene (HDPE)</td>
<td>796</td>
</tr>
<tr>
<td>Ductile Iron (DI) / Cast Iron (CI)</td>
<td>687</td>
</tr>
<tr>
<td>Others</td>
<td>306</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,376</strong></td>
</tr>
</tbody>
</table>

**Non-revenue water (NRW)**

Another issue in the water supply industry in Sabah is the high level of non-revenue water (NRW). NRW is non-chargeable water that is generated, caused by physical losses through leakage and overflow, apparent losses through water theft, inaccurate meter readings and sometimes through free usage such as water consumption for firefighting activities (DHI, 2011). NRW greatly adds to the overall operating cost and acts as a barrier to improve or extend water supply service (van den Berg, 2015).

Generally, almost 80% of the leakage contributes to NRW and the rest is due to apparent loss. The national average NRW is at 35.6% (Hussein, Yoneda, et al., 2017). In 2016, Sabah NRW was at 52 % which corresponds to 634 million litres per day, a minor improvement from 2015 which was at 667 million litres per day, 55.1% from the system output volume (National Water Services Commission, 2016). The staggering value is among the highest in Malaysia. Other, often overlooked factor, in NRW is the lack of policies on un-used water pipe closure. This often occurs in rural areas where old pipe connections to houses without any residents are left without meter suspension and are eventually abandoned. These pipes would usually leak and contribute to great water loss.
The Malaysian government has providently dedicated a sum of 1.4 billion Ringgit Malaysia for the NRW programme starting in 2018 (Ministry of Finance Malaysia, 2017), a positive continuation of the preceding programme which had begun in the early 2000s. The program execution involves the replacement of old pipelines and meters. Additionally, intensive leakage control through district metering zones (DMZ) was implemented in several districts, including Kota Kinabalu, Penampang, and Putatan. 25% of NRW reduction is expected in the year 2020.

Available Water Resources

Three main water resources are abundantly available in Sabah; i.e. surface water, rainwater, and groundwater. Each one is related to one another in some way. As a tropical country, Malaysia receives plenty of rainfall annually. The precipitation is sometimes harvested, but often becomes surface runoff where it infiltrates the soil and is stored underneath the earth’s surface as groundwater. Surface runoff stored in lakes, streams or oceans are known as surface water (Davis and Cornwell, 2013). Groundwater resources accounts for 90% of the global freshwater and a small portion of surface water that sums up to 442 thousand cubic kilometres of water (Tarbuck and Lutgens, 2015). The effects of global warming have significantly affected the water cycle. The extreme temperature variance has changed the rainfall variability throughout the year. As a result, the alternation between extreme drought and precipitation occurs (Loo, Billa, et al., 2015; Chan, 2006), both of which have significant effects on water supply resources in terms of capacity, accessibility, and quality. Extreme rainfall results in flooding of water catchments, increase of sediments, causing debris such as mud and sand to clog treatment systems, and further complicate water collection, treatment, and distribution (NRO, 1994).

Surface Water

Sabah water supply generally relies on river water, though some part of the state still depends on other surface water source such as lake. Water quality used for potable water intake in Malaysia is monitored based on the Malaysian Raw Water Standard (RWS) which is equivalent to the guideline enacted by the World Health Organization (WHO). Table 2 highlights the chemical characteristic of river water in several isolated river tributaries in Sabah. Based on a comparison against RWS, the majority of the parameters are within acceptable range except for chemical oxygen demand (COD), Ammonia-Nitrogen and total suspended solids (TSS).

Surface Water Quality

Surface water quality are affected by various sources of contamination which can be generalised into point source and non-point source pollution. Sewage pollution is a prime example of point source pollution. Discharge of sewage without proper or insufficient treatment causes increase of nutrient load which results in eutrophication and reduced dissolved oxygen (Cravo, Fernandes, et al., 2015; Burford, Revill, et al., 2012). Other than aquatic life threat, human health is also at risk as extreme bacteria and pathogenic content in sewage can cause numbers of disease (Xiao, Hu, et al., 2018; Almeida and Soares, 2012). On the other hand, non-point source of pollution are pollutant that leach into the water bodies from less obvious point of discharge such as from agricultural pollutant by-product i.e.: pesticide and fertilizer (Tankiewicz, Fenik, et al., 2010). Nonetheless, surface water quality is highly affected by the precipitation level. High precipitation will cause dilution of pollutant concentration. Although increased rainfall could result in other issues such as soil erosion and sedimentation as well as spike in suspended solids due to increase water flow.
<table>
<thead>
<tr>
<th>Location</th>
<th>Beluran</th>
<th>Beluran</th>
<th>Beluran</th>
<th>Sukau</th>
<th>Sukau</th>
<th>Sukau</th>
<th>Lower Catchment</th>
<th>Tambunan</th>
<th>Tambunan</th>
<th>Tambunan</th>
<th>Beaufort</th>
<th>RWS&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main River</strong></td>
<td><strong>Sugud River&lt;sup&gt;a&lt;/sup&gt;</strong></td>
<td><strong>Sahab River</strong></td>
<td><strong>Wansayan River</strong></td>
<td><strong>Kelipatan River</strong></td>
<td><strong>Resang River</strong></td>
<td><strong>Lumun River</strong></td>
<td><strong>Kalimanap River</strong></td>
<td><strong>Nukakatan River</strong></td>
<td><strong>Mesangoh River</strong></td>
<td><strong>Luangkan Rompong Lake</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.01</td>
<td>7.08</td>
<td>6.82</td>
<td>7.02</td>
<td>5.3 - 6.5</td>
<td>5.2 - 6.7</td>
<td>6.6 - 7.0</td>
<td>6.34 - 8.3</td>
<td>7.79 - 8.18</td>
<td>6.0 - 8.5</td>
<td>5.5 - 9.0</td>
<td></td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>4.93</td>
<td>1.93</td>
<td>3.66</td>
<td>3.2</td>
<td>4.3 - 6.2</td>
<td>3.5 - 5.6</td>
<td>1.9 - 4.1</td>
<td>6.19 - 6.81</td>
<td>6.9 - 7.79</td>
<td>3.9 - 11.4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>0.07</td>
<td>27.29</td>
<td>0.11</td>
<td>2.22</td>
<td>0.05 - 0.1</td>
<td>0.01-0.03</td>
<td>0.03-0.04</td>
<td>0.05 - 0.09</td>
<td>0.05</td>
<td>0.06</td>
<td>71.8 - 86.2</td>
<td></td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>155.28</td>
<td>45,574.65</td>
<td>180.3</td>
<td>4,373.45</td>
<td>110.8</td>
<td>236.5</td>
<td>52.9</td>
<td>76.9</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>3.19</td>
<td>1.27</td>
<td>4.01</td>
<td>2.49</td>
<td>1.3 - 2.1</td>
<td>2.9 - 3.2</td>
<td>3.1 - 3.6</td>
<td>0.38 - 0.59</td>
<td>0.52 - 0.65</td>
<td>n.m&lt;sup&gt;*&lt;/sup&gt;</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>18.08</td>
<td>751.15</td>
<td>21.03</td>
<td>24.38</td>
<td>53.8</td>
<td>100.0</td>
<td>36.8</td>
<td>35.1</td>
<td>0.67 - 3.4</td>
<td>3.5 - 4.8</td>
<td>n.m</td>
<td></td>
</tr>
<tr>
<td>Total Coliform (CFU/100 ml)</td>
<td>3,594.88</td>
<td>1,108.28</td>
<td>1,753.25</td>
<td>3,029.53</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>17.0 - 169</td>
<td>33 - 137</td>
<td>n.m</td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Ammonia-Nitrogen (mg/L)</td>
<td>0.52</td>
<td>98.44</td>
<td>0.7</td>
<td>4.75</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.09 - 0.27</td>
<td>0.03 - 0.32</td>
<td>n.m</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>33.0</td>
<td>42.0</td>
<td>-</td>
<td>49 - 75</td>
<td>49 - 96</td>
<td>0.1 - 4.0</td>
<td>1.0 - 3.4</td>
<td>n.m</td>
</tr>
</tbody>
</table>

<n.m: not measured>

Data adapted from: <sup>a</sup>(Harun and Fikri, 2016), <sup>b</sup>(Harun, Dambul, et al., 2014), <sup>c</sup>(Cleophas, Isidore, et al., 2013) and <sup>d</sup>(Heng, Chukong, et al., 2006)
<sup>e</sup>RWS is imposed by the Ministry of Health Malaysia from (MMOH, 2010)
Even though Sabah has abundant of rivers and its tributaries, water scarcity still occurs, which is mainly due to polluted waters and costly development. Surface water is extremely influenced by anthropogenic discharges and weathering (Simeonov, Stratis, et al., 2003). Surface water pollution is Sabah can be grouped into rural, urban and semi-urban pollution based on its locality and developmental activities. Pollution occurring in rural areas is mainly from land clearing for logging, plantation, mining or agricultural activities. Fertilizer nutrients, increased suspended solids and heavy metal residues are commonly found in these areas. On the other hand, sub-urban and urban are heavily polluted by industrial and domestic sourced discharge. Improper solid waste handling in industrial and residential areas causes floating debris and leachate seepage into water bodies. Land clearing for rapid construction areas and ever growing landfill further add to the erosion and sedimentation issues (NRO, 1994).

The quality of surface water should agree to the standard outlined in the INWQS. Basic markers for the river water quality are based on the level of BOD, COD, DO, pH, TSS, and NH₃-N (Hasan, Jamil, et al., 2015).

**Rainwater**

Sabah collects 1,500 to 3,000 mm of precipitation annually. Nonetheless, rainfall level can be distinguished between regions of southern, northwest and central parts of the state due their topographical characteristic. Generally, the central and southern part of Sabah receives and evenly distributed precipitation, although the central region collects a lower level due to the mountainous range in the region. Northwest region collects higher level of precipitation in October and June with February and August being the driest months. Based on the annual rainfall distribution as shown in Figure 2, harvesting and storing of rainwater could be implemented as an alternative for water supply. Moreover, initiation of such initiative has been instigated, following the drought between 1997 – 1998 (Lee, Mokhtar, et al., 2016; Che-Ani, Shaari, et al., 2009).
Figure 3: Sabah Monthly Rainfall Distribution (Malaysian Meteorological Department, 2017)
Quality of rainwater is influenced by several factors such as the locality and neighbouring activities, collection system and storage material, rainfall time span, and interval of wet and dry climate (Che-Ani, Shaari, et al., 2009; Kasmin, Bakar, et al., 2016; Yaziz, Gunting, et al., 1989; Despins, Farahbakhsh, et al., 2009; Shaheed, Wan Mohtar, et al., 2017). In general, urban areas with more industrial activities will have more suspended debris in the atmosphere which will be carried during rainfall (Man, 2015). Material for storing containers for harvested rainwater, such as plastic cisterns is more acidic as compared to a concrete storage (Despins, Farahbakhsh, et al., 2009).

**Rain Water Quality**

Quality of harvested rainwater majorly affected by contamination occurring during collection and storage. Most rainwater harvesting systems, especially in residential areas utilize roof-top as a collection method which is exposed to atmospheric pollutions, animal droppings, and debris such pieces of tree branch, leaves or even small garbage (Krisha, 2005; Yaziz, Gunting, et al., 1989). Analysis of collected rainwater harvested from parts of Malaysia (Table 3) shows that heavy metal concentrations have a tendency to go above the limit specified in RWS particularly zinc, iron, aluminium, cadmium, chromium and lead. Prolonged exposure to heavy metal are highly dangerous to the human body as it may bio-accumulate and cause nervous system destruction (Elango and Kannan, 2007). In urban and semi-urban areas, atmospheric pollution settlement onto the harvesting surfaces are more prominent (Sánchez, Cohim, et al., 2015) lead being most commonly detected (Leong, Oh, et al., 2017). Lead content may be coming from painted roof that contain lead, lead flashing or even atmospheric settlements (Huston, Chan, et al., 2012). Utilization of a galvanized metal roof may cause zinc leaching (Lee, Yang, et al., 2010; Yaziz, Gunting, et al., 1989; Nicholson, Clark, et al., 2009), while old and corroded roof is the main contributor to heavy metal contamination (Sánchez, Cohim, et al., 2015). Other than heavy metal, microbial contamination (Kasmin, Bakar, et al., 2016) from bacteria and pathogen are also significant mainly due to animal droppings or decomposing dead animals left on harvesting surface (Ahmed, Gardner, et al., 2011).
Table 3: Quality of harvested rainwater samples against RWS

<table>
<thead>
<tr>
<th>Area</th>
<th>Not specified, Malaysia(^a)</th>
<th>Urban, Selangor Malaysia(^b)</th>
<th>Semi Urban, Selangor Malaysia(^c)</th>
<th>Semi Urban, Johor Malaysia(^d)</th>
<th>Semi Urban, Sabah, Malaysia(^e)</th>
<th>RWS(^f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Rainwater Type/Rainwater type</td>
<td>First Flush</td>
<td>Stored Rainwater</td>
<td>Galvanized Iron roof</td>
<td>Concrete Tile roof</td>
<td>Container Collection Method</td>
<td>Zinc Roof</td>
</tr>
<tr>
<td>pH</td>
<td>6.5 - 6.9</td>
<td>6.54 - 7.21</td>
<td>6.4 - 6.6</td>
<td>6.8 - 6.9</td>
<td>n.m(^*)</td>
<td>4.26 - 6.06</td>
</tr>
<tr>
<td>Temperature</td>
<td>n.m</td>
<td>n.m</td>
<td>28.0 - 28.1</td>
<td>28.1</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>7.31 - 7.92</td>
<td>7.05 - 7.76</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>6.24 - 6.84</td>
</tr>
<tr>
<td>Conductivity((\muS/cm))</td>
<td>n.m</td>
<td>n.m</td>
<td>50.7 - 97.0</td>
<td>86.5 - 135.2</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>11.2 - 44</td>
<td>0.4 - 3.1</td>
<td>10.0 - 22.0</td>
<td>24 - 56</td>
<td>n.m</td>
<td>57 - 68</td>
</tr>
<tr>
<td>Total Solid (mg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>64 - 119</td>
<td>116 - 204</td>
<td>70.55 - 202.84</td>
<td>n.m</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>58.7 - 138</td>
<td>6.6 - 48.2</td>
<td>13 - 28</td>
<td>23 - 47</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>15.0 - 48.0</td>
<td>0.7 - 2.0</td>
<td>52 - 91</td>
<td>95 - 153</td>
<td>n.m</td>
<td>14 - 43</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>68.6 - 191</td>
<td>25.3 - 50</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td></td>
<td>13.4 - 16</td>
<td>1.67 - 5.86</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------</td>
<td>-------------</td>
<td>------</td>
<td>------</td>
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</tr>
<tr>
<td>BOD (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faecal Coliform</td>
<td>n.m</td>
<td>n.m</td>
<td>0 - 8</td>
<td>0 - 13</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>Total Coliform</td>
<td>n.m</td>
<td>n.m</td>
<td>25 - 63</td>
<td>41 - 75</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>Plate counts x 10^3</td>
<td>n.m</td>
<td>n.m</td>
<td>21 - 32</td>
<td>41 - 51</td>
<td>n.m</td>
<td>n.m</td>
</tr>
<tr>
<td>Zinc (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>294 - 497</td>
<td>49 - 96</td>
<td>32.11 - 82.65</td>
<td>n.m</td>
</tr>
<tr>
<td>Lead (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>145 - 254</td>
<td>102 - 271</td>
<td>1.03 - 7.03</td>
<td>0.001</td>
</tr>
<tr>
<td>Cadmium (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>-</td>
<td>-</td>
<td>0.22 - 1.62</td>
<td>n.m</td>
</tr>
<tr>
<td>Iron (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>9.80 - 44.18</td>
<td>n.m</td>
</tr>
<tr>
<td>Aluminimium (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>3.91 - 27.97</td>
<td>n.m</td>
</tr>
<tr>
<td>Chromium (µg/L)</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.45 - 0.75</td>
<td>n.m</td>
</tr>
</tbody>
</table>

*n.m: not measured

data adapted from:  
a(Kasmin, Bakar, et al., 2016),  
b(Yaziz, Gunting, et al., 1989),  
c(Alahmr, Othman, et al., 2012),  
d(Rahmat, Ali, et al., 2008)
and  
e(Ayog, Ayog, et al., 2016)

*RWS is imposed by the Ministry of Health Malaysia from (MMOH, 2010)
Based on the annual precipitation level around Sabah, employment of rainwater harvesting and collection for freshwater source is highly potential. On the other hand, the implementation of a big scale harvesting and collection infrastructure may require a sizeable amount of investment. In the time being, improvement on the current domestic harvesting structure will be highly beneficial to ensure its effectiveness and quality of water harvested. This has been previously proven to have a positive impact toward reducing the reliance upon piped water by a study conducted in Sandakan in 2009. Other encouraging benefit found were rising on groundwater level, enhanced agricultural activities, lessening of soil erosion, strengthening of river management and probable climate change control (Ani, 2009). Nonetheless, such implementation requires an immense support from the government to provide guidelines and establishment of harvested water treatment system in ensuring optimum harvesting and storing as well as safe water quality.

**Groundwater**

Although groundwater is not universally utilized in Malaysia, groundwater has numbers of benefits as compared to other water sources. Groundwater is a more reliable supply as it is less susceptible to drought (Ismail, 2009), has better quality and require minimal treatment as it is not exposed to surface contamination and will require smaller expense for withdrawal and distribution as it is closer to point of need. Utilizing groundwater may be the answer for water issues such as consistent water supply disruption and increased water charge (ASM, 2011). Unfortunately, groundwater usage in Malaysia has only reached below 10% from the overall water consumption (Abd Razak and Abd Karim, 2009; Manap, Sulaiman, et al., 2013). Groundwater is only majorly used in regions with serious surface water constraint such as Kelantan, Selangor, Kedah, Perlis and Melaka (Chu, 2004). Kelantan as an instance has been using mainly groundwater as fresh water supply as 70% of its total water supply since the early 1990’s (Suratman, 2004; Abd Razak and Abd Karim, 2009). On the other hand, Sabah groundwater utilization is primarily in coastal areas such as Sandakan, Kota Belud and rural villages with no water supply (Abd Razak and Abd Karim, 2009). Numbers of groundwater basins in Malaysia have been detected for potential extraction and usage (Ayob and Rahmat, 2017) although further research is still required. To understand the quality of groundwater below the soil layers, a comprehensive knowledge on the mineral content of the encompassing soil is important (Abdullah, Musta, et al., 1997). Five types of aquifer are found in Malaysia, namely shallow alluvial, deep alluvial, hard rock pear and island aquifer. Extraction of these aquifers is through dug, driven or drilled wells. Aquifers with gravel and sand have the most yield of 50 - 100 cubic meters per hour. Such yield is commonly seen in alluvial aquifers. Aquifer with limestones is able to supply up to 50 cubic meters per hour is classified as hard rock aquifer. Sandstones and volcanic rock aquifers on the other hand can yield up to 30 cubic meters per hour (Abd Razak and Abd Karim, 2009).

As compared to Peninsular Malaysia and Sarawak, Sabah groundwater usage is not high enough (Chu, 2004). Research has shown that Sabah has several potential groundwater basins scattered around the state. Based on the geological formation, Lower Ganduman, Togopi and Upper Ganduman Formation has been found in Lahad Datu and Sandakan Formation in Sandakan (Saleh and Samsudin, 2013; Abd Razak and Abd Karim, 2009). Crocker Formation lays sandstone strata and Quaternary Alluvium with substantial groundwater yield potential (Faisal, Omang, et al., 1994). Along the shorelines, quaternary and recent alluvium provide lower production, which would be adequate for smaller scale residential in rural areas (Abd Razak and Abd Karim, 2009). Conversely, islands in Sabah rely greatly to groundwater sources. Manukan Island, for instance, is overlaying a Quaternary Alluvium which is mostly un lithified loose sediments that holds good storage of groundwater (Aris, Abdullah, et al., 2007).
**Groundwater Quality**

Data for groundwater quality around Sabah are limited as present research are mostly dedicated to island areas (Kura, Ramli, et al., 2015) due to their higher reliance on groundwater. Study shows that groundwater quality is well within the limit imposed in INWQS. A few parameters such as Total Dissolved Solid (TDS), SO4\(^{2-}\), Na\(^+\) ion and Cl\(^-\) cation are occasionally exceeding these limits due to leaching from nearby agricultural and residential discharge (Shirazi, Adham, et al., 2015). Higher Cl\(^-\) concentration is due to seawater seepage caused by excessive extraction (Abdullah, Musta, et al., 1997). Leachate seepage coming from landfill or even dumpsites (Atta, Yaacob, et al., 2015; Suratman, Tawnie, et al., 2011) and direct sewage discharge (Tubau, Vázquez-Suñé, et al., 2017; Fahnline, 2013) also contribute to groundwater pollution. The groundwater content could also be affected by the natural geological formation, as an example Gypsum originating from rocks and soils will result in higher SO4\(^{2-}\) content (Kura, Ramli, et al., 2015; Hing, 1994). Heavy metals may be a result of human activities or even geological characteristic (Kura, Ramli, et al., 2015).

Overall reviews demonstrate the potential of groundwater utilization as supplementary or even primary source of fresh water in Sabah. Then again, underestimation and failure to recognize these potential had led to the underuse of these resources. This may be due to the fact that Malaysia still blessed with plentiful of surface water. In order to fully utilize the groundwater, constraints such as lack of technical knowledge, field expertise, guidelines and policies specific for groundwater have to be overcome (Chu, 2004; NRO, 1994).

**Domestic Wastewater**

Domestic wastewater is an unconventional water resource that is rarely discussed. Lower pollutant concentration and high accessibility give domestic wastewater higher potential as a water resource which will otherwise be untreated and indiscriminately discharged. Research has shown that as much as 90% of domestic wastewater is discharged without prior treatment (Chen and Yao, 2014). Domestic wastewater mainly comes from water used to assist domestic activities such as toilet flushing, personal washing, laundry, food preparation, and kitchen utensil cleaning. Thus the main contaminant in domestic wastewater is human body waste, i.e. faeces and urine. Fresh domestic wastewater is usually grey turbid liquid with earthy but inoffensive odour. It contains solids such as faeces, rags, plastics, and food wastes and small non-settle able solids suspension (Mara, 2004). Study showed that typical domestic wastewater may contain the average concentration of BOD\(_5\) and COD values of 59.0 and 96.0 mg/L respectively. The ammonia content averaged between 20 – 60 mg/L and faecal coliform of 2.8 x 10\(^4\) to 5.6 x 10\(^4\) CFU/mL (Giri, Takeuchi, et al., 2006).

Domestic wastewater can be utilized as a source of water when treated and recycled. Although it may not suitable to be utilized as potable water as it needs extensive treatment to reach suitable quality, a simple treatment can be used to reduce pollutant concentration to a level acceptable for non-consumable usages such as landscape maintenance, irrigation and toilet flushing (Yaser and Safie, 2020). This could be highly beneficial as it can reduce the demand for clean piped water in rural areas that otherwise have limited resources. Recycling of domestic wastewater also can reduce raw wastewater discharge and can be beneficial to reduce groundwater or waterbodies pollution.
Table 4: Quality of groundwater samples against RWS.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tiga Island&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Seligaan Island&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Bakkugan Island&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Kechil Island&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Manukan Island&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Sahabat Plantation, Lahad Datu&lt;sup&gt;d&lt;/sup&gt;</th>
<th>RW S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underlying Rock</strong></td>
<td>Mudstone, sandstone and conglomerate</td>
<td>Carbonate rock, mudstone and Quartenary Alluvium</td>
<td>Quartenary Alluvium, Sandstone and Shale</td>
<td>Sandstones and Claystone interbeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature (˚C)</strong></td>
<td>26.7 - 29.8</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>6.84 - 7.35</td>
<td>7.2 - 7.7</td>
<td>7.4 - 7.7</td>
<td>7.2 - 7.96</td>
<td>7.1</td>
<td>5.5 - 9.0</td>
<td></td>
</tr>
<tr>
<td><strong>DO (mg/L)</strong></td>
<td>1.08 - 6.12</td>
<td>1.5 - 3.6</td>
<td>1.4 - 1.9</td>
<td>-</td>
<td>0.08</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Salinity (ppt)</strong></td>
<td>0.1 - 0.5</td>
<td>n.m</td>
<td>n.m</td>
<td>0.38 - 1.13</td>
<td>n.m</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Conductivity (µS/cm)</strong></td>
<td>329 - 1005</td>
<td>1.3 - 4.9</td>
<td>0.3 - 0.5</td>
<td>1663 - 8703</td>
<td>n.m</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>TDS (mg/L)</strong></td>
<td>164 - 502</td>
<td>n.m*</td>
<td>n.m</td>
<td>336.67</td>
<td>674.5</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>Total Hardness</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>-</td>
<td>351.5</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td><strong>K</strong>&lt;sup&gt;+&lt;/sup&gt;</td>
<td>5.81 - 8.89</td>
<td>n.m</td>
<td>n.m</td>
<td>10.0 - 71.0</td>
<td>1.72</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Na</strong>&lt;sup&gt;+&lt;/sup&gt;</td>
<td>0.90 - 7.53</td>
<td>n.m</td>
<td>n.m</td>
<td>45 - 2393</td>
<td>20.62</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td><strong>Mg</strong>&lt;sup&gt;2+&lt;/sup&gt;</td>
<td>1.70 - 3.43</td>
<td>n.m</td>
<td>n.m</td>
<td>6.67 - 194</td>
<td>29.59</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td><strong>Ca</strong>&lt;sup&gt;2+&lt;/sup&gt;</td>
<td>21.30 - 51.87</td>
<td>n.m</td>
<td>n.m</td>
<td>197 - 415</td>
<td>72.63</td>
<td>-</td>
<td></td>
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<tr>
<td><strong>HCO&lt;sub&gt;3&lt;/sub&gt;</strong>&lt;sup&gt;-&lt;/sup&gt;</td>
<td>119.0 - 330</td>
<td>318</td>
<td>322</td>
<td>367 - 408</td>
<td>284 - 512</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Cl</strong></td>
<td>50.48 - 489.85</td>
<td>53 - 194</td>
<td>43374</td>
<td>359 - 2674</td>
<td>15.09</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>SO&lt;sub&gt;4&lt;/sub&gt;</strong>&lt;sup&gt;2-&lt;/sup&gt;</td>
<td>3.0 - 82.0</td>
<td>n.m</td>
<td>n.m</td>
<td>80 - 490</td>
<td>178</td>
<td>250</td>
<td></td>
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<tr>
<td><strong>Fe Total</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>5.87</td>
<td>1</td>
<td></td>
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<tr>
<td><strong>Mn</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.22</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td><strong>Si</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>56.87</td>
<td>-</td>
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<tr>
<td><strong>Cu</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.01</td>
<td>1</td>
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<td><strong>Pb</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>ND</td>
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<td><strong>As</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>ND</td>
<td>0.01</td>
<td></td>
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<tr>
<td><strong>CO&lt;sub&gt;3&lt;/sub&gt;</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>2.79</td>
<td>-</td>
<td></td>
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<tr>
<td><strong>PO&lt;sub&gt;4&lt;/sub&gt;</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>1.35</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>NH&lt;sub&gt;3&lt;/sub&gt;-N</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.7</td>
<td>1.5</td>
<td></td>
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<tr>
<td><strong>NO&lt;sub&gt;2&lt;/sub&gt;</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.03</td>
<td>-</td>
<td></td>
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<tr>
<td><strong>NO&lt;sub&gt;3&lt;/sub&gt;</strong></td>
<td>0.8 - 3.70</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>2.33</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>CN</strong></td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>n.d**</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td><strong>F</strong></td>
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<td>n.m</td>
<td>n.m</td>
<td>n.m</td>
<td>0.49</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

<sup>*n.m: not measured, **n.d: not detected</sup>
data adopted from: a(Lin, Abdullah, et al., 2009), b(Abdullah and Musta, 1999), c(Aris, Abdullah, et al., 2007; Praveena, Lin, et al., 2010), d(Hing, 1994)

‘RWS is imposed by the Ministry of Health Malaysia from (MMOH, 2010)

ND: not detected

### DISTRIBUTION SYSTEM STRATEGIES

Centralized concepts for water service industries have been practiced for decades especially in densely populated areas (Sitzenfrei and Rauch, 2014; Sapkota, Arora, et al., 2015). The concept implies the collection, and treatment of large volumes of water in a centralized location before distribution to consumers. There are the two major components in a centralized system, the central treatment plant and distribution system that consists of an extensive network of pumps and piping (Asano, Burton, et al., 2007). It predominantly withdraws water from a selected reservoir and treats it to a potable standard and is highly dependent on water availability from the selected resource (Jeong, Broesicke, et al., 2018). In Sabah specifically, a centralized system is utilized for its major townships and withdraws water from seven main dams: Babagon, Pinangsoo, Sepagaya, Timbangan, Telibong, Milau and Segaliud (JBA, 2014).

A centralized water supply system seems more favourable in a financial sense. It is argued that a large yet centred infrastructure for water treatment is less costly than a great number of smaller scaled systems (Wilderer and Schreff, 2000). As such, it is primarily utilized more in large cities. China as an example utilizes a centralized system in its mega cities. Only a small amount of decentralized greywater reuse projects are currently in operation which are observed under university research (Chen, Ngo, et al., 2013; Liang and van Dijk, 2010). A case study conducted to evaluate the performance of centralized water system in a densely populated area has shown that centralized water supply distribution presents advantages in an urban setting in terms of safety, reliability, and stability. The system was able to improve water reclamation efficacy and productivity as well as to enhance pollutant removal through the advancement of technology. A decentralized system on the other hand was able to increase flexibility and convenience to water supply systems in special circumstances particularly for multiple users with varied water quality requirements (Chen et al., 2017).

A decentralized system requires shorter distribution networks as treatment is performed in proximity of the water source or point of need (Wilderer and Schreff, 2000; Crites and Tchobanoglosus, 1998). Technical and economic breakdown shows that a decentralized system are more practical and is able to provide the following: (i) adaptability to the ever evolving demands of water supply in developing nations, (ii) elimination of costly and lengthy pipeline networks to isolated areas, (iii) provide solution for lower energy consumption used for pumping in undulating terrains, (iv) prevention of pipe leakage due to decreased pipeline length, (v) cost effectiveness in terms of operating and maintaining due to marginally smaller scale plants (Wilderer and Schreff, 2000; Van Afferden, Cardona, et al., 2015; Engin and Demir, 2006; Weber, Cornel, et al., 2007; Falco and Webb, 2015).

Based on these facts, a decentralized system seems more practical than a centralized water system. However, focus should be emphasised on complementing the current water system rather than completely replacing it. Piratla & Goverdhanam (2015) have reported that a decentralized grey water treatment plant was able to provide a reduction of piped water dependency by 17%. The system was able to complement the current water distribution system during 25% spike of water demand. Furthermore, decentralized water system utilization in developing countries will mean the provision of treated water to isolated areas. A small scale decentralized water system in Brazil has shown an increase of water access by 6% after 10 years of employment. Smaller scale plants operated by the communities encourage a sense of
accountability and ownership among the locals which ensure attention for efficient operation of the system (Barde, 2017). On the other hand, a complete shift of the water system in Venezuela to a decentralized system demonstrate 20% of rise in efficiency due to absence of a dependency to governmental management (Higuerey, Trujillo, et al., 2017).

Ultimately, modification of the current water service system in Sabah is seen highly beneficial. Although a complete shift may not able to be accomplished, implementation of a decentralized water system in rural and semi-urban areas will provide good outcomes. Lower cases of pipe leakage in lengthy pipelines, smaller maintenance cost, and elimination of pumping requirement in hilly areas will be achieved. Moreover, complete exploitation of available resources from surface, rainwater and groundwater will mean better access of treated water to all region in the state.

CONCLUSION

The weakness in Sabah’s water service industry is evident, especially in the rural areas. Some areas with potable water access experience regular interruptions and poor quality of water due to reoccurring operational and technical issues. With an increase in the population there is a growing need for a better water provision strategy. Review shows that Sabah has abundant water resources apart from surface water alone. Rainwater and groundwater have a great potential to be implemented as the primary water resource or to complement surface water during supply shortages. Water resource utilization should be applied based on resource availability in the area of concern. Rainwater harvesting facilities and storage can be implemented in areas with high annual rainfall such as the western and eastern part of Sabah. In the southeast area, where rainfall is evenly distributed throughout the year, it can be collected and utilized for agricultural activities in the area, i.e. palm oil plantation. On the other hand, groundwater extraction can be utilized in the coastal regions such as Beaufort, Lahad Datu and Sandakan and other highly potential groundwater areas such as in the Crocker Formation. Potential of domestic wastewater recycling for non-consumable utilization should also be considered to further reduce dependencies on piped clean water.

The utilization of rainwater and groundwater would be highly advantageous since it requires minimal treatment and can be extracted and stored at the point of demand, eliminating the need for long distribution systems and thus reducing the cost of construction, pumping operation, and pipeline maintenance. As such, a shift to decentralized water treatment system instead of a centralized one will be feasible. Nevertheless, the shift from the current system to a decentralized water system should be based upon a scientific approach, taking into consideration the expenditure and sustainability of the shift. A minor setback foreseen in a decentralized system in remote areas would be the technology utilized which should be simple and require little or no skills; as operation and maintenance will be conducted by the local community.

DECLARATION

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