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

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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 of 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 (NH_3^-N) and total suspended solids (TSS) exceed the standard (Harun and Fikri, 2016; Harun, Dambul, et al., 2014; Heng, Chukong, 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

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 supply (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.

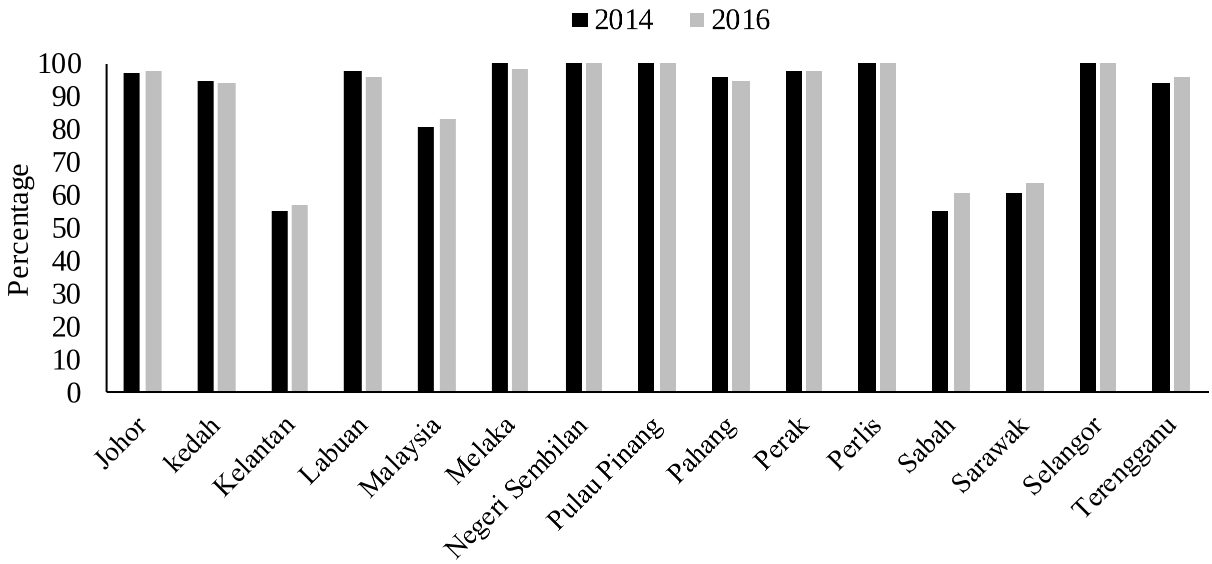

Figure 2: Status of pipe water access in each state for 2014 and 2016

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 was 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 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)

Material	**Length (km)**
Asbestos Cement (AC)	2,345
Mild Steel (MS)	2,622
Unplasticized polyvinyl chloride (uPVC)	1,620
High-density Polyethylene (HDPE)	796
Ductile Iron (DI) / Cast Iron (CI)	687
Others	306
Total	8,376

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 2: Quality of isolated river water samples against RWS

Location	**Beluran**	**Beluran**	**Beluran**	**Beluran**	**Sukau**	**Sukau**	**Sukau**	**Tambunan**	**Tambunan**	**Beaufort**	
Main River	**Sugud River[a]**				**Lower kinabatangan Catchment[b]**			**Liwagu River[c]**		**Padas River[d]**	**RWS[e]**
Tributaries / Lake	**Suguta River**	**Sabang River**	**Wansayan River**	**Kelipatan River**	**Resang River**	**Lumun River**	**Kalinanap River**	**Nukakatan River**	**Mesangoh River**	**Luangan Rompong Lake**	
pH	7.01	7.08	6.82	7.02	5.3 - 6.5	5.2 - 6.7	6.6 - 7.0	6.34 - 8.3	7.79 - 8.18	6.0 - 8.5	5.5 - 9.0
DO (mg/L)	4.93	1.93	3.66	3.2	4.3 - 6.2	3.5 - 5.6	1.9 - 4.1	6.19 - 6.81	6.9 - 7.79	3.9 - 11.4	-
Salinity	0.07	27.29	0.11	2.22	0.05 - 0.1	0.01-0.03	0.03-0.04				-
Conductivity (µS/cm)	155.28	45,574.65	180.3	4,373.45	110.8 - 236.5	52.9 - 175.3	76.9 - 180..9	0.05 - 0.09	0.05 - 0..06	71.8 - 86.2	-
BOD (mg/L)	3.19	1.27	4.01	2.49	1.3 - 2.1	2.9 - 3.2	3.1 - 3.6	0.38 - 0.59	0.52 - 0.65	n.m*	6
COD (mg/L)	18.08	751.15	21.03	24.38	53.8 - 100.0	36.8 - 51.4	35.1 - 45.8	0.67 - 3.4	3.5 - 4.8	n.m	10
Total Coliform (CFU/100 ml)	3,594.88	1,108.28	1,753.25	3,029.53	n.m	n.m	n.m	17.0 - 169	33 - 137	n.m	5,000
Ammonia-Nitrogen (mg/L)	0.52	98.44	0.7	4.75	n.m	n.m	n.m	0.09 - 0.27	0.03 - 0.32	n.m	1.5
TSS (mg/L)	n.m	n.m	n.m	n.m	33.0 - 42.0	49 - 75	49 - 96	0.1 - 4.0	1.0 - 3.4	n.m	-

*n.m: not measured

data adapted from: [a](Harun and Fikri, 2016), [b](Harun, Dambul, et al., 2014), [c](Cleophas, Isidore, et al., 2013) and [d](Heng, Chukong, et al., 2006)

[e]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 NH_3^- 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).

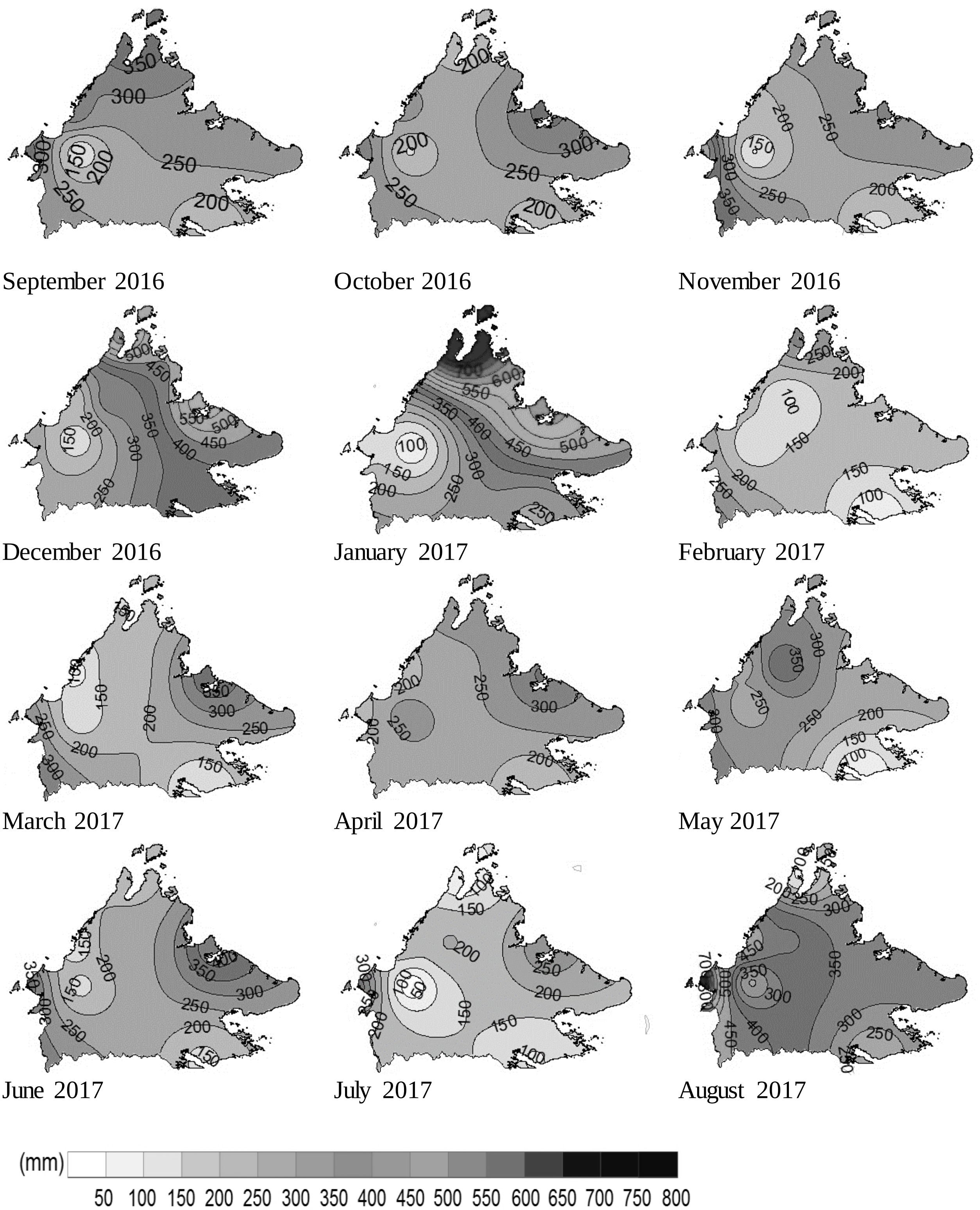

Figure 3: Sabah Monthly Rainfall Distribution (Malaysian Meteorological Department, 2017)

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 (Krishna, 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

Area	**Not specified, Malaysia[a]**		**Urban, Selangor Malaysia[b]**		**Semi Urban, Selangor Malaysia[c]**	**Semi Urban, Johor Malaysia[d]**	**Semi Urban, Sabah, Malaysia[e]**		**RWS[f]**
Roof Type/ Rainwater type	**First Flush**	**Stored Rainwater**	**Galvanized Iron roof**	**Concrete Tile roof**	**Container Collection Method**	**Zinc Roof**	**Nipah-thatched roof**	**Galvanized Iron roof**	
pH	6.5 - 6.9	6.54 - 7.21	6.4 - 6.6	6.8 - 6.9	n.m*	4.26 - 6.06	7.05	6.43	5.5 - 9.0
Temperature	n.m	n.m	28.0 - 28.1	28.1	n.m	n.m	n.m	n.m	n.m
DO (mg/L)	7.31 - 7.92	7.05 - 7.76	n.m	n.m	n.m	6.24 - 6.84	2.37	0.8	n.m
Conductivity(μS/cm)	n.m	n.m	50.7 - 97.0	86.5 - 135.2	n.m	n.m	n.m	n.m	n.m
Turbidity (NTU)	11.2 - 44	0.4 - 3.1	10.0 - 22.0	24 - 56	n.m	57 - 68	58.4	1.53	1000
Total Solid (mg/L)	n.m	n.m	64 - 119	116 - 204	70.55 - 202.84	n.m	n.m	n.m	n.m
TDS (mg/L)	58.7 - 138	6.6 - 48.2	13 - 28	23 - 47	n.m	n.m	n.m	n.m	1500
TSS (mg/L)	15.0 - 48.0	0.7 - 2.0	52 - 91	95 - 153	n.m	14 - 43	44	42	n.m
COD (mg/L)	68.6 - 191	25.3 - 50	n.m	n.m	n.m	n.m	n.m	n.m	10

BOD (mg/L)	13.4 - 16	1.67 - 5.86	n.m	n.m	n.m	n.m	n.m	n.m	6
Faecal Coliform (/100 ml)	n.m	n.m	0 - 8	0 - 13	n.m	n.m	n.m	n.m	n.m
Total Coliform (/100 ml)	n.m	n.m	25 - 63	41 - 75	n.m	n.m	n.m	n.m	5000
Plate counts x 10^3 (/ 100 ml)	n.m	n.m	21 - 32	41 - 51	n.m	n.m	n.m	n.m	n.m
Zinc (µg/L)	n.m	n.m	294 - 497	49 - 96	32.11 - 82..65	n.m	n.m	n.m	3
Lead (µg/L)	n.m	n.m	145 - 254	102 - 271	1.03 - 7.03	0.001 - 0.004	n.m	n.m	0.05
Cadmium (µg/L)	n.m	n.m	-	-	0.22 - 1.62	n.m	n.m	n.m	0.003
Iron (µg/L)	n.m	n.m	n.m	n.m	9.80 - 44.18	n.m	n.m	n.m	1
Aliminium (µg/L)	n.m	n.m	n.m	n.m	3.91 - 27.97	n.m	n.m	n.m	-
Chromium (µg/L)	n.m	n.m	n.m	n.m	0.45 - 0.75	n.m	n.m	n.m	0.05

*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 [f](Ayog, Ayog, et al., 2016)
[f]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 unlithified 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), SO_4^{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 SO_4^{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 2.8×10^4 to 5.6×10^4 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.

Location	**Tiga Island[a]**	**Seligaan Island[b]**	**Bakkugan Kechil Island[b]**	**Manukan Island[c]**	**Sahabat Plantation, Lahad Datu[d]**	**RWS**
Underlying Rock	**Mudstone, sandstone and conglomerate**	**Carbonate rock, mudstone and Quartenary Alluvium**		**Quartenary Alluvium, Sandstone and Shale**	**Sandstones and Claystone interbeds**	
Temperature (˚C)	26.7 - 29.8	n.m	n.m	n.m	n.m	-
pH	6.84 - 7.35	7.2 - 7.7	7.4 - 7.7	7.2 - 7.96	7.1	5.5 - 9.0
DO (mg/L)	1.08 - 6.12	1.5 - 3.6	1.4 - 1.9	-	0.08	-
Salinity (ppt)	0.1 - 0.5	n.m	n.m	0.38 - 1.13	n.m	-
Conductivity (µS/cm)	329- 1005	1.3 - 4.9	0.3 - 0.5	1663 - 8703	n.m	-
TDS (mg/L)	164 - 502	n.m*	n.m	336.67 - 6564	674.5	1500
Total Hardness	n.m	n.m	n.m	-	351.5	500
K^+	5.81 - 8.89	n.m	n.m	10.0 - 71.0	1.72	-
Na^+	0.90 - 7.53	n.m	n.m	45 - 2393	20.62	200
Mg^{2+}	1.70 - 3.43	n.m	n.m	6.67 - 194	29.59	150
Ca^{2+}	21.30 - 51.87	n.m	n.m	197 - 415	72.63	-
HCO_3^-	119.0 - 330	318 - 322	367 - 408	284 - 512	-	-
Cl^-	50.48 - 489.85	53 - 194	43374	359 - 2674	15.09	-
SO_4^{2-}	3.0 - 82.0	n.m	n.m	80 - 490	178	250
Fe Total	n.m	n.m	n.m	n.m	5.87	1
Mn	n.m	n.m	n.m	n.m	0.22	0.2
Si	n.m	n.m	n.m	n.m	56.87	-
Cu	n.m	n.m	n.m	n.m	0.01	1
Pb	n.m	n.m	n.m	n.m	ND	0.05
As	n.m	n.m	n.m	n.m	ND	0.01
CO_3	n.m	n.m	n.m	n.m	2.79	-
PO_4	n.m	n.m	n.m	n.m	1.35	-
NH_3-N	n.m	n.m	n.m	n.m	0.7	1.5
NO_2	n.m	n.m	n.m	n.m	0.03	-
NO_3	0.8 - 3.70	n.m	n.m	n.m	2.33	10
CN	n.m	n.m	n.m	n.m	n.d**	0.07
F	n.m	n.m	n.m	n.m	0.49	-

*n.m: not measured, **n.d: not detected

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)
[e]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 Tchobanoglous, 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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REFERENCE

Abd Razak, Y. and Abd Karim, M. H. (2009) "Groundwater in the Malaysian Context" in Groundwater Colloquium 2009, Groundwater Management in Malaysia -Status and Challenges. Putrajaya, Malaysia, Academy of Sciences Malaysia (ASM), 1–14.

Abdullah, M. H. and Musta, B. (1999) Phreatic Water Quality of the Turtle Islands of East Malaysia: Pulau Selingaan and Pulau Bakkugan Kechil. Borneo Science, **6**, 1–9.

Abdullah, M. H., Musta, B., and Md. Tan, M. (1997) A Preliminary Geochemical Study on Manukan Island, Sabah. Borneo Science, **3**, 43–51.

Van Afferden, M., Cardona, J. A., Müller, R. A., Lee, M. Y., and Subah, A. (2015) A new approach to implementing decentralized wastewater treatment concepts. Water Science and Technology, **72**(11), 1923–1930.

Ahmed, W., Gardner, T., and Toze, S. (2011) Microbiological Quality of Roof-Harvested Rainwater and Health Risks: A Review. Journal of Environment Quality, **40**(1), 13. [online] https://www.agronomy.org/publications/jeq/abstracts/40/1/13.

Alahmr, F. O. M., Othman, M., Abd Wahid, N. B., Halim, A. A., and Latif, M. T. (2012) Compositions of dust fall around semi-Urban Areas in Malaysia. Aerosol and Air Quality Research, **12**(4), 629–642.

Almeida, C. and Soares, F. (2012) Microbiological monitoring of bivalves from the Ria Formosa Lagoon (south coast of Portugal): A 20years of sanitary survey. Marine Pollution Bulletin, **64**(2), 252–262. [online] http://dx.doi.org/10.1016/j.marpolbul.2011.11.025.

Ani, A. I. . (2009) Rainwater harvesting system evaluation: A resident experience in Sabah, Malaysia. International Symposium in Developing Economies: Commonalities Among Diversities, 26–39.

Appan, A. (1997) Roof water collection systems in some Southeast Asian countries: Status and water quality levels. Journal of the Royal Society of Health, **117**(5), 319–323. [online] http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed4&NEWS=N&AN=1998050802.

Ariffin, M. and Sulaiman, S. N. M. (2015) Regulating Sewage Pollution of Malaysian Rivers and its Challenges. Procedia Environmental Sciences, **30**, 168–173. [online] http://linkinghub.elsevier.com/retrieve/pii/S1878029615006246.

Aris, A. Z., Abdullah, M. H., and Kim, K. (2007) Hydrogeochemistry of Groundwater in Manukan Island, Sabah. The Malaysian Journal of Analytical Sciences, **11**(2), 407–413.

Aris, A. Z., Lim, W. Y., Praveena, S. M., Yusoff, M. K., Ramli, M. F., and Juahir, H. (2014) Water Quality Status of Selected Rivers in Kota Marudu , Sabah , Malaysia and its Suitability for Usage. Sains Malaysiana, **43**(3), 377–388.

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R., and Tchobanoglous, G. (2007) *Water Reuse–issues, Technologies and Applications*, New York, USA, McGraw Hill.

ASM (2011) *Sustaining Malaysia ' s Future: Mega Science Framework Study Water Sector - Final Report*,

Atta, M., Yaacob, W. Z. W., and Jaafar, O. Bin (2015) The potential impact of leachate-contaminated groundwater of an ex-landfill site at Taman Beringin Kuala Lumpur, Malaysia. Environmental Earth Sciences, **73**(7), 3913–3923. [online] http://link.springer.com/10.1007/s12665-014-3675-x.

Ayob, S. and Rahmat, S. N. (2017) Rainwater Harvesting (RWH) and Groundwater Potential as Alternatives Water Resources in Malaysia : A Review. MATEC Web Conference, **04020**(103).

Ayog, J., Ayog, J. L., Dullah, S., and Ramli, R. (2016) Harvested Rainwater Quality Assessment on the Effects of Roof Materials to the First Flush Runoff. Transactions on Science and Technology, 271–276.

Barde, J. A. (2017) What Determines Access to Piped Water in Rural Areas? Evidence from Small-Scale Supply Systems in Rural Brazil. World Development, **95**, 88–110. [online] http://dx.doi.org/10.1016/j.worlddev.2017.02.012.

van den Berg, C. (2015) Drivers of non-revenue water: A cross-national analysis. Utilities Policy, **36**, 71–78. [online] http://dx.doi.org/10.1016/j.jup.2015.07.005.

Burford, M. A., Revill, A. T., Smith, J., and Clementson, L. (2012) Effect of sewage nutrients on algal production, biomass and pigments in tropical tidal creeks. Marine Pollution Bulletin, **64**(12), 2671–2680. [online] http://dx.doi.org/10.1016/j.marpolbul.2012.10.008.

Chan, N. W. (2006) A comparative study of water resources usage by households in Georgetown-Malaysia and Pattaya-Thailand. Iranian Journal of Environmental Health Science & Engineering, **3**(4), 223–228. [online] http://journals.tums.ac.ir/abs/3377.

Che-Ani, A. I., Shaari, N., Sairi, A., Zain, M. F. M., and Tahir, M. M. (2009) Rainwater harvesting as an alternative water supply in the future. European Journal of Scientific Research, **34**(1), 132–140. [online] http://www.scopus.com/inward/record.url?eid=2-s2.0-68849093029&partnerID=tZOtx3y1.

Chen, F. and Yao, Q. (2014) The Development of Rural Domestic Wastewater Treatment in China. Advanced Materials Research, **1073–1076**, 829–832.

Chen, Z., Ngo, H. H., and Guo, W. (2013) A Critical Review on the End Uses of Recycled Water. Critical Reviews in Environmental Science and Technology, **43**(14), 1446–1516. [online] https://doi.org/10.1080/10643389.2011.647788.

Chen, Z., Wu, Q., Wu, G., and Hu, H. Y. (2017) Centralized water reuse system with multiple applications in urban areas: Lessons from China's experience. Resources, Conservation and Recycling, **117**, 125–136. [online] http://dx.doi.org/10.1016/j.resconrec.2016.11.008.

Chu, L. H. (2004) Groundwater Utilization and Management in Malaysia. Thematic Session on Geo-environment of Delta and Groundwater Management in East and Southeast Asia, CCOP Annual Session, 83–93. [online] http://www.ccop.or.th/download/pub/41as_ii.pdf.

Cleophas, F. N., Isidore, F., Han, L. K., and Bidin, K. (2013) Water quality status of Liwagu River , Tambunan , Sabah , Malaysia. Journal of Tropical Biology and Conservation, **10**, 67–73.

Cravo, A., Fernandes, D., Dami??o, T., Pereira, C., and Reis, M. P. (2015) Determining the footprint of sewage discharges in a coastal lagoon in South-Western Europe. Marine Pollution Bulletin, **96**(1–2), 197–209. [online] http://dx.doi.org/10.1016/j.marpolbul.2015.05.029.

Crites, R. W. and Tchobanoglous, G. (1998) *Small and decentralized wastewater management systems*, New York, McGraw-Hill.

Davis, M. L. and Cornwell, D. A. (2013) *Introduction to Environmental Engineering*, Singapore, Mc Graw Hill.

Despins, C., Farahbakhsh, K., and Leidl, C. (2009) Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada. Journal of Water Supply: Research and Technology - AQUA, **58**(2), 117–134.

DHI (2011) Non-Revenue Water: Custom solutions for water utilities to reduce leakage and optimise pipe networ management. DHI Solution.

DID (2009) *Rainwater Harvesting: Guidebook on Planning and Design*, Drainage, Malaysian Department of Irrigation and Drainage.

Distefano, T. and Kelly, S. (2017) Are we in deep water? Water scarcity and its limits to economic growth. Ecological Economics, **142**, 130–147. [online] http://dx.doi.org/10.1016/j.ecolecon.2017.06.019.

Elango, L. and Kannan, R. (2007) Rock-water interaction and its control on chemical composition of groundwater. Concepts and Applications in Environmental Geochemistry, **5**(07), 229–246. [online] http://www.sciencedirect.com/science/article/pii/S1474817707050115 (Accessed November 28, 2017).

Engin, G. O. and Demir, I. (2006) Cost analysis of alternative methods for wastewater handling in small communities. Journal of Environmental Management, **79**(4), 357–363.

Fahnline, E. (2013) The production and remediation of malaysia's groundwater resources. Ensearch Sustainability and Environmental Management Conf. and Exhibition, 1–52.

Faisal, M., Omang, S. A. K., and Tahir, S. (1994) Geology of Kota Kinabalu and its implications to groundwater potential. Geololy Society Malaysia, Bulletin, **38**, 11–20.

Falco, G. J. and Webb, W. R. (2015) Water Microgrids: The Future of Water Infrastructure Resilience. Procedia Engineering, **118**, 50–57.

Giri, R. R., Takeuchi, J., and Ozaki, H. (2006) Biodegradation of domestic wastewater under the simulated conditions of Thailand. Water and Environment Journal, **20**(3), 169–176.

Harun, S., Dambul, R., Abdullah, M. H., and Mohamed, M. (2014) Spatial and seasonal variations in surface water quality of the Lower Kinabatangan River Catchment , Sabah , Malaysia. Journal of Tropical Biology and Conservation, **11**, 117–131.

Harun, S. and Fikri, A. H. (2016) *Report on Water Quality Monitoring in Sugut River and its Tributaries*, Kota Kinabalu, Sabah.

Hasan, H. H., Jamil, N. R., and Aini, N. (2015) Water Quality Index and Sediment Loading Analysis in Pelus River, Perak, Malaysia. Procedia Environmental Sciences, **30**, 133–138. [online] http://linkinghub.elsevier.com/retrieve/pii/S1878029615006180.

Heng, L. Y., Chukong, L. N., Stuebing, R. B., and Omar, M. (2006) The Water Quality of Several Oxbow Lakes in Sabah, Malaysia and its Relation to Fish Fauna Distribution. Journal of

Biological Sciences, **2**(6), 365–369.

Higuerey, A., Trujillo, L., and González, M. M. (2017) Has efficiency improved after the decentralization in the water industry in Venezuela? Utilities Policy, **49**, 127–136.

Hing, T. T. (1994) Hydrochemistry of groundwater at Sahabat region, Sabah. Newsletter of the Geological Society of Malaysia., **20**(3), 229–230.

Hussein, M., Yoneda, K., Othman, N., Mohd Zaki, Z., and Mohd Yusof, M. H. (2017) Effects of Number of Connections and Pipe Length To the Water Losses in Melaka. Jurnal Teknologi, **79**(3), 45–59. [online] http://www.jurnalteknologi.utm.my/index.php/jurnalteknologi/article/view/9874.

Huston, R., Chan, Y. C., Chapman, H., Gardner, T., and Shaw, G. (2012) Source apportionment of heavy metals and ionic contaminants in rainwater tanks in a subtropical urban area in Australia. Water Research, **46**(4), 1121–1132. [online] http://dx.doi.org/10.1016/j.watres.2011.12.008.

Isa, N. M., Aris, A. Z., Lim, W. Y., Sulaiman, W. N. A. W., and Praveena, S. M. (2014) Evaluation of heavy metal contamination in groundwater samples from Kapas Island, Terengganu, Malaysia. Arabian Journal of Geosciences, **7**(3), 1087–1100.

Ismail, W. M. Z. W. (2009) "Groundwater for Domestic Needs in Kelantan" in Groundwater Colloquium 2009, Groundwater Management in Malaysia -Status and Challenges., 149–156.

Jasin, B. and Tating, F. F. (1991) Late Eocene planktonic Foraminifera from the Crocker Formation, Pun Batu, Sabah. Warta Geologi, **17**(4), 187–191.

JBA (2014) Jabatan Bekalan Air (JBA) - Empangan Air Negeri Johor. Sabah Water Dam. [online] http://www.jba.gov.my/index.php/en/empangan-air-negeri-sabah (Accessed January 19, 2018).

Jeong, H., Broesicke, O. A., Drew, B., and Crittenden, J. C. (2018) Life cycle assessment of small-scale greywater reclamation systems combined with conventional centralized water systems for the City of Atlanta, Georgia. Journal of Cleaner Production, **174**, 333–342. [online] http://linkinghub.elsevier.com/retrieve/pii/S0959652617325015.

Kadhum, S. A., Ishak, M. Y., Zulkifli, S. Z., and Hashim, R. binti (2015) Evaluation of the status and distributions of heavy metal pollution in surface sediments of the Langat River Basin in Selangor Malaysia. Marine Pollution Bulletin, **101**(1), 391–396.

Kasmin, H., Bakar, N. H., and Zubir, M. M. (2016) Monitoring on The Quality and Quantity of DIY Rainwater Harvesting System. IOP Conference Series: Materials Science and Engineering, **136**, 1–8. [online] http://stacks.iop.org/1757-899X/136/i=1/a=012067?key=crossref.fff6394d3e607d908e96ee0ecfd1f8f3.

Kelly, E., Lee, K., Shields, K. F., Cronk, R., Behnke, N., Klug, T., and Bartram, J. (2017) The role of social capital and sense of ownership in rural community-managed water systems: Qualitative evidence from Ghana, Kenya, and Zambia. Journal of Rural Studies, **56**, 156–166. [online] https://doi.org/10.1016/j.jrurstud.2017.08.021.

Krishna, J. (2005) *The Texas Manual on Rainwater Harvesting*, Austin, Texas. [online] http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Texas+Manual+on+Rainwater+Harvesting#0.

Kura, N. U., Ramli, M. F., Sulaiman, W. N. A., Ibrahim, S., and Aris, A. Z. (2015) An overview of groundwater chemistry studies in Malaysia. Environmental Science and Pollution Research, 1–19. [online] http://dx.doi.org/10.1007/s11356-015-5957-6.

Lee, C. (2011) Privatization, water access and affordability: Evidence from Malaysian household expenditure data. Economic Modelling, **28**(5), 2121–2128. [online] http://dx.doi.org/10.1016/j.econmod.2011.05.003.

Lee, J. Y., Yang, J. S., Han, M., and Choi, J. (2010) Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources. Science of the Total Environment, **408**(4), 896–905. [online] http://dx.doi.org/10.1016/j.scitotenv.2009.11.001.

Lee, K. E., Mokhtar, M., Mohd Hanafiah, M., Abdul Halim, A., and Badusah, J. (2016) Rainwater harvesting as an alternative water resource in Malaysia: potential, policies and development. Journal of Cleaner Production, **126**, 218–222.

Leong, J. Y. C., Oh, K. S., Poh, P. E., and Chong, M. N. (2017) Prospects of hybrid rainwater-greywater decentralised system for water recycling and reuse: A review. Journal of Cleaner Production, **142**, 3014–3027.

Liang, X. and van Dijk, M. P. (2010) Financial and economic feasibility of decentralized wastewater reuse systems in Beijing. Water science and technology : a journal of the International Association on Water Pollution Research, **61**(8), 1965–1973.

Liew, W. L., Kassim, M. A., Muda, K., Loh, S. K., and Affam, A. C. (2014) Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: A review. Journal of Environmental Management, **149**, 222–235. [online] http://dx.doi.org/10.1016/j.jenvman.2014.10.016.

Lin, C. Y., Abdullah, M. H., Aris, A. Z., and Praveena, S. M. (2009) A Baseline Study on Groundwater Quality of the A Baseline Study on Groundwater Quality of the Tourist Island , Pulau. Modern Applied Science, **3**(5), 62–74.

Liu, J., Liu, Q., and Yang, H. (2016) Assessing water scarcity by simultaneously considering environmental flow requirements, water quantity, and water quality. Ecological Indicators, **60**, 434–441. [online] http://dx.doi.org/10.1016/j.ecolind.2015.07.019.

Loo, Y. Y., Billa, L., and Singh, A. (2015) Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. Geoscience Frontiers, **6**(6), 817–823. [online] http://linkinghub.elsevier.com/retrieve/pii/S167498711400036X (Accessed August 29, 2017).

Malaysian Meteorological Department (2017) Malaysian Climate. MET Malaysia, 1–2. [online] http://www.met.gov.my/in/web/metmalaysia/climate/generalinformation/malaysia?p_p_id=56_INSTANCE_zMn7KdXJhAGe&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=2&_56_INSTANCE_zMn7KdXJhAGe_page=1 (Accessed September 5, 2017).

Man, S. (2015) Sistem penuaian air hujan : Kajian kes kesediaan masyarakat di Rainwater harvesting : A case study of public readiness in Bandar. , **11**(11), 53–62.

Manap, M. A., Sulaiman, W. N. A., Ramli, M. F., Pradhan, B., and Surip, N. (2013) A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arabian Journal of Geosciences, **6**(5), 1621–1637.

Mara, G. (2004) *Domestic Wastewater Treatment in Developing Countries*, New York, Earthscan.

Ministry of Finance Malaysia (2017) *Malaysian Budget Report*, Kuala Lumpur, Malaysia.

MMOH, M. M. of H. (2010) Drinking Water Quality Surveillance Programme - Ministry of Health. [online] http://kmam.moh.gov.my/public-user/drinking-water-quality-standard.html.

National Water Services Commission (2016) *Non Revenue Water (NRW)*, [online] http://www.span.gov.my/index.php/en/statistic/water-statistic/non-revenue-water-nrw-2016.

Nicholson, N., Clark, S. E., Long, B. V, Spicher, J., and Steele, K. a (2009) "Rainwater Harvesting for Non-Potable Use in Gardens: A Comparison of Runoff Water Quality from Green vs. Traditional Roofs" in World Environmental and Water Resources Congress 2009. Reston, VA, American Society of Civil Engineers, 1–10. [online] http://ascelibrary.org/doi/10.1061/41036%28342%29146.

NRO (1994) *Natural Resources Office Sabah: Water Resources Master Plan, Final Report Overview*,

Nyemba, A., Manzungu, E., Masango, S., and Musasiwa, S. (2010) The impact of water scarcity on environmental health in selected residential areas in Bulawayo City, Zimbabwe. Physics and Chemistry of the Earth, **35**(13–14), 823–827. [online] http://dx.doi.org/10.1016/j.pce.2010.07.028.

Padfield, R., Tham, M. H., Costes, S., and Smith, L. (2016) Uneven development and the commercialisation of public utilities: A political ecology analysis of water reforms in Malaysia. Utilities Policy, **40**, 152–161.

Piratla, K. R. and Goverdhanam, S. (2015) Decentralized Water Systems for Sustainable and Reliable Supply. Procedia Engineering, **118**, 720–726.

Praveena, S. M., Lin, C. Y., Aris, A. Z., and Abdullah, M. H. (2010) Groundwater Assessment at Manukan Island, Sabah: Multidisplinary Approaches. Natural Resources Research, **19**(4), 279–291. [online] http://dx.doi.org/10.1007/s11053-010-9124-y.

Rahmat, S. N. B., Ali, Z. M., and Musa, S. (2008) "Treatment of Rainwater Quality Using Sand Filter" in International Conference on Environment 2008 (ICENV 2008)., 1–8.

Rijsberman, F. R. (2006) Water scarcity: Fact or fiction? Agricultural Water Management, **80**, 5–22.

Saimy, I. S. and Yusof, N. A. M. (2013) The Need for Better Water Policy and Governance in Malaysia. Procedia - Social and Behavioral Sciences, **81**, 371–375. [online] http://linkinghub.elsevier.com/retrieve/pii/S1877042813015127.

Saleh, H. and Samsudin, A. R. (2013) Geo-Electrical Resistivity Characterization of Sedimentary Rocks in Dent Peninsular, Lahad Datu, Sabah. Borneo science, **32**, 33–43.

Salleh, H. M. and Malek, N. A. (2012) *Non-Revenue Water, Impact To The Services, Environment And Financial*, [online] http://www.kettha.gov.my/kettha/portal/document/files/Pdf Innovasi Kettha/NRW Impact To The Service,Environment And Financial.pdf.

Sánchez, A. S., Cohim, E., and Kalid, R. A. (2015) A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. Sustainability of Water Quality and Ecology, **6**, 119–137.

Sapkota, M., Arora, M., Malano, H., Moglia, M., Sharma, A., George, B., and Pamminger, F. (2015) An overview of hybrid water supply systems in the context of urban water management: Challenges and opportunities. Water (Switzerland), **7**(1), 153–174. [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-84920875758&doi=10.3390%2Fw7010153&partnerID=40&md5=3d410c20acf9e654bcdccbc19ef66cbc.

Sefie, A., Aris, A. Z., Shamsuddin, M. K. N., Tawnie, I., Suratman, S., Idris, A. N., Saadudin, S. B., and Wan Ahmad, W. K. (2015) Hydrogeochemistry of Groundwater from Different Aquifer in Lower Kelantan Basin, Kelantan, Malaysia. Procedia Environmental Sciences, **30**, 151–156. [online] http://www.sciencedirect.com/science/article/pii/S1878029615006210.

Shaheed, R., Wan Mohtar, W. H. M., and El-Shafie, A. (2017) Ensuring water security by utilizing roof-harvested rainwater and lake water treated with a low-cost integrated adsorption-filtration system. Water Science and Engineering, **10**(2), 115–124. [online] http://dx.doi.org/10.1016/j.wse.2017.05.002.

Shirazi, S. M., Adham, M. I., Zardari, N. H., Ismail, Z., Imran, H. M. D., and Mangrio, M. A. (2015) Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia. Journal of Water and Land Development, **24**(1–3), 11–19.

Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., and Kouimtzis, T. (2003) Assessment of the surface water quality in Northern Greece. Water Research, **37**(17), 4119–4124. [online] http://www.sciencedirect.com/science/article/pii/S0043135403003981#BIB1 (Accessed September 19, 2017).

Sitzenfrei, R. and Rauch, W. (2014) Investigating transitions of centralized water infrastructure to decentralized solutions - An integrated approach. Procedia Engineering, **70**, 1549–1557. [online] http://dx.doi.org/10.1016/j.proeng.2014.02.171.

Suratman, S. (2004) 6.6. IWRM: Managing the Groundwater Component in Malaysia. Malaysia Water Forum, Kuala Lumpur, Malaysia, 19–22. [online] http://scholar.google.ca/scholar?start=100&q=iwrm&hl=en&as_sdt=1,5#22.

Suratman, S., Tawnie, I., and Sefei, A. (2011) Impact of landfills on groundwater in Selangor, Malaysia. ASM Science Journal, **5**(2), 101–108.

Tan, J. (2012) The Pitfalls of Water Privatization: Failure and Reform in Malaysia. World Development, **40**(12), 2552–2563. [online] http://dx.doi.org/10.1016/j.worlddev.2012.05.012.

Tankiewicz, M., Fenik, J., and Biziuk, M. (2010) Determination of organophosphorus and organonitrogen pesticides in water samples. TrAC - Trends in Analytical Chemistry, **29**(9), 1050–1063. [online] http://dx.doi.org/10.1016/j.trac.2010.05.008.

Tarbuck, E. J. and Lutgens, F. K. (2015) *Earth Science*, England, Pearson.

Tubau, I., Vázquez-Suñé, E., Carrera, J., Valhondo, C., and Criollo, R. (2017) Quantification of groundwater recharge in urban environments. Science of The Total Environment, **592**, 391–402. [online] http://linkinghub.elsevier.com/retrieve/pii/S0048969717306307 (Accessed September 13, 2017).

UNICEF and WHO (2017) *Progress on Drinking Water, Sanitation and Hygiene*, [online] http://apps.who.int/iris/bitstream/10665/258617/1/9789241512893-eng.pdf%0Ahttp://www.wipo.int/amc/en/%0Ahttp://www.wipo.int/amc/en/.

Wang, J., Li, Y., Huang, J., Yan, T., and Sun, T. (2016) Growing water scarcity, food security and government responses in China. Global Food Security, **14**, 1–9. [online] http://dx.doi.org/10.1016/j.gfs.2017.01.003.

Weber, B., Cornel, P., and Wagner, M. (2007) Semi-centralised supply and treatment systems for (fast growing) urban areas. Water Science and Technology, **55**(1–2), 349–356. [online] http://wst.iwaponline.com/content/55/1-2/349.abstract.

WHO and UNICEF (2014) Progress on sanitation and drinking-water - 2014 update. Monitoring Programme for water supply and sanitation, 1–78. [online] http://books.google.com/books?hl=en&lr=&id=irXCej15ax8C&oi=fnd&pg=PA56&dq=Drinking+Water+and+Sanitation&ots=nB6oNXONjK&sig=ccf20ooYvn9F1SWv_miDYvNkEAs.

Wilderer, P. A. and Schreff, D. (2000) Decentralized and centralized wastewater management: A challenge for technology developers. Water Science and Technology, **41**(1), 1–8.

Xiao, S., Hu, S., Zhang, Y., Zhao, X., and Pan, W. (2018) Influence of sewage treatment plant effluent discharge into multipurpose river on its water quality: A quantitative health risk assessment of Cryptosporidium and Giardia. Environmental Pollution, **233**, 797–805. [online] http://linkinghub.elsevier.com/retrieve/pii/S0269749117326817.

Yan, X., Ward, S., Butler, D., and Daly, B. (2017) Performance assessment and life cycle analysis of potable water production from harvested rainwater by a decentralized system. Journal of Cleaner Production, **172**, 2167–2173.

Yaser, A. Z. and Safie, N. N. (2020) *Green Engineering for Campus Sustainability*, Springer Singapore.

Yaziz, M. I., Gunting, H., Sapari, N., and Ghazali, A. W. (1989) Variation in Rainwater From Roof Ctachments. Water Research, **23**(6), 761–765.

Zeng, Z., Liu, J., and Savenije, H. H. G. (2013) A simple approach to assess water scarcity integrating water quantity and quality. Ecological Indicators, **34**, 441–449. [online] http://dx.doi.org/10.1016/j.ecolind.2013.06.012.

Zhou, Q., Deng, X., and Wu, F. (2017) Impacts of water scarcity on socio-economic development: A case study of Gaotai County, China. Physics and Chemistry of the Earth, Parts A/B/C. [online] http://linkinghub.elsevier.com/retrieve/pii/S1474706516302285.

Zin, T., SabaiAung, T., Saupin, S., Myint, T., KhinSN, D., Soe Aung, M., and S, S. B. (2015) Influencing Factors for Cholera and Diarrhoea: Water Sanitation and Hygiene in Impoverished Rural Villages of Beluran District, Sabah Malaysia. Malaysian Journal of Public Health Medicine, **15**(1), 30–40.