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Techno-socio-economic analysis of fog-to-water solution for climate change hazard area: Sumba Island, Indonesia

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Abstract

The global demand for water has been growing rapidly in the last decade with a global population growth rate of 1.1% p.a., which is equivalent to 81 million people per year. Southeast Asian countries are facing severe water scarcity challenge due to their location in the tropics. In 2018, the Sumba Island experienced the highest temperature of 36°C and lesser rainfall of 911.1 mm^3 per year and it was classified as a long dry island prone to drought due to dry winds from Australian deserts. This paper focuses on the perceived effect of water scarcity on livelihoods in the Mandahu Village, Indonesia, due to climate change. Sampling and survey covered rural households and the findings showed that the average household of 4 to 8 people consumed around 250 dm^3 of water per day. The community relied on two main sources of clean water from two main springs. However, the prolonged dry season from May until December every year results in major challenges to access water and eventually affect the agricultural productivity. Hence, the feasibility of the fog collection technology has been investigated from technological, economic and social points of view as a reliable and cost-effective source of water. The outcome of this work will produce a feasibility statement for fog-to-water as an alternative solution counteracting water scarcity in the Sumba Island, a solution which can be replicated in other climate change stricken hot spots in Southeast Asia.

Key words: *climate change, fog collector, hazard, Southeast Asia, water scarcity*

INTRODUCTION

Indonesia is the largest archipelago in the world. Indonesia is a country in Southeast Asia and Oceania located between the Indian and the Pacific Oceans. It bridges two continents, Australia and Asia. Indonesia consists of five major islands (Sumatra, Java-Madura, Kalimantan, Sulawesi, and Papua) and more than 17,000 smaller islands [WINQVIST *et al* 2008]. There are two distinct seasons in Indonesia, wet and dry thorough a year. In general, the country has a tropical rainforest climate. Therefore, temperature ranges from 21°C to 33°C, except at higher altitudes. Climate change has affected seasons and rainfall in Indonesia which caused economic, environmental and social impacts in various areas. The World Bank analysis ranked Indonesia 12th among 35 countries that face high mortality risks due to multiple hazards, including tsunamis, floods, landslides, droughts, earthquakes, and volcanic eruptions [MCSWEENY *et al.* 2010. As the fourth most populous country in the world in 2014, the shocks of climate change are already felt in Indonesia, with more frequent droughts, heat waves and floods. Indonesia is predicted to experience a temperature increase of 0.8°C by 2030 [OKTAVIANI *et al.* 2011]. Drought nowadays occur every three years compared to previous every four years before 1960 [SYAUKAT 2011]. Climate change, rainfall and temperature are the most influential variables and it has been estimated that temperature increased 0.9–2.2°C in 2006 and it is expected to increase 1.1–3.2°C by 2100 [USAID 2017]. A research by the Asian Development

Bank projects a 70 cm rise in the sea level by 2100 to affect more than 42 million people [VINKE *et al.* 2017]. The El Nino events (decrease in rainfall) can lead to longer dry seasons and drought, thus impact agricultural production and water availability in Indonesia [BHUVANESWARI *et al.* 2013; UNDP 2017].

Southeast Asia countries have faced a growing water scarcity challenge due to its geographic location between the tropics. This means that the weather tends to be hot and humid. This research focuses on one of climate hazard hotspots according to the Global Climate Risk Index which is the Sumba Island classified as a long dry island prone to drought due to dry winds from Australian desserts. The Sumba Island is located in the second lowest part of Indonesia and has a semi-arid climate. The long dry season from May until December every year results in major challenges to access water and it eventually affects the agricultural productivity of fields and plantations. This leads to changes in food production. In order to adapt to the adverse implications of climate change, this region requires special attention to overcome the extreme scarcity of water resources and to protect its ecosystems while maintaining economic benefits. Research methods include the reflective analysis of the historical weather trends, comparative studies on fog capture technologies and community engagement of 50 rural households. Research questions covered factors that affect basic living conditions under the current water consumption pattern, size of a household, current electricity consumption, solutions for electricity supply, current solution for water supply, job types, source of income and the education level. The research also aimed to evaluate the hypothesis that water scarcity deteriorates living conditions and livelihood of the rural community due to climate change, in particular vulnerable groups of women and children. Thus, the research investigates the techno-socio-economic feasibility of the fog-to-water technology as a suitable fresh water supply solution in the Sumba Island.

Photo 1. Sumba Island – one of the Eastern Island of Indonesia, located in the province of East Nusa Tenggara (phot. M. Karuniasa)

STUDY METHODS

STUDY AREA, SAMPLING AND DATA COLLECTION

The study was conducted in the Sumba Island, one of Eastern Islands of Indonesia. It is located in the province of East Nusa Tenggara (Photo 1). The coordinates of the Sumba Island are as follows: 119°45' and 120°52' E and 9°16'-10°20' S. The majority of the island area in the East Sumba Regency (60%). According to the Central Bureau of Statistics of East Nusa Tenggara Province, the Sumba Island has 781,093 inhabitants [BPS 2017]. This island experiences higher temperatures of 36°C and lesser rainfall than 911.1 mm^3 per year 2018. Due to climate change, the total annual rainfall in the Sumba Island is very far from the national average of 2400 mm^3. The Sumba Island is one of poorer islands in Indonesia and has remained relatively excluded from the Indonesian modernization. Predominant economic sectors in the Sumba Island are agriculture, plantation, forestry, hunting and fisheries [BPS 2013; 2016]. Only 11% of the area in the Sumba Island suffers from limited water resources and shortage of technologies. The Sumba Island has a unique geographical structure with low-rise landscape, limestone (karst) hills with very high calcium content in ground water, which is unsafe to drink. Like many other volcanic islands, Indonesia has steep volcano mountains.

This village has two springs and starts to dry up. The nearest river is 3 km walking distance away. Households in the community also harvest rainwater for washing only. Since the approach to water supply is not sustainable, the island is the right location for the study. The Sumba Island's landscape is characterized by sinkholes and caves formed by the dissolution of soluble rock. This causes a very high content of calcium in the ground water, especially near Blora, Central Java, where local communities consume unsafe water but have no other choice. The water filter that can partly remove calcium is costly for low income families. The target population surveyed under the study are the rural households in the Mandahu Village, East Sumba, Indonesia. Multi-stage random sampling was used to select respondents. The Mandahu Village was selected due to the observed prevalence of water scarcity in the area. Data were collected using an interview schedule.

The Sumba Island is the first 'iconic island' designated by the Dutch NGO Hivos International together with the Indonesian government and various other international organizations to reach 100% renewable energy supply [FREDERIKS 2013; Hivos 2012]. The renewable energy resources include hydro, wind, solar, biogas and biofuel [GOKKON 2015]. Small micro-hydro power and biogas plants were built in areas of scarce water resources and high population of livestock on the Sumba Island. Table 1 shows types of renewable energy in the Sumba Island and the potential based on the Sumba Iconic Island [SII 2016]. Clean water supplied to households, businesses and farmer's crops and livestock is pumped from wells and other water sources. Unfortunately, due to the climate change, consumption of clean water is growing but the availability of freshwater is decreasing. Two alternatives are available in order to fulfil the needs for freshwater. These include legally limited use of currently available water resources or finding alternative water resources using conventional approaches [METER *et al.* 2014].

Table 1. Renewable energy in the Sumba Island (Sumba Iconic Island)

Renewable energy	Amount (unit)	Installed capacity
Micro-hydro	12	3 421 kW
Wind	100	50 kW
Solar	centralised = 39 decentralise = 14 829	9 119 kW_p 439 kW_p
Biomass	1	30 kW

Source: SII [2016].

In the largely tropical country of Indonesia, East Sumba has an atypically semi-arid climate and it is classified as a dry island due to its long dry season from May until December (7 months) each year and a major challenges to access a water [FISHER *et al.* 2006; MONK *et al.* 1997], as shown in Photo 2a. This region needs special attention because during the dry season, many streams dry up and villagers depends on wells for scarce supplies of water. The extreme climate condition altered the soil quality and adversely impacted the agricultural activity of local farmers, as shown in Photo 2b. In dry areas of the northeast region, no agriculture crop can be grown. The only livestock that can withstand the extreme climate conditions are the Sumba horses and Indian Brahman cows.

The Sumba Island is mostly covered by a deciduous monsoon forest, partly extremely dry without harmonious green where the landscape resembles a savannah. Only 7% of the area is covered with the original forest. Strong and dry Australian winds additionally dry out the soil. The life of the Sumba community is more difficult than others, especially the northern part of Sumba is extremely dry which affects agriculture and livestock. The soil quality is poor due to deforestation and erosion. Rain distribution in the Sumba Island is as follows: 800–1000 mm·y^{-1} in the Northeast, 1000–1500 mm·y^{-1} in the Central Region, and 1500–2000 mm·y^{-1} in the South-West. The dry climate change reduced the intensity of the annual rainfall, caused droughts, and resulted in the creeping food insecurity and the poverty in the Sumba Island. The growing poverty in East Nusa Tenggara affected around 900 thousand to 1 million people in 2000–2014. It is attributed to the anthropogenic climate change and cyclical meteorological phenomena [AL-FARUQ *et al.* 2016]. According to climate condition in East Nusa Tenggara (BPS, 2016), the annual precipitation ranges from 770–3800 mm per year with dry season starting from April to November. An analysis of drought due to climate change in Sumba Island, East Nusa Tenggara had been carried out [SIPAYUNG *et al.* 2019] until 2040.The finding predicted that there will be extreme dry conditions in August 2022, 2024, 2028, 2030 and 2033 using time series analysis. The low rainfall directly affects the availability of clean water for the needs of public and farm management. In Sumba, another prolonged dry season resulted from El-Nino in early 2015 [WV 2016]. The air temperature is higher than the average which alters the weather pattern in the Sumba Island dramatically.

Photo 2. Two different looks of Sumba: a) unlimited water resources near Kantor Desa, Kantor Village; b) community owed paddy field during the drought season in Mandahu Village; (phot. *H. Laily*)

Due to water shortages and rising water prices, fog water collection has become ever more attractive option. The technology has been tested and proven for decades making it an investment opportunity. As shown in the example, Bellavista poor communities can sell water obtained from fog collectors in the village [TIEDEMANN, LUMMERICH 2010]. Fog collectors provide water. More importantly, fog water harvesting can be used in areas where other water sources are scarce or non-existent.

RESULTS AND DISCUSSION

SOCIO-ECONOMIC ASPECT

Based on the statistics, the current water consumption in the Mandahu Village (dm^3 per day and distribution) is around 250 dm^3 of water per day for daily needs, such as washing and cooking, in a household of 4–8 people. Water is also needed for the livestock, on average 1 buffalo needs 60 dm^3 of water per day, while cows need 20 dm^3, and pigs 10 dm^3 of water per day. Currently, in the Mandahu Village, clean water is supplied from two main springs. In the village work plan for 2019, the village government resorted to the PAMSIMAS (Ind. Penyediaan Air Minum dan Sanitasi Berbasis Masyarakat) program for the procurement of solar water pumping (SWP), reservoirs, and piping. Recently, the SWP system has been installed and began to be utilized by the community. The system had been used for less than three days before it stopped operating due to the damage of the solar panel system by a storm and a poor quality of its construction. According to the community, the two springs can provide water throughout the year. 2019 was the driest year in the last 5 years. During the 4 months, the spring has shrunk, and for 2 months there was no water in the spring. To overcome the issue of unreliable water supply from springs, the community buys water from the Kombapari Village (neighbouring village) at IDR300,000 (approx. USD21) for 5000 dm^3. In addition to the two springs and buying water from the nearby village, the community also harvests rainwater. The rainy season in the Mandahu Village is generally from December to March. They use rainwater only for washing and not for cooking or drinking. Based on 2018 statistics for the sub-district of Katala Hamu Lingu, there are two rivers that flow in the Mandahu Village, the Karanggat River and Tana Rara River. The Tana Rara River is one of tributaries of the Mauliru River. It is the same water source for people living in the Waingapu City (capital city of East Sumba district, ±65 km from the village). The two springs in the Mandahu Village were previously rivers. However, in 2002, a great flood hit the village and caused a landslide that closed major parts of the river area and turned them into swamps. The main activity in the community is agriculture. The majority of people are farmers. Commodities produced are hazelnut, turmeric, rice, and corn. Since the farming still heavily relies on rainwater, the harvest season for rice and corn only occur once a year. The corn stock normally can survive until the next harvesting season. But sometimes, famine may occur usually 1–2 months before the planting season which is generally from December until February. To cope with that situation, the community buys rice and corn in Lewa or Waingapu. The community usually sells their products during market days which are held every two weeks in the village or selling their crops to Lewa or Waingapu.

This shortage water supplies and water scarcity problem in the Sumba Island, Indonesia, need special attention and it is more challenging than in other drought hazard hotspots in Southeast Asia because the weather and climate are not erratic and the availability of clean water is limited. More than 63% of the community in the Sumba Island do not have access to safe and clean water. They rely on rainwater for drinking during normal days (4–5 months in a year). During a prolonged dry session, which takes 7 months in a year, and less rainfall between 800 to 1000 $mm \cdot y^{-1}$ in the northeast areas of the Sumba Island, most water sources dry up. People have to travel for more than 10 km daily to fetch water. However, the water is found to be unsafe for drinking. They often buy water from water trucks, which costs IDR 250,000 (USD3299). This water still needs to be boiled before drinking due to its poor quality. The villagers also buy gallon refills that cost them IDR10,000 (USD132). The poor water quality causes more coughing after drinking according the Eastern Sumba Regency. More 50% of the population are children (8–10 children per household). Thus, the cost per dm^3 of water is not an unaffordable solution for these low income rural communities (1.9 mln IDR = 153 Euro) [HIVOS 2012].

Water scarcity issue has resulted in health problems including bladder disease and kidney infections where the villagers have to travel for long distance for medical health assistance (cost incurred of IDR 20,000 = USD264). Some of very weak patients are transported on stretchers rather than riding a motorbike. The Sumba Island is also one of the poorest islands in Indonesia that suffer from malaria and high infant mortality rate due to poor health care amenities and sanitation. People are found to defecate in open areas, which increases diarrhea and causes a series of malnutrition issues. Drought caused by the scarcity of water is a constant threat for the island, as families become indebted and starve due to the climate change which continues to wreak havoc on this small community [CRAINE 2013].

TECHNO-ECONOMICS

The fog to water harvesting is a green technology and renewable source that can capture fog and change it into water. This renewable source does not depend on groundwater, surface water, precipitation and water from oceans. The fog water harvesting is inexpensive, simple, sustainable, and requires low maintenance, and it has been studied in over 20 countries across six continents [DOMEN *et al.* 2014]. Fog harvesting has been adopted worldwide, including the Chile's Atacama Desert, one of the driest deserts, as shown in Photos 3 and 4, but has not been installed yet in Southeast Asia. The Atacama Desert is often shrouded in a thick fog. The idea of harvesting fog was first developed in South America in the 1980s. Today, there are such projects in Chile, Peru, Ghana, and Eritrea. Our fog to water solution is expected to contribute to health improvement and reduction of diseases caused by the consumption of unsafe/contaminated water. Abstraction of underground water is energy consuming and depends on rainfall intensity and altered underground structure. Additionally, a slope covered by rainforest is located in the south of the Sumba Island. This unique geographical condition allows the south facing slope to remain moist even during a dry session. This boosts the potential of the fog-to-water solution for arid regions.

Photo 3. The Atacama Desert is one of the driest places on Earth; source: PEREIRA [2008]

Photo 4. Nets capture moisture which is collected and filtered then mixed with underground water (phot.: Dar Si Hmad)

Two kinds of fog water collectors are widely used: standard fog collector (SFC) and large fog collector (LFC). Figure 1 shows difference between the SFC and the LFC. The SFC of 1 m^2 is used for field tests, the LFC of 40 m^2 is used for operational tests and sometimes quarter size fog collectors (QFCs) of 0.25 m^2 are used for field tests [GANDHIDASAN *et al.* 2018]. Fog is a stratus cloud that consists of condensed water droplets diameters of which vary from 0.001 to 0.04 mm [GANDHIDASAN *et al.* 2018]. Usually, a fog collector comprises a vertical mesh made from polymaterials, such as polypropylene or polyethylene and nylon. Fog is collected by the collision of suspended droplets with a vertical mesh. They join together to form large droplets which flow down the net into a collecting drain and into a tank [ABDUL-WAHAB, LEA 2008]. The Canadian Fog Quest used the LFC and collect up to 500 dm^3 of water on a single foggy day [LOSTER 2015]. Generally, water from fog-to-water harvesting can be used for human, animals and agriculture without further treatment because it meets national drinking water standards and World Health Organization (WHO) standards for water quality. The fog water cost is about one quarter of the traditional water supply cost, where water is delivered by truck to the village at around USD1.87 per m^3 instead of USD7.25 per m^3 based on certain assumptions about equipment durability, meteorological condition etc., according to calculations performed by CERECEDA *et al.* [1992].

The technology of fog water harvesting is a low-cost maintenance and low operational cost compared to conventional water supply systems since it does not require electrical power, fuel, and spare parts. Maintenance includes the tightening of a loose cable, examining and patching of rips in the mesh, mending of torn mesh, and cleaning of water tanks from debris or algae which can be done by a trained community [CHANDRAPPA *et al.* 2011]. The cost of square meter of the mesh installed is usually the only cost of fog water harvesting. The cost may range from USD25 to USD50 per m^2 of mesh for commonly used two-dimensional Raschel mesh fog collections systems [FESSEHAYE *et al.* 2017]. These costs depend on the material of mesh, piping and collection systems. For example, for the LFC with the mesh of 40 m^2, the cost may range from USD1000 to USD2000, while for a mesh of 48 m^2, the cost ranges between USD1200 and USD2400 [QADIR *et al.* 2018]. LFC Raschel mesh nets of 40 m^2 cost USD200 per unit which is USD5 per m^2 of a mesh [DODSON, BARGACH 2015]. An estimated USD40,000 is the cost of a system suitable for a village (100 LFC units) but the cost might vary depending on where the access to the site and the length of pipelines [SCHEMENAUER, CERECEDA 1994]. A polypropylene mesh is expected to last more than 20 years. Although high efficiency three dimensional (3D) spacer fabric nets are more expensive (USD830 per m^2), the mesh can produce double or triple the amount of water and it is more resistant to harsh conditions [MILLER 2019]. The selection of mesh depends on its durability, price, availability, and water draining properties. Nowadays, other type than the Raschel mesh have been developed to increase efficiency, durability, reduce cost, and improve availability and water draining properties. These include Aluminet greenhouse shade nets with a high-density polyethylene mesh coated with aluminum and a poly-yarn mesh co-knitted with stainless steel for additional strength [SHANYENGANA *et al.* 2003]. Local topography, demand for water, and availability of financial resources and materials determine the number and size of meshes. Table 2 shows water collection rates from fog collection systems described in other papers.

Water supply to people living in arid, mountainous coastal regions is improved by fog water harvesting all over the world. Figure 1 shows global mean cirrus cloud frequencies and night minus day difference. These data indicate an estimation on the likelihood of fog formation. They are mostly confined to tropical and subtropical belts,

Table 2. Water collection rates from fog water harvesting

Project	Total collecting surface (m^2)	Water collected ($dm^3 \cdot day^{-1}$)
University of South Africa	70	3 800
Yemen	40	4 500
Cape Verde	200	4 000
Dominican Republic	40	4 000
Eritrea	1 600	12 000

Source: own elaboration based on: SCHEMENAUER *et al.* [2004] and OLIVIER [2008].

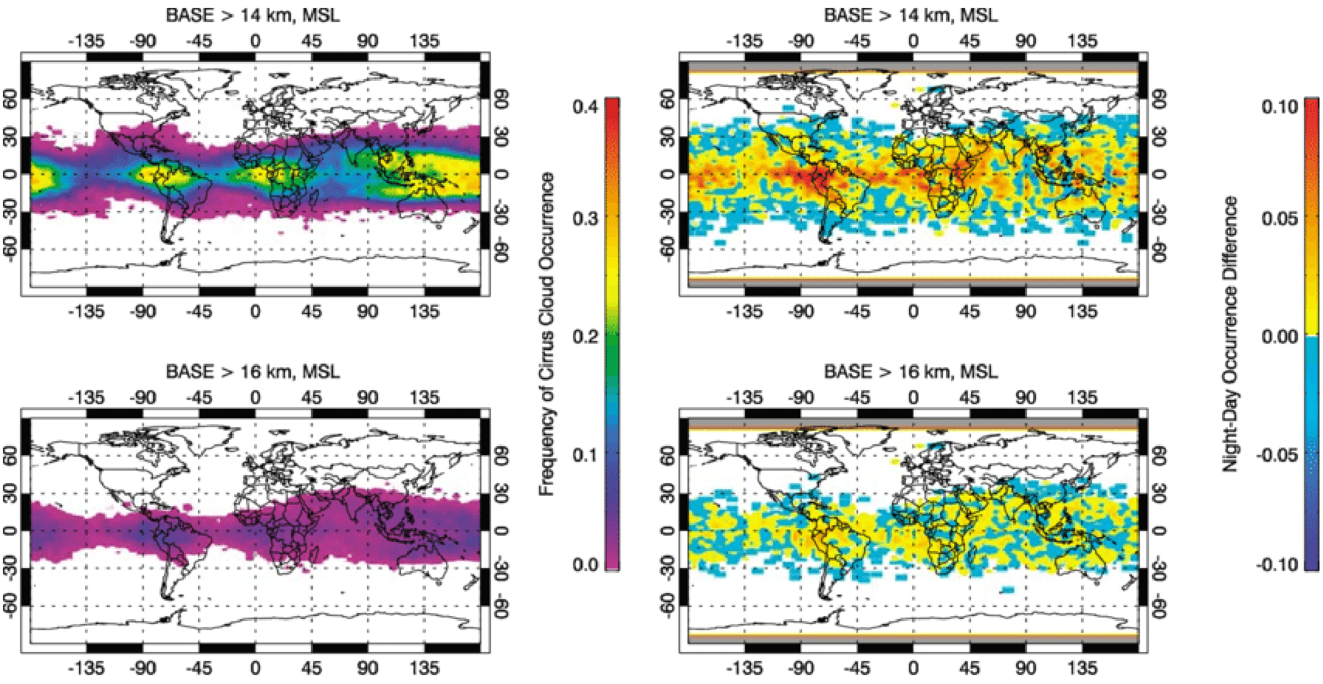

Fig. 1. Global frequency of occurrence of all cirrus clouds with cloud base altitudes above 14.0 km MSL and 16.0 km MSL (left). The corresponding night minus day differences, approximating the presence of tropical tropopause layer cirrus clouds (right); source: SASSEN *et al.* [2009]

with frequencies of occurrence as high as 30% and 10% respectively. Interestingly, the >14.0 km MSL cirrus clouds are mostly detected at night and they occur in the majority of regions, while >16.0 km MSL cirrus clouds do not show a strong tendency for day or night maxima. It is surprising as the latter cirrus clouds are likely to be geometrically and optically thinner in this sample, and they are expected to be sampled during daytime due to possible solar noise effects on the CALIOP data collection [SASSEN *et al.* 2009].

Environmental conditions such as high dew point temperatures, high humidity, and high elevation are known to favour fog formation. Figure 2 shows relative humidity for six years from 2013 until 2018. Fog water harvesting is a suitable method when relative humidity exceeds 68-90%, since relative humidity of 90% and 98% promotes fog formation [DAVTALAB *et al.* 2013]. Figure 2 also shows the fog water harvesting has a great potential as an alternative source of fresh water to the Sumba Island due to its high relative humidity of more than 68% in 6 years. Due to geological factors, fog formation is usually the highest in mountainous areas near the coast. As Sumba is a mountainous island where it is difficult to access and utilize water, fog water harvesting is a particularly suitable technology to be applied and installed, especially that conventional sources of water supply are generally more costly [PIRNIA *et al.* 2019].

There are also other innovative technologies to access fresh water. These include desalination, wastewater reuse, water reservation, and rainwater harvesting. Seawater desalination technologies have been developed over the last several decades specially to supply water in arid regions of the world. Desalination removes salt and other minerals from seawater. The process separates saline seawater into two streams which are a fresh water stream containing a low concentration of dissolved salt and minerals, and a concentrated brine stream, which has salt and mineral concentrations higher than that of the feed water [KHAWAJI *et al.* 2008]. A variety of desalination technologies have been developed over the years. The most popular of them are thermal distillation and membrane distillation. The Middle East region's petroleum reserves keep energy costs low and make thermal distillation technologies widely used, while the United States mainly use membrane distillation technologies. Saudi Arabia, USA, the United Arab Emirates, Spain and Kuwait are five leading countries regarding their desalination capacity [BAAWAIN *et al.* 2015]. Over the years, the cost of desalination technologies has decreased but it still remains higher than fresh water ab-

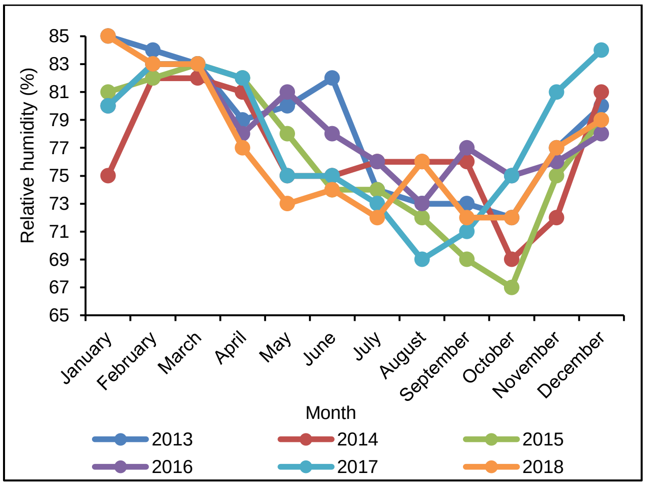

Fig. 2. Relative humidity (*RH*) in Sumba Island between 2013 and 2018; source: BPS [2019]

straction from rivers or groundwater, water recycling and water conservation. Therefore, many countries are unable to afford to rely on these technologies as sources of freshwater. In 2013, the desalination cost ranged from USD0.45 to USD1.00 per cubic meter. More than half of the cost is the energy cost, and since energy prices are very volatile, the actual cost can vary substantially [ZHANG, BABOVIC 2012]. The high energy demand for desalination poses challenges related to the greenhouse gas emissions, such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), nitric oxide (NO), and carbon monoxide (CO). There are also growing volumes of chemicals (cleaning chemicals, anti-corrosion, anti-foaming, and biocides, e.g. chlorine, for controlling biological growth) that are used for saline water pre-treatment and post-treatment, which have significant impacts to the environment [LATTEMANN, HÖPNER 2008; QDAIS 2008; YOUNOS 2005].

World's water resources will not change but the amount of wastewater produced is increasing, and the infrastructure and management systems are not adequate to countervail the growing wastewater volume. Water is used and contaminated by human and its physical, chemical or biological properties are changed by certain substances which make water unsafe for drinking [AMOATEY, BANI 2011].

Wastewater treatment is the process and technology that is used to remove most of the contaminants to ensure a sound environment and good public health [AMOATEY, BANI 2011]. Wastewater use is other alternative to consider as a part of the solution to water scarcity in the Sumba Island. Financial, environmental and social costs associated with water quality and availability are vital. Wastewater must be treated to protect the environment and foster public health. Wastewater can be treated in wastewater treatment plants which include physical, chemical and biological treatment processes to make sure that the processed water is hygienically safe from bacteria and viruses. The increase in the accumulation of waste all around the world and the discharge in heavy metals to water streams due to the development of technology, urbanization and industrialization. This ecological problem needs to be solved (New Technologies in Wastewater Treatment 2014) since it affects waterways due to the discharge of inadequately treated industrial wastewater containing heavy metals [ARIFFIN *et al.* 2017]. These poses a risk to civic health as heavy metal polluted wastewater is used to irrigate [SIDDIQUE *et al.* 2015]. Variety of activities are needed, such as disposal of industrial, and agricultural waste and other products to avoid the destructive impact of heavy metals. Wastewater streams containing an increased heavy metal content have negative effects on human bodies and may be lethal. Some technologies used in the handling of wastewater include ozonation, ultrafiltration, aerobic treatment (membrane bioreactor), forward osmosis, reverse osmosis, and advanced oxidation. Currently, the main disadvantage of wastewater reuse technologies is the financial cost of their installation and maintenance [REARDON *et al.* 2013]. Singapore is one of countries that used wastewater treatment for a clean water supply. Wastewater treatment would require special attention and expertise. Singapore puts much emphasis on supply and demand management, wastewater and storm water management, institutional effectiveness, and creating an enabling environment. This includes a strong political will, effective legal and regulatory frameworks, and an experienced and motivated workforce [TORTAJADA 2006].

Natural water resources are affected by water used and increased pressure due to climate change and population growth, as well as agricultural irrigation and manufacturing. Rainwater harvesting is a conventional water management practice and has a long tradition of thousands of years [ABDULKHALEQ, ALHAJ AHMED 2007]. It is a technology based on simple techniques, such as natural and/or artificial ponds and reservoirs for collecting and storage of rainwater from rooftops, land surfaces or rock catchments. One liter of water per square meter is equivalent to one millimeter of harvested water [HELMREICH, HORN 2009]. After collecting and storing, rainwater can be used by households for drinking, cooking, sanitation etc., as well as for agricultural production. It can also be used to maintain groundwater levels. Rainwater harvesting techniques and implementation methods vary from place to place depending upon specific climatic conditions, land topography, hydrogeological conditions etc. The collection, transportation, and storage systems are basic components of a typical rainwater harvesting system [DHINGRA *et al.* 2020]. In households, the collection system may be simpler than big systems installed in the industry to cater for a large catchment area. Industrial sale solutions use reservoirs from which water can be pumped to different water treatment plants or used for recharging groundwater bodies. Several types of filters for the removal of solid and organic materials are used to improve the quality of rainwater [RAHMAN 2017]. The pH control involves filtration, disinfection and buffering. Filtration and disinfection are necessary. The latter uses ultraviolet light or chemicals to treat water designated for drinking and cooking [DEVI *et al*. 2012].

Rainwater harvesting has financial benefits as it does not require to pay the bill for rainwater collected. Thus, water bills can be reduced by about 40-50% by using rainwater for domestic purposes. A rainwater harvesting system does not depended on any installation, expensive technology and monitoring, which makes it easy to maintain. To collect significant amount of water, an installation needs to be built to drain rainwater from the catchment area [MBILINYI *et al.* 2005]. Unfortunately, low rainfall limits supply of rainwater, which makes rainwater harvesting not suitable as an alternative water source in the Sumba Island. Regular maintenance and technical skills are also required to avoid waterborne diseases spread by mosquitoes. However, studies have indicated that the microbial quality of harvested rainwater is substandard and does not always comply with drinking water standards [AHMED *et al.* 2011, HAMILTON *et al.* 2019]. Water preservation is needed by a designation of a strip of land for feeding streams that are utilized for water supply and a science-based allocation policy has to be designed to safeguard water in the environment and transform water management. Table 3 summarizes water supply solutions in the Sumba Island and results of each alternative fresh water supply.

Table 3. Alternative solutions for water supply in the Sumba Island

Solution	Conditions during December–April (5 months)	Conditions during dry season May–November (7 months)
Water from river	– only accessible for those who live nearby – most of the community need to walk for more than 10 km to fetch water	– riverbed dried up – soil quality altered – water source depleted – strong and dry Australian wind from June to August additionally dries out soil
Gravity fed water system	– only accessible for those who live nearby hillside water source with sufficient potential difference and available heads – requires external energy for water transportation that mainly rely on fossil fuel	
Underground water	– only accessible for those live nearby – rely on NGO to build the wells – very high in calcium and unsafe to drink due to limestone (karst) landscape – bladder disease and kidney infections – villagers have to travel for long distance for medical assistance (cost incurred of IRD 20,000)	
Rainwater harvesting	– required large water storage, reply on NGO sponsorship	
Water pumps	– active system required external energy; mainly rely on fossil fuel	
Portable water filter	– rely on NGO's sponsorship and donation. – not affordable by the community	
Water truck	– costly, around IRD 250,000 spent. – no guarantee of water quality	pricier due to urgent demand
Gallon filler	– costly, around IRD 10,000 spent. – resulted in more coughing after drinking	

Source: own study.

CONCLUSIONS

Water is vital for all forms of life. It is a precious, essential and abiotic component of the ecosystem. Global warming and an increased number of drought periods result in water supply constraints. This affects rural households the most as they are affected by the scarcity of water due to insufficient rainfall and high exposure to solar radiation. Water scarcity increases the cost of water abstraction, and energy and time needed, and hampers the access to water. Due to water shortages and rising water technology prices, fog collection has become ever more attractive. Since the technology has been tested and proven for decades, it has become interesting for investment. Fog water harvesting has a great potential to supply communities with fresh water, especially communities which have little annual rainfall but frequent occurrence of fog. Current studies and full-scale applications indicate that the technology is both feasible and sustainable. While fog water harvesting is the most suitable for providing water in developing and rural regions, a valuable water source should be considered in the Sumba Island. Since it does not need a continuous energy supply, fog water harvesting can be beneficial for isolated communities that depend on external water supplies and scarce or erratic rainfall. As a conclusion, fog water harvesting can be considered the most suitable and potent of all technologies for the supply of fresh water in the Sumba Island.

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