



Adaptation of Coastal and Small Island Communities on the Assessment and Application of Clean Water Technology Provision

Adaptasi Masyarakat Pesisir dan Pulau-Pulau Kecil terhadap Kaji-Terap Teknologi Pemenuhan Ketersediaan Air Bersih

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ARTICLE INFO

Histori artikel:
Diterima 17 Oktober 2021
Disetujui 24 Desember 2021
Diterbitkan 31 Januari 2022

Kata kunci:
Air Bersih
Masyarakat Pesisir
Pengkajian Teknologi
Adaptasi
Pulau-pulau Kecil

ABSTRAK

Pemenuhan akses air bersih yang laik bagi masyarakat merupakan isu ke-6 dari 17 isu tujuan pembangunan berkelanjutan (TPB). Tujuan berkelanjutan ini bertumpu pada pilar ekonomi, sosial dan lingkungan yang diperkuat oleh peran teknologi. Kawasan pesisir dan pulau-pulau kecil memiliki tantangan yang relatif lebih besar ditengah isu perubahan iklim dalam memenuhi ketersediaan air bersih. Penelitian ini bertujuan untuk mengembangkan model aplikasi teknologi tepat guna melalui analisis adaptasi masyarakat dalam pemenuhan akses air bersih. Masyarakat desa Mare Kofo dan Mare Gam di Pulau Mare, Provinsi Maluku Utara yang terdiri dari ketua RT/RW dan pemangku kepentingan setempat sebagai object dalam riset ini. Metode kualitatif dan kuantitatif digunakan untuk menginvestigasi tingkat adaptasi masyarakat. Analisis data dilakukan melalui tahap pengumpulan data sekunder skala kota, pengamatan lapangan dan wawancara. Hasil penelitian menunjukkan bahwa masyarakat Pulau Mare telah melakukan adaptasi dalam memenuhi kebutuhan air bersih dengan menggunakan sumur bor komunal yang dikelola oleh pemerintah desa setempat dan teknologi pemanenan air hujan. Diperoleh pula bahwa potensi maksimal hasil tangkapan air hujan pada hunian terkecil dengan luasan atap rumah 42 m² adalah sebesar 56.915 liter per tahun, atau setara dengan 65% dari kebutuhan air bersih domestik.

INFORMASI ARTIKEL

Article history:
Received 17 October 2021
Accepted 24 December 2021
Published 31 January 2022

Kata kunci:
Clean Water
Coastal Community
Technology Assessment
Adaptation
Small Islands

ABSTRACT

Providing access to clean water for the community is the 6th goal of 17 sustainable development goals (SDGs). The SDGs are based on economic, social, and environmental pillars that are strengthened by the role of technology. Coastal areas and small islands have relatively more significant challenges amid climate change issues in meeting the availability of clean water. This research aims to develop an appropriate technology application model through analyses on community adaptation in fulfilling access to clean water. The research objects were the village communities of Mare Kofo and Mare Gam on Mare Island in North Maluku Province, which consisted of local wards and local stakeholders. Qualitative and quantitative methods were applied to investigate the level of community adaptation. Data analysis was carried out through the stages of collecting secondary city-scale data, field observations, and interviews. This study indicates that the people of Mare Island have adapted to meet their clean water needs by using communal drilled wells managed by the local village government and rainwater harvesting technology. It was also found that the maximum potential for rainwater catchment in the smallest dwelling with a roof area of 42 m² is 56,915 liters per year, or equivalent to 65% of domestic clean water needs.

1. INTRODUCTION

1.1 Background

Climate change is a serious issue that has become a global concern over the decades. The phenomenon of climate change and its derivatives has been spotted and reported by various countries, (IPCC, 2014). Climate change specifically harms the hydrological aspect. Many researchers argue that climate change affects the availability of water sources in the form of melting glaciers, floods, droughts, to the impact on the agricultural irrigation sector (Arnell et al., 2004; Kundzewicz et al., 2008; Jaswal et al., 2015; Singh et al., 2016; Uggupta et al., 2015; Wang et al., 2014). Several studies in Indonesia also show that the problem of clean water is closely related to climate change (Rachmawati et al., 2015; Marganingrum & Sudrajat, 2018).

One of the critical issues regarding clean water is the provision of water for communities on small islands. Schwerdtner et al. (2012) found that water problems in small islands in Indonesia are triggered by the geographical aspect of small islands and exacerbated by changes in rainfall. Archipelago communities tend to be isolated and have different characters from mainland communities (Gheuens et al., 2019). They make it a big challenge when there are problems in fulfilling clean water. Communities in small islands are forced to make various adaptation efforts to meet their water needs.

The United Nations in 2015 adopted the Sustainable Development Goals (SDGs) as a common goal to tackle hunger, protect the environment and sustain the world for a prosperous society by 2030 (United Nations, 2015). The SDGs have 17 goals: the sixth goal on Clean Water and Sanitation. Weststrate, (2019) states that the SDGs are a continuation of the Millennium Development Goals (MDGs), which in this context must ensure that the fulfillment of water needs includes water quality, affordability, availability, and accessibility. Formerly, MDGs was introduced in 2000 by the UN as a global collaborative platform to alleviate crisis on human capital, infrastructure, and human rights (Liverman, 2018).

Indonesia has adopted the sixth goal of the SDGs in its Medium-Term Development Plan (RPJMN) 2020–2024 in the housing sector, one of which is an indicator that states 100% access to safe drinking water from protected sources. The government has made various efforts to support the achievement of SDGs targets, both in the form of public services through the Ministry of Public Works and Housing's (PUPR) Program, and business schemes water provision through Regional-Owned Enterprise (BUMD). However, not all communities have access to clean water, especially island communities. Previous research (Azhoni et al., 2018) found that a combination of bottom-up and top-down approaches in climate change adaptation actions in the clean water sector is needed to strengthen institutional aspects in various conditions.

1.2 Objectives

The aim of this study is to determine the form of adaptation of clean water fulfillment by small island communities in Indonesia. It is crucial to apply clean water

treatment technology to be sustainable following local capabilities and local conditions. The suitability of the application of technology and the design of community institutions greatly influences the sustainability of the community's clean water supply system.

2. METHODS

2.1 Location

This study was located at Mare Island, Tidore Islands, North Maluku Province, as shown in Figure 1. This study was a part of the promotion of Sea Water Reverse Osmosis (SWRO) membrane technology by one of the membrane manufacturers from Japan in 2019. The selection of the location provides insight into the forms of adaptation carried out by a small island in eastern Indonesia. Based on Central Bureau of Statistic (BPS) data in 2020, the population of Mare Island is 910 inhabitants, consisted of 488 inhabitants of Marekofo and 422 inhabitants of Maregam



Figure 1. Mare Island, North Maluku (Google Map, 2021)

2.2 Data Collection and Analysis

The data collection method was done using two approaches, namely secondary data collection at the macro level and in-depth interviews with the people of Mare Island. They cover village officials, RT/RW, and local stakeholders who know about clean water problems. The analysis was carried out with a combination of qualitative and quantitative approaches. The process of identifying local problems was assessed using a Deductive Theory approach (Bitektine, 2007), which aims to extract information from the process of social life. Exploration of various efforts to meet the need for clean water aims to provide an understanding of the community's ability to adapt to the existence of resources in the era of climate change, (Bateman et al., 2002; Calderon et al., 2012; Pinem et al., 2016). Meeting the water needs of the rainwater harvesting process is carried out using an annual rain catch potential approach, as published by the Regional District of Nanaimo, Canada (2012) regarding household-scale rainwater harvesting guidelines, (Heryani et al., 2013; Ali et al., 2017) the formulation is shown in Equation 1:

$$Vh = C \times th \times A \dots \dots \dots (1)$$

Where;

Vh : volume of rainwater that can be harvested (liters)

C : run-off coefficient

th : annual precipitation (mm),

A : cross-sectional area of the roof/rain catcher building (m²),

The run-off coefficient is a value that describes the surface's ability to drain water. The use of run-off coefficients can be used in large-scale watershed applications (Meijerink, 1970; Miardini & Susanti, 2016). The run-off coefficient refers to (Suripin, 2003), can also be applied in small scale areas, as shown in Table 1.

Table 1. Run-off coefficient

No	Land use	Run-off Coefficient	No	Land use	Run-off Coefficient
1	Business		7	Lawns, Heavy Soil	
a.	CBD/ downtown	0.7–0.95	a.	Flat 2%	0.13–0.17
b.	Sub-urban/ neighborhood	0.5–0.7	b.	Average 2–7%	0.18–0.22
			c.	Steep >7%	0.25–0.35
2	Housing		8	Lawns, Sandy Soil	
a.	Detached Home	0.3–0.5	a.	Flat 2%	0.05–0.1
b.	Housing compound, detached	0.4–0.6	b.	Average 2–7%	0.1–0.15
c.	Housing compound, attached	0.6–0.75	c.	Steep >7%	0.15–0.2
d.	Kampong	0.25–0.4			
e.	Apartment	0.5–0.7			
3	Industrial Area		9	Playgrounds	0.2–0.35
a.	Light Industry	0.5–0.8			
b.	Heavy Industry	0.6–0.9			
4	Pavement		10	Park, Cemeteries	0.1–0.25
a.	Asphalt and Concrete	0.7–0.95			
b.	Bricks, paving	0.5–0.7			
5	Roofs	0.75–0.95	11	Forest, woodland	
				Flat 0–5%	0.1–0.4
				Average 5–10%	0.25–0.5
6	Train station area, railways	0.1–0.35		Steep 10–20%	0.3–0.6

3. RESULT AND DISCUSSION

3.1 Indonesia SDGs target and achievement

The SDGs are inseparable from the MDGs; they were introduced since 2002, and many countries have adopted the concept. The MDGs have eight goals with the topic of clean water and sanitation, including the seventh target. The importance of the water and sanitation sector is based on the paradigm that achieving clean water and proper sanitation targets is the primary fundamental of disease avoidance, (Weststrate et al., 2018). The achievement of MDGs in the water and sanitation sector in 2012 has reached 90% compared to 1990 which only reached 76% worldwide (WHO, 2018). Furthermore, the SDGs accommodate the water and sanitation sector in the sixth goal. There are differences in the substance of the SDGs and MDGs for the water and sanitation sector. Weststrate et al., (2018) found that the MDGs tend to focus on increasing access to adequate water and sanitation but are not in-depth in determining related indicators. However, SDGs goal six is considered not to focus too much on the political and policy aspects related to increasing access to water and sanitation.

In Indonesia, Bappenas (2019) and BPS (2020) reported that the achievement of the SDGs target for households with access to adequate drinking water sources has reached 90.2%. During 2015–2020. the percentage of households with access

to adequate drinking water sources continued to increase from 84.95% in 2015 to 90.2% in 2020. Details of achievements over five years are shown in the Figure 2.

During these five years, the percentage of access to clean water and sanitation increased by 5.25% and average growth of 1.05% per year. Compared with the timeline for meeting the SDGs targets until 2030. Indonesia has achieved about one-third of the total target in the last five years. In the next decade, Indonesia still has to meet the remaining 9.8% of the target set.

The challenge in achieving access to water and proper sanitation for the community is the declining environmental quality due to pollution and increasing human needs. Ministry of Environment and Forestry (2021) reports that Indonesia's Water Quality Index (IKA) 2020 has increased by 0.91 points to 53.53 compared to 2019. Although IKA has increased, it has not met the RPJMN target of 55.1 point. It indicates that there are still contamination cases in water sources. Another condition shows that many Indonesians who meet their drinking water needs come from unsustainable sources, such as refilled water or bottled water (explained later). One of the criteria of the SDGs regarding access to adequate drinking water is that it can be accessed at any time and meets the established health standards.

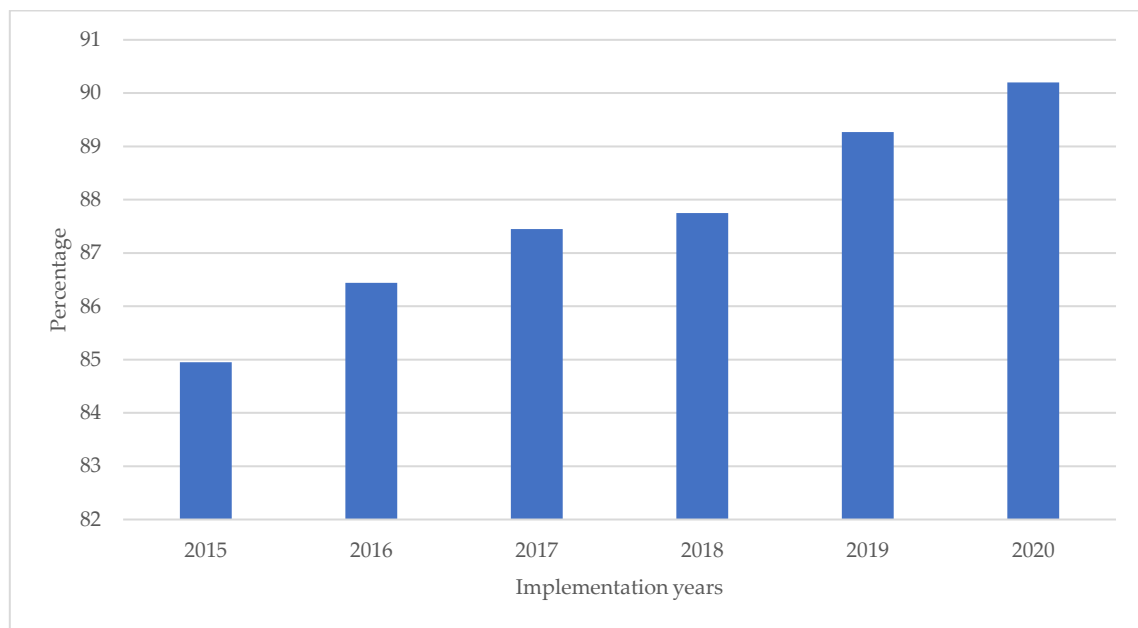


Figure 2. The achievement of Indonesia SDGs target #6

3.2 Water provision for the communities

In general, Indonesia's clean water supply model includes various options: refill water, protected wells, unprotected wells, deep wells, piped water, bottled water, protected springs, unprotected springs, rainwater harvesting, surface water, and water terminals. The Ministry of Health (2020) noted that the fulfillment of drinking water for the Indonesian people was dominated by refilled water by 31%, while the minor portion was water terminals at 0.3%. The existence of a clean water pipeline system is still relatively low, at 13.1%. This figure is lower than the combined use of wells, both protected and deep wells, totaling 30%. Details of the distribution of clean water for the community are shown in Table 2.

Table 2. Clean Water Provision by Source in Indonesia

No	Drinking Water Source	Percentage
1	Refill Water	31.1
2	Protected Well	15.9
3	Deep Well	14.1
4	Tap water/ Pipe	13.1
5	Bottled water	10.7
6	Protected Spring	4.2
7	Unprotected Well	3.8
8	Unprotected Spring	2.5
9	Rain Harvesting	2.3
10	Retailing System	1.4
11	Surface Water	0.6
12	Water Terminal	0.3

Source: Ministry of Health (2020)

Of the 13.1% of clean water piping services in Indonesia, most drinking water companies are managed by BUMD (regional-owned enterprise) at 55.5%, BUMDES (village-owned enterprise) at 10.8%, and SOEs at 10.5%. The existence of regional-owned drinking water company (PDAM) as a provider of clean water is inseparable from Law Number 5 of 1962 on Regional Companies and Minister of Home Affairs Regulation Number 7 of 1998 on the Management of Regional

Drinking Water Companies. Based on these regulations, PDAM is a Regional Government-Owned Company which is engaged in drinking water services. In fact, up to five years of implementing the SDGs in Indonesia, the role of PDAMs has not been able to reach all levels of society maximally. PDAM is considered still focused on business efforts in urban areas and has not provided access to clean water to people in remote areas. Hadipuro (2010) has highlighted the phenomenon of PDAM's dual function as a business entity and the function of government social services to the community. The PDAM, as a public company, carries out the task of providing social services in the field of clean water. However, on the other hand, it is allowed to benefit, as stated in the Minister of Home Affairs Regulation Number 23 of 2006 on Technical Guidelines and Procedures for Setting Drinking Water Tariffs at Regional Drinking Water Companies. Another study conducted by Haekal & Tiningsih (2020) in Depok, Indonesia, found that PDAMs run their operations based on government regulations and are audited regularly by the Agency for the Improvement of Drinking Water Supply System Implementation (BPPSPAM). Technical and financial performance are two different things, which allows for good financial performance conditions but without improvements in technical performance, such as customer growth or water consumption efficiency. This situation explains the conditions of financial performance does not always reflect the service coverage, as illustrated in Table 3

Table 3. Clean water provision in Indonesia by operator

No	Operator	Percentage
1	State Owned Enterprises	10.5
2	Regional-owned Enterprises	55.5
3	Village-owned Enterprises	10.8
4	Technical Management Unit	1.7
5	Building Operator	3.9
6	Other Management Groups	17.5

Source: Ministry of Health (2020)

3.3 Community adaptation for water provision in Mare Island

The forms of adaptation in the coastal communities in meeting the needs of clean water are very diverse; social character and community participation strongly influence. Some scholars (Ari et al., 2013; Maulidatuz et al., 2016) found that the level of community participation and social capital correlated with the sustainability of community organizations providing clean water. Adaptation measures and social capital have often correlated each other. Social organization within the communities plays significant influences in water management system. Mare Island has solid social characteristics; many social organizations consist of the fisheries/marine sector, pottery artisans, and communal clean water managers in collaboration with the local village government. Another study by Tawari et al. (2020) found also that the presence of informal organizations in North Maluku run the informal norms and should be actively involved by the government for the sake of more effective resources management. Based on the survey results in Mare Island, it found that the geographical characteristics of the island and the social community, as shown in Table 4.

Table 4. Attribution of Mare Island, Maluku Utara Province

Attributes	Mare Island	Note
Area (km ²)	6.03	
Population (2017)	910	
Density per km	151	
Distance to Prov Capital (km)	24.5	
Distance to Nat Capital (km)	2,401	
Source of clean water	Deep Well	
Cost (per m ³)	-	Free, voluntary cost Rp. 15,000
Capacity L	5,000	Reservoir
Customer (households)	275	
Management	Village water management bodies	The members cover both government and social entities
Alternative source of Clean Water	Rain Harvesting, Springs, others	
Cost	-	Free, done by each household
Institutional Body for Water Management	Yes, Community	
Key Aspects of Water Needs	Availability, Sustainability, Hygienic.	Obtained from
Key Aspects of the Proposed Water Treatment Technology	Performance, Ease in Operation, Maintenance, Alternative Energy.	interview activities

The PDAM of Tidore Islands is still focusing its activities on improving services in the mainland/city. Water supply in small islands depends on programs from the central government or non-governmental organizations. Several ministries related to the small island water supply program, namely the Ministry of Public Works and Housing, the Ministry of Maritime Affairs and Fisheries, and the Ministry of Villages, Development of Disadvantaged Regions and Transmigration. The fulfillment of clean water for Mare Kofo Village and Mare Gam Village relies on drilled wells located in each village.

Mare Kofe and Mare Gam villages only get its main power supply from the state electric company (PLN) between 18:00–24:00, the rest use generators or another lighting independently. This condition worsened by each village having only one deep well as a source of clean water. Water from the well is pumped into a reservoir, then distributed to people's homes by a piping system. In Mare Gam, the cost of clean water is set at Rp. 15,000 per month, which is used to buy generator fuel. Meanwhile, in Mare Kofo, the community can use clean water for free because the management fee comes from village funds. There are no drinking water filling stations on the island. Some people who use gallon water have to buy it by crossing to Tidore Island at approximately Rp. 10,000 per gallon. The distance from Mare Island to Tomolou Tidore Harbor using a fishing motorboat is about 60–90 minutes.

The existing communal wells are powered with generator sets and provided with 5000 L water tank capacity at each. Assumed that the operation of communal wells are three times a day, therefore the distributed water to the community is around 15,000 L. Referring to national standard, SNI 6728.1:2015, the daily domestic water requirement in rural Indonesia per capita is 60 L/day. Therefore, the three times operation of communal wells is only sufficient to meet 52% of daily domestic needs. The challenges in operating the communal wells in remote area is the availability of power source. For a such time of operations, the availability of power in the daytime to operate the communal wells is unavailable. Additional operating time more than three times a day will implies to the additional cost for fuels, thus it might burden the community funds. Beyond this water sources, the community have to find alternative water sources such as springs, private wells or even buying from other places.

One of the noticeable forms of adaptation, residents also rely on rainwater stored in temporary shelters using buckets and water barrels. Community who has difficulty in accessing clean water prefer to take this kind of measures. Harsoyo (2010) categorizes rainwater harvesting measures into two ways: harvesting from roofs and harvesting using water structures. Rainwater harvesting from the roof is used on an individual scale, while water structures are used for communal or watershed areas. In their study, Ali et al. (2017) also recommends that rain harvesting be used directly for non-potable purposes. If the harvested water is used for consumption purposes, then, of course, it must go through further processing

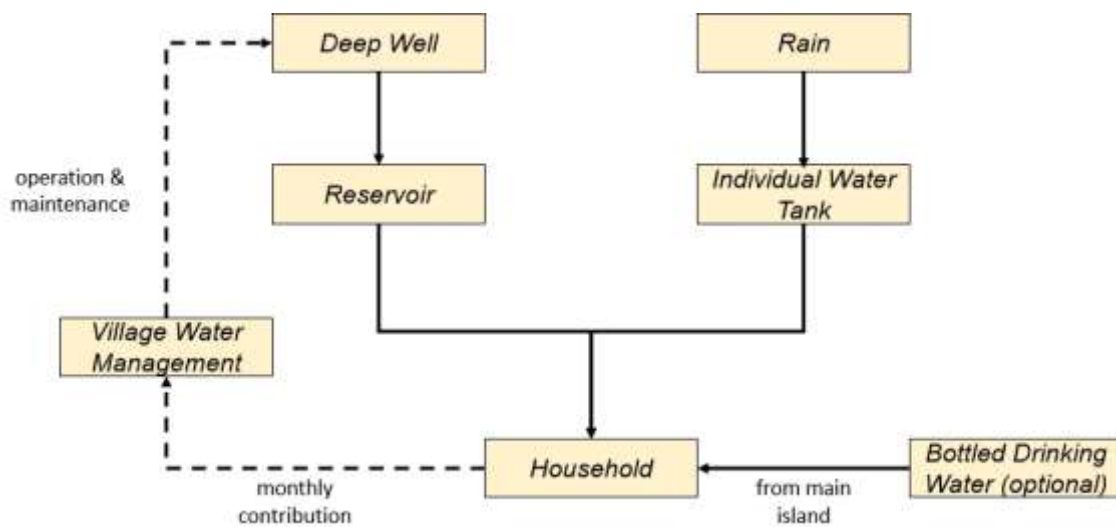


Figure 3. Clean water provision model in Mare Island

Based on the total rainfall data from six weather stations, the average rainfall in 2019 in the Tidore Islands was 1,771.42 mm³/year, as shown in Table 5. As an illustration, the observations show that the average size of a small house on Mare Island is 7x6 m = 42 m², the type of roof used is

galvanized (C 0.9), so the potential for harvesting rainwater that can be obtained in one year is based on equation (1), is 66,959 L/year. The simple storage method using barrels and buckets is assumed to result in a water loss of 15% so that the potential net volume of water stored for one year is 56,915 L.

Table 5. Annual Rainfalls

No	Month	Rainfalls in each weather stations (mm)						Average (mm)
		Dowora	Ome	Akekolano	Akelamo	Payahe	Wama	
1	January	197	219	192	137	164	62	161.83
2	February	34	38	52	78	215	45	76.92
3	March	41	50	26	93	147	9	60.92
4	April	180	273	356	242	236	32	219.83
5	May	179	297	232	232	152	37	188.17
6	June	257	382	261	626	292	149	327.83
7	July	184	257	200	513	419	221	298.92
8	August	50	108	68	102	189	106	103.83
9	September	25	55	45	26	85	33	44.83
10	October	232	243	228	250	248	113	219.00
11	November	0	1	3	1	2	7	2.25
12	December	125	68	93	39	72	6	67.08
Annual		1,503.5	1,991.0	1,756.0	2,339.0	2,219.0	820.0	1,771.42

Referring to SNI 6728.1:2015 and assumed number of family members in a household is four people, so in one day, each household needs 240 L of water for domestic needs. It means that the potential 56,915 L/year of rainwater harvesting can meet a maximum of 65% of clean water needs for domestic needs in one year. Regardless to the potential, not everyone harvests rainwater; even if so, not all water can be stored continuously due to limited storage units.

3.4 Alternative Technology Intervention

The use of communal wells and rainwater harvesting to meet drinking water needs in the long term will be vulnerable to climate change. Seawater intrusion and changes in rain patterns are common problems in small islands, (Haque et al., 2016; Purnama, 2019). Pearce et al. (2018) found that water vulnerability is not only affect physical health, but also mental health and physiological sense for family welfare. The scarcity may give more mental pressure to the family. The time spend to collect water may also reduce family quality time.

Seawater intrusion in coastal areas can be seen from changes in taste, pH, electrical conductivity (EC), and total dissolved solids (TDS). The same thing can happen to Mare Island in the future. Alternative studies and applications of appropriate technology are needed to ensure the fulfillment of drinking water in the future. Some of the critical information obtained in Table 4 shows that the community wants a guarantee of sufficient water availability and is supported by reliable technology that uses alternative energy sources. The facts that the condition of the islands is experiencing a crisis in electricity. Based on the characteristics of coastal areas and small islands, one of the possible alternatives is Sea Water Reverse Osmosis technology equipped with solar cells.

Laboratory tests were carried out to assess the condition of seawater on Mare Island, as shown in Table 6. This laboratory test was carried out to explore the basic parameters adjusted to the specifications of the prototype membrane by Toyobo Engineering. Other studies scholars (Al-Wazzan et al., 2002; Jaber 2004; Greenlee et al., 2009; Lapuente, 2012)

found that the characteristics of seawater that use similar technology might vary, as shown in Table 7.

Table 6. Seawater parameters on Mare Island

Parameter	Unit	Concentration
Mo Alkalinity	mg/L	123
Chloride	mg/L	20,592
Calium	mg/L	311
TDS	mg/L	32,800
Conductivity	umhos/cm	52,000
COD	mg/L	23
Magnesium	mg/L	1,412
TSS	mg/L	<2
Sodium	mg/L	11,486
pH		8
Sulphate	mg/L	2,819
TOC	mg/L	5.4

Table 7. Variations of seawater parameters condition

Parameter	Unit	Concentration
Calcium	mg/L	410–693
Magnesium	mg/L	303–1,550
barium	mg/L	0.01–0.05
Strontium	mg/L	5–13
Boron	mg/L	4–5.3
Sodium	mg/L	2,462–12,000
Chloride	mg/L	70–23,000
Kalium	mg/L	39–390
Iron	mg/L	<0.02–0.05
Manganese	mg/L	<0.01–0.05
Silica	mg/L	0.04–8
Sulphate	mg/L	2,400–3,016
Bromine	mg/L	65
Fluoride	mg/L	1.4–2.15
Bicarbonate	mg/L	120–152
Nitrate	mg/L	35–50
pH	pH	+/- 8

With these parameters, the seawater condition on Mare Island is more or less the same quality as in other places. However, to ensure the SWRO treatment system works well, it is necessary to have pre and post treatment facilities. Valavala et al. (2011), Shahabi et al. (2015), Hanna (2016) stated that desalination technology using RO has a high tendency for fouling to occur, so processing facilities are needed to ensure the quality of feed water. Therefore, adequate pre and post treatment are recommended to the system.

4. CONCLUSION

Over the past six years, the index of households with access to safe drinking water has increased. In 2020, 90.2% of households had a good source of drinking water. However, most of the fulfillment of drinking water sources is still relies on unsustainable sources, refill water and bottled water. The fulfillment of clean water needs in Mare Island shows that the fulfillment of clean water for household needs is carried out in two approaches, namely communally using communal wells and harvesting rainwater. The potential of rainwater harvesting at the individual level can meet a maximum of 65% of domestic water needs in one year. However, all stakeholders should consider on the potential and threats of

climate change, especially those related to sea-level rise and changes in wet and dry months that impact efforts to fulfill clean water. Seawater desalination system operated by solar power and equipped remote monitoring system can be the best option for the disadvantages region in Indonesia that are suffering from a shortage of electricity energy and drinking water, especially in the coastal areas.

ACKNOWLEDGEMENT

The authors would like to thank you the Toyobo Engineering for the grants, and the Ministry of Village, Development of Disadvantaged Regions and Transmigration of Republic Indonesia for the guidelines so we can conduct the study.

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