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The feasibility of investment installation using SWRO in Seribu Island, Indonesia

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ABSTRACT

Population balance and water availability need to be considered. Indonesia as an agrarian country has abundant marine resource wealth. This condition makes Indonesia a center for marine tourism. The purpose of this research was to analyze water management in Seribu islands as national and foreign marine tourism which are then considered in the provision of sustainable clean water. This research method used descriptive ecological analysis which refers to the literature and data sourced from the amount of groundwater availability based on rainfall, evapotranspiration, and dry length. Secondary data collected in this study include statistics and monographs of the study area, climatological meteorological data in the form of rainfall, dry months, and air temperature is taken throughout 2019. The results showed that the water quality in the Seribu Islands deteriorated when the dry season arrived and when excessive groundwater extraction occurred. In addition, efforts to develop water management in the Seribu Islands are unplanned and sustainable while the population continues to increase. The growth of homestays, the number of tourists, public facilities such as hospitals, schools, and dormitories triggered the conversion of planting land. Pramuka Island has an unplanned harbor development which has an impact on water resources. Management and planning for the development of Reverse Osmosis Seawater (SWRO) in the Seribu Islands need to be reconsidered for the supply and management of resources also for the water conservation activities that have not been effective.

Conflict of interest: The authors declare that they have no conflicts of interest.

Introduction

Indonesia is the second largest number of islands in the world after Canada, with 13.466 islands (Geospatial Information Agency, 2013)[1] with mostly tens of thousands of small islands. According to UNESCO (1991) and Indonesian Constitution No. 27 (2007), a small island defines as an area equal to or less than 2000 square kilometers with all its economic unity. The definition also includes very small islands as the term attached to an island whose surface area does not more than 100 km^2 or the width does not exceed 3 kilometers and where the water scarcity is even severe and surface water deposits are mostly absent[2].

The coastal area and small islands are part of the natural source which needs to be preserved in its sustainability and utilized for the maximum prosperity of current as well as future generations[3-5]. Christianto also take the conclusion that the law (Indonesian Constitution No 27, 2007) is concerned with the fact that small island has biodiversity potential and are hence significant for social, economic, and environmental development and also, geographically, as the backbone of national sovereignty[6]. The growth and development of the small and very small island, from the hydrological perspective, is often constrained by the need for more water resource availability. This is caused by the small area of rainfall water catchment and groundwater deposit[7]. The freshwater deposit depends on the infiltration rate, the width of the island, the islands physiography (high or low topography) and geology (the type of rock or soil), vegetation cover, climate, also the sea current as well as the tidal wave around the island. Groundwater lense in small and very small islands[8,9].

The infiltration rate is determined by the climate, which influences the availability and the high of the water table. The quantity of rainfall and its variation, also evapotranspiration, plays an essential role in water resource quality and availability. The small island is classified into high and low topography. High islands have steeper land and soft permeability bedrock since they are volcanic islands thus the runoff and surface management contribute to the water balance. On the other hand, low islands have a flat surface with moderate to high permeability soils and rocks resulting in a minimum of surface runoff, and groundwater as the main component of water balance is abundant. But in small island cases, very high permeability causes the mixing of salt water from the ocean with the freshwater resulting in brackish groundwater[10,11].

The type and density of vegetation in small islands also contribute to the hydrological cycle. Trees, bushes, and grass normally adapt to the local climate[12] and do not require irrigation. They slow the surface runoff and erosion (sediment) in high islands, and recharge thus the infiltration rate can be increased, and drought hazards can be avoided. Falkland also finds that small and tiny islands have the potential hazard caused by saltwater intrusion into the groundwater and the impact of climate change[13]. If the driving development is for tourism, we need to pay attention that it will give pressure on the environment, especially the drop in groundwater quality, decrease in coastal flora and fauna populations, economic and aesthetic values, and accelerate the disaster occurrence. Therefore, the small island development as a tourist spot needs to be concern with sustainable water management.

The development of small and tiny tropical islands with a dense population in Seribu Islands, Indonesia, is often constrained by a fragile ecosystem with insufficient water resources. The nature of small islands that it has only a small catchment areas and groundwater storage[14,15], the fact that the salt water can intrude the aquifers[16], and the fact that the damage of climate change may affect directly its sustainability, make the management of water resources very complicated. Therefore, it needs the development of additional unconventional water resources, e.g. Sea Water Reverse Osmosis (SWRO), water barge and transportation. However, the question of whether this unconventional approach is able to deal sustainably with the demand and make society better off has fostered an interesting debate. The establishment of those unconventional water sources especially Sea Water Reverse Osmosis (SWRO) in Seribu Islands

will bring more harm than good for several reasons such as making the environmental awareness of the society decreased; unstable water supply; and that there is another priority to be concerned which will later be elaborated in this research.

Environmental conservation efforts that focus on conserving water for sustainable management play a very important role. Indonesia as an archipelagic country with a large population has a huge obligation to preserve water. Water is one of the determining factors in the elements of human life. Therefore, the implementation of sustainable water management is a multi-prerequisite to be implemented in Indonesia. Specifically in Indonesia, the development of small islands which are central to the island has not yet shown a focus on water management[17]. Island development in Indonesia is limited to the development of tourist objects without being accompanied by sustainable environmental management. The Seribu Islands is one of the districts consisting of small islands in it with a very dense population. Environmental conditions in the Seribu Islands are limited by fragile ecosystem conditions with insufficient water resources. The nature of the small islands in the Seribu Islands has only a small catchment area and groundwater storage. Thus, management of clean water management is needed accordingly.

The fact that Seribu Islands have high levels of salt water which can disturb aquifer water so clean water management is needed for its sustainability. Water resources management techniques are very complicated, requiring the development of additional non-conventional water resources, such as Sea Water Reverse Osmosis (SWRO), water transportation, and transportation. However, this unconventional approach is not the best solution for citizens in tackling the availability of clean water. The reason for this being an important point is that the establishment of unconventional water sources, especially Sea Water Reverse Osmosis (SWRO) in the Seribu Islands, will have a detrimental impact such as making public environmental awareness reduced; unstable water supply; and that there are other priorities to be considered which will be elaborated in this study.

Pramuka Island is one of the most important islands in the Seribu Islands district. As the capital city of the Pramuka Island district has a high level of population density, marine tourism visits from tourists also become a factor of population density. Pramuka Island was chosen because of its role as the capital of the district where all administrative buildings and infrastructure are built. Pramuka Island has the facilities of the Untung Jawa National Research and Development Agency as the most significant number of visitors per month (47,000 visitors)[18].

The previous studies Raharjo, show that Pramuka Island has a tendency to experience the threat of drowning, this is affected by climate change and global warming which results in rising sea levels, which can reduce coastlines and abrasion[19]. This condition forces inhabitants to meet the need for clean water sourced from groundwater, this condition has the potential to decrease land subsidence which leads to the sinking of Pramuka Island. Basically, Pramuka Island is oriented as a stopover (accommodation) for tourism in the surrounding islands[20]. This condition makes it possible to produce domestic waste[21]. Several facilities and infrastructure are needed such as rain harvesting to increase rainwater recharge by making infiltration wells, making clean water installations by making desalination, making waste and waste processing, and making groundwater usage rules in the small island region[22-24]. The real condition on Pramuka Island has been informing that the behavior of the community has not shown any effort on the behavior of carrying out an eco-conservation of the clean water cycle on Pramuka Island. The condition of the people of Pramukan Island represents the overall situation of water supply, water management strategies; how the community adapts to water scarcity, and efforts to implement solutions successfully, and need to be prioritized.

Therefore, according to the problems this study aims to analyze water management in the Seribu Islands as a national and foreign marine tourism which are then considered in the provision of sustainable clean water.

Method

Study area

The research was conducted in Kepulauan Seribu Regency, Special Capital Region of Jakarta, Indonesia from March to May 2019 with temperatures ranging from 21°C - 32°C with an average humidity of 80%. The research area includes the islands in the Gulf Jakarta is geographically located at 5°24´ - 5°45´ latitude and 106°25´ - 106°40´ east longitude.

Field sampling

Seribu Islands Regency has eleven islands, consisting of Coconut Island, Kelapa Dua Island, Panggang Island, Harapan Island, Pramuka Island, Tidung Island, Besar Island, Payung Besar Island, Pari Island, Untung Jawa Island, Lancong Besar Island and Sebira Island. The islands inhabited by many residents are Coconut Island, Panggang Island, and Pramuka Island. Pramuka Island is the Capital of the Seribu Islands Regency. This island has a high population density with the highest number of tourist visits throughout the year. Therefore, the research sample of environmental management for water management in the Seribu Islands, Indonesia is Pramuka Island.

Data analysis

Data analysis was conducted through quantitative by descriptive ecological methods referring to literature and field data through observation (obtaining data), interviews (knowing population and tourist visits in the study area in relation to the needs and use of clean water), mapping of land and water sources (so that obtain data management of water management that has been done and soil properties including soil texture, soil acidity (pH), soil drainage and salinity), as well as documentation (in the form of notes, transcripts, books, newspapers, magazines, inscriptions, field notes, lengger, and agenda[25]. Secondary data collected in this study include statistics and monographs of the study area, climatological meteorological data in the form of average rainfall, number of dry months, and air temperatures taken from January to December 2019. Descriptive research with an ecological approach in This research is describing, analyzing, and providing information about the quality and quality characteristics itas water in the Seribu Islands. Descriptive analysis is used to analyze the status and techniques of sustainable water management sourced from groundwater availability data based on rainfall, evapotranspiration, and dry length. All data obtained were analyzed and supported using meta-analysis techniques sourced from articles. The data processing steps used in the study was presented in Fig 1.

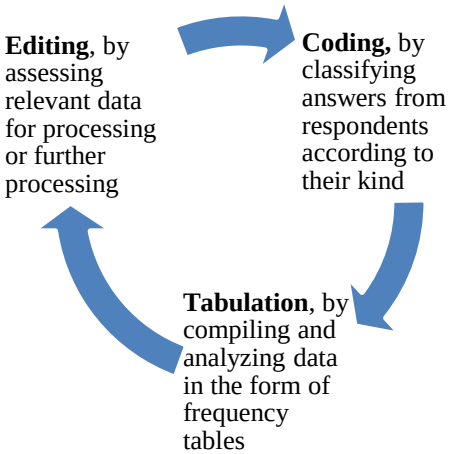

Fig 1. The step of data processing[26]

Results and Discussion

The Seribu islands are the chain islands located on the northern coast of Jakarta, consisting f 108 islands stretching 45 km north to the Java Sea. Estradivari et al. describe Only 13 islands

are fully developed; 11 islands are homes to resorts and two islands are historic parks[27]. The 23 are privately owned and are not open to the public. The rest of the islands are either uninhabited or support a fishing village" (2016).

The island chains are coral atoll groups that developed in the Pleistocene ages before the sinking of the Sunda shelf[28,29]. Seribu islands as the part of Java Sea has different depth from 7- 75m and are surrounded by shallow lagoons with a moderate permeability layer of limestone bedrock. According to Estradivari et al., monthly rainfall in the Seribu Islands is recorded on average at 142.54 mm with the lowest rainfall in June (0 mm) and the highest in September (307 mm)[27]. The month fluctuation of temperature and average salinity follow the fluctuation of the warm Java Sea[30,31]. Thus, it provides the full life variety of stony coral as well as other marine organism. That combination has a high aesthetic value which supports coral reef tourism and recreation.

Estradivari, et al. report that "An area of 107.489 hectares of land and sea was declared by the Minister of Agriculture in 1982 and designated by a Forestry Ministerial Decree in 2002 as the Taman Nasional Laut Kepulauan Seribu (Thousand Islands Marine National Park)[27]. Public access is prohibited on two of the islands, Panjaliran Barat and Panjaliran Timur, where sea turtles are conserved". The beauty is accompanied by its location close to the capital (less than 50 km) making the aesthetic value so meaningful and advantageous. This is proven by the development of the significant marine tourism industry in this region. People also value the Seribu islands as an important area of the fishery and another food resource for local people and even Jakarta citizens as the big capital city. This can understand because as the West Monsoon wind blew, the sea stream with low salinity came from the South China Sea and then flew to the east. The rainy season is lowering the salinity of the stream that came from Sumatra Island and Sunda Strait which will meet at the northern side of Seribu Islands. This two stream mixing is thought to be the cause of the number of fish in the waters of the Seribu Islands[32]. Furthermore, the coral-reef ecosystem became even more essential for knowledge development since it is located not far from leading national universities (*Universitas Indonesia, Institut Pertanian Bogor, and Institut Teknologi Bandung*). To encourage eco-tourism (knowledge-based), the LIPI Oceanology Research Station (National Research and Development Agency) was built on Pari island, 12 km away from Pramuka island. Visitors of that facilitation can study mangroves, coral reefs, and seagrass ecosystems.

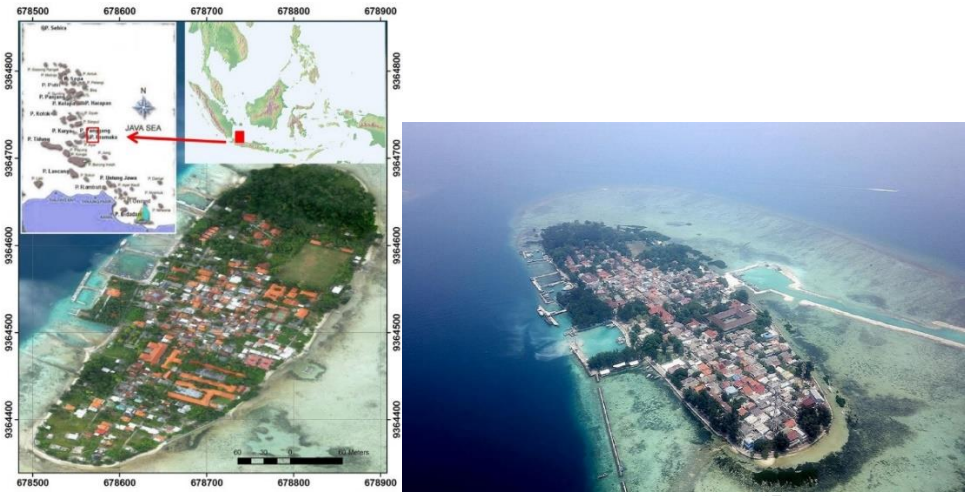

Fig 2. The Pramuka island and current situation[17]

The adaptation behavior emerges because of the interaction of human with their environment resulting in the feedback relationship which often creates the shape of the unique culture in the society[33]. This culture continues to develop and change to adjust to the

environmental condition[34]. This interaction of humans and nature is also accelerated if both are taken place in vulnerable areas because instinctively humans will respond to their natural condition with the form of particular adaptation[33].

Cahyadi, et al. in their research information that previously, the adaptation form of Seribu Islanders toward the scarce water resource, especially on Pramuka island is toward rainfall harvesting by collecting the rainwater from their house roof[35]. This harvesting is used by every house on Pramuka island (Fig 2). However, only some houses maintain to have this system in their home nowadays. This is happening since the introduction of Reverse Osmosis technology established by the government four to five years ago. Besides, this particular adaptation starts to become unpopular since the big amount of bottled water was being transported using small ferry boats from Jakarta.

The study concludes that the Pramuka island people tend to choose the SWRO water and bottled product because it is easier for them to get as more transportation traffic from Jakarta and they assume that the quality of the groundwater on the island is not as good as previous condition[35]. The groundwater in most area of the island is becoming brackish because of seawater intrusion[36]. It reveals that geologically Pramuka island has medium to high soil permeability which affects the rainfall water can easily infiltrate. The quality of water even gets worse when the dry season comes and when the over-extraction of groundwater occurs. Added to the unsustainable development while the populations are continuously soaring. The growth of tourist homestays, and public facilities such as the hospital, schools, and dormitories for the student from another island, have triggered the conversion of vegetated land. Fig 3 showed that the change of land usage from 2004 to 2008. The development of building rate reaches 2.6% in that particular time[37].

Fig 3. The land usage in Pramuka island from 2004-2008[35]

This condition leads to the reduction of the catchment area. Moreover, an un-ecofriendly drainage system and watertight road network using solid material and side-road drainage cause the rainwater which falls from building's roof flows directly to the ocean (Fig 4). This means that rainfall is the main source of water that recharges the groundwater thrown away as it is useless.

Fig 4. Drainage system in Pramuka island, the surface runoff directly to the sea[36]

Pramuka island also suffer from un-well planned quay which again take effect on the water resource. The construction on at the west side of the island dredges the coastal area so that it has adequate depth for the ship to dock. This condition induces the seawater intrusion on the west side of the island which is now facing directly with the deep sea; making the intrusion level higher compared with the eastern side that is surrounded by the shallow flat reef[36]. The damage to the water quality of the island is mostly caused by poor wastewater and trash management. Formerly, there is a waste processing installation and also the operators. However, that infrastructure is now unfunctional. This circumstance generates garbage accumulation at the eastern part of the island. This lead to freshwater contamination where that area has a vulnerable geological material to contamination[35].

The cope with all the water source problems mentioned above, the local government came out with the idea of desalinating the seawater. This process of separation of water from salt to produce freshwater is offered because brackish or seawater is abundant. Recently, the plan to establish more Sea Water Reverse Osmosis (SWRO) plants has also become a political issue/maneuver. The local government intends to continue the project that previously proven failed in 2016 due to the un-responsible contractor. They allocate 93 billion rupiahs for eight new SWRO plants in the populated Seribu Islands this year.

Pramuka island has two installations[35] using reverse osmosis technology. One of it owned by the local government and another one is run by a private company. However, private SWRO is the only plant that operates because of the high-cost operation. The seawater salinity on small island shortens the useful age of its tool such as the membrane which can only be imported from a foreign nation. This circumstance became an obstacle for the government where the bureaucracy to request funding for maintenance usually takes a lot of time. Thus the government SWRO plant has not operated for quite some time because of the tool breakdown.

The SWRO plants in several islands are also un-functional because of the source of brackish water polluted by the high metal particle. Therefore, prior treatment is needed. Also, because of the distance, the underwater electricity cable from the mainland (Jakarta) for domestic use is unable to power the pump of the SWRO plant due to the low voltage. The energy requirements are high varying from 2.5 to 10KWh per cubic meter[38]. The same case also happens on Untung Jawa island[18], where the SWRO plant can not meet the demand of 2400 Islanders and 10.000 visitors every week because it only operates for 6 hours and just generates 50 cubic meters per day[39]. Ade further report that local the Islanders only use water from SWRO plan for watering domestic crops, washing clothes and kitchenware because the water still tastes bad[39]. “The islanders do not dare to drink the water because the total dissolved salinity (TDS) or solids content in SWRO processed water is still quite high (325mg/L), even though it meets Ministry of Health standards of 500mg/L they prefer bottled water which has only 70mg/L although they need to pay an extra price for that.” The availability of new technology created for the purpose to ease and improve the quality of human life sometimes generates the spillover effect. In this case, SWRO technology in Seribu islands, makes the islander feel they already contribute to the water plant perseverance by paying the price to get a better quality of fresh water. In Untung Jawa Island, for instance, for a gallon (19 liters) of SWRO freshwater, the islander only pays Rp. 2,000,- (US$ 20 cents)[18].

In the Seribu islands tourism business, tourists are not encouraged to safe, fresh water because the homestay owner already charges a certain price as the weekend-price package which is very cheap because they need to set the competitive rate so that the tourist may use their service rather than other homestay or even other islands and its attraction. Because the price does not include the externalities price, and because SWRO technology can not meet the demand on the busy weekend with a lot of tourists coming they still pump the water from the ground. Of course, the environment is the one that pays the price.

The reason why the SWRO plant cannot meet the water demand in Seribu island can be categorized into two factors; high technology with significant capital investment and the

political policy of controlled price. With high tech and massive capital investment, not many technicians or mechanical engineers are competent to deal with this water generator if something goes wrong. Furthermore, combined with the expensive maintenance and big capital investment, the local government and its department became really careful to maintain the production at the safest level (which is far from its optimum usage) for the sake of tool endurance (age).

Second, SWRO establishment is considered a political maneuver. The government does not really search for revenue/benefit except for political gain. Recognizing the strategic place for all mainland (Jakarta) citizens to spend their holiday, and the vote of over 22,000 islanders, the politicians/bureaucrats set the price of water and even bear the funding to subsidize the cost from the private SWRO plant. This policy leads to the unstable supply of SWRO water, especially in the northern district of Seribu islands where the water bragging from the mainland becomes economically inefficient because of the distance (40-60 km). Because of the determined price, the producer will only get a smaller surplus and force them only to generate a certain amount of water below the market equilibrium (demand meets the price). This led to the scarcity of water production. The condition even gets worse when the group of people gets early access to the resource and will sell it more expensive. This happens on the farther island from the coastal line of Jave (e.g. Harapan, Bira Besar Island, etc.).

The establishment of the SWRO plant is also not appropriate with the priority assessment method using SWOT (strengths, weakness, opportunities, threats) approach. Sinulingga et al. present that "the highest three priorities action to deal with water management and tourism in Seribu islands i.e (a) establish the visitor limitation policy to preserve the island and water sustainability, (b) arrange the regulation and create the local organization which also integrate with the existing organization to manage the water resource in the island, (c) developing the eco-tourism involving the Islanders, agencies, universities, and social activity group (*LSM in Indonesia*)[40].

The project-based and social approach is not as prestigious as infrastructure. We also do not try to undermine the SWRO's role in fulfilling part of the society's demand on water and its importance in severe weather or condition. But we should consider the fact that in any part of the world, the SWRO framework is not designed to be the primary alternative. Take Australia for example, or Israel where 30% of their water supply came from this technology, but they are precisely aware of the wastewater management; sustainable water policy, or regulation including environmental water allocation. Things that happen in Indonesia, mostly in Seribu islands people are invited to be overrated with the SWRO technology by local government and set the non-instant approaches aside.

The establishment of SWRO is not the priority because Seribu islands have a decent climate horizon where the average air humidity of 80%[27]. From November to April, the rainy season lasts ranging from 10 to 20 days per month. While the dry season occurs from May to October with 4-10 rainy days per month. People will be still able to manage the water through rainfall harvesting and create the bio pore infiltration hole to prevent drought in the dry season. Sinulingga et al. demonstrate that groundwater availability can be known from the rainfall rate (P) minus actual evapotranspiration (Ea) and runoff (Qro)[40]. The total rainfall rate (P) in Pari island is 1358.4 mm/year. According to the calculation of the water balance table, the actual evapotranspiration (Ea) is 656.44 mm/year. The runoff extent gained from the calculation of water balance and monthly runoff is 0.119525114 (m^3/dt). The width of Pari island is 41.32 ha or 0.4132 km^2.

$Q_{AT} = P - Ea - Q_{T0}$
$Q_{AT} = 561290.88 – 271241.008 – 49.3877771\ m^3/year$
$Q_{AT} = 290000.48\ m^3/year$

The summarize base on the calculation that the groundwater supposed to be 290000.48 m3/year (Fig 5). It was consists of the availability throughout eight months surplus because of the rainy season (November-July) and four months deficit (July-Oktober). Additionally, the demand distribution of domestic use of its 932 people and average visits per day (160 persons), public schools and number of livestock (123), the need ratio of the water availability at Pari island is normal. 2013's ratio shows 16% and increases to 19% in 2018 and 22% in 2023.

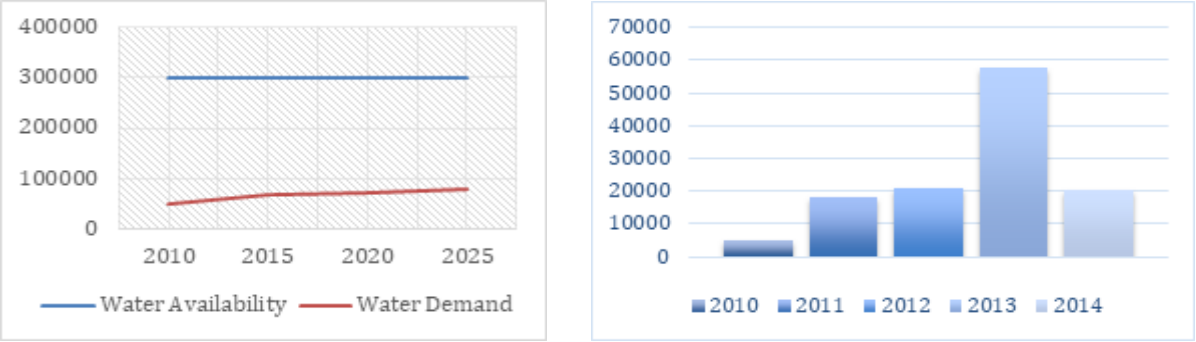

Fig 5. Projection of water demand (left), the number of tourist visits (right)

The particular calculation decribe that SWRO was not more important than maintaining groundwater storage and quality due to the surplus of water throughout the year. The strategic approaches to sustain the groundwater quality such as maximizing the infiltration rate, rainfall harvesting, creating wastewater and garbage processing, are worth to prioritized and are also not more expensive than the manufacturing cost of new SWRO plants. Although it is a long process, and the outcomes are not too noticeable or immediate, the series of projects that involve local people to do monitoring, discussion, and protection will gradually help society to improve their capacity and understanding, including the gender relation concern in water management, which is greater than the length of time it may take.

The local government at the very first beginning, needs to evaluate the total freshwater and calculate the demand for sustainable economic and social development. After that, the development and use of freshwater should be measured and monitored by the structural and operational mechanisms such as controlled groundwater pumping, infiltration galleries, borehole drilling, wastewater collection and treatment plant, and reuse of water scheme. The government can also 'buy back' the water from islanders and establish an effective distribution system so that the water consumption can be measured and billed to the customer. Tourists or consumers must be encouraged to save water and discourage to use it wastefully. public awareness must be promoted, and the policy must be enforced by involving society. Those series of approaches are indeed not the low-budget process. Also, the number of tourists may also threaten by the extra cost of water conservation. However, if the price is right and the collaborative funding by taking advantage from many donors from government and non-government organizations which mostly targeted the local capacity improvements rather than infrastructures are set. The process to get closer to the holistic approach of to sustainable small island development became rational.

Conclusion

Population growth and tourism development sector in the Thousand Islands has an impact on decreasing the availability of clean water quality. Management and planning for the development of SWROs on Seribu Island need to be reconsidered due to the current water resources and ineffective management and conservation.

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Author contributions

All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by [**Dina Maulina**], [**Ave Suakanila Fauzisar**], [**Diana Hernawati**] and [**Lia Septya**]. The first draft of the manuscript was written by [**Dina Maulina**] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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