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Estimation of Water Carrying Capacity for Settlement Activities in Small Islands: A Case Study of Small Islands of North Tiworo District, Muna Sub District, Indonesia

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ABSTRACT

This research aimed to estimate a coastal water quality change and its carrying capacity regarding the population settlement. Estimating the carrying capacity was taken using a quality standard comparison method, where the water quality was generated from field measurement with the quality of water according to the Ministerial Decree of Environment No. 51 of 2004. The principal component analysis was carried out to seek a parameter grouping of water quality in each location, while probability linear regression test was conducted to estimate the water carrying capacity. The results of this research indicated that the total population of Tiworo Archipelago has a significant correlation with ammonia concentration in the waters. The Quality Standard Ratio (QSR) value of ammonia currently was about 0.18, that is under its carrying capacity standard of 1. The number of the population according to the ammonia carrying capacity was about 39,541 people that was predicted happening on 160 years ahead, where the QSR ammonia value will reach 1, with an assumption of population growth rate of 1.36% per year. If the scenario was taken by decreasing the population growth rate as high as 1% per year, the carrying capacity of ammonia will happen 218 years later, and reversely when the population growth rate increased to be 1.5% per year, the carrying capacity of ammonia was going to occur on 146 years ahead. However, if this scenario was conducted by managing the local domestic waste, the ammonia carrying capacity limit was going to happen on 228 years ahead. Although various scenarios are able to be carried out to maintain the water quality, the water carrying capacity currently in the research location is either still high enough to support settlement activity of populations or marine aquaculture activity.

INTRODUCTION

A phenomenon of coastal settlement in the small islands is one of the forms in space utilization (Dahuri 2001). One of triggering factors on settlement in these areas is due to the existence of natural resources such as coral reefs, seagrass, mangrove, fish, ocean energy, and environmental services (Dahuri 2003). The uses of those resources are still going on, even though, access to transportation, education, health care, market, technology, and information is still limited. In Indonesia, the potential lands of small islands are huge to be utilized by human settlement. In fact it shows that among 17,508 islands only 12.38% or 2,167 islands are currently inhabited, and remaining 87.62% or 15,338 islands are still left inhabited (Ministerial of Maritime Affairs and Fisheries 2007). The inhabiting small islands tend to be utilized for settlement activities and other activities (White et al. 2004).

A form of space utilization for settlement activities is also the main factor relating to land uses (Rotinsulu et al. 2018). The tendency of population growth and various conducting activities are implicated logically on land use change, land vegetation loss, increase in carbon emission, and the small islands becoming vulnerable to the environmental changes. Beside impacts on the mainland ecosystem, the settlement also generates solid and liquid waste that is able to escalate pollutants contained in the water (Cao et al. 2017). Another land uses of small islands is also marine tourism. Kurniawan et al. (2016) mentioned that tourism development is a popular activity enough in the small islands, for instance, marine tourism development conducting in Gili Trawangan, Gili Meno, and Gili Air that are lo-

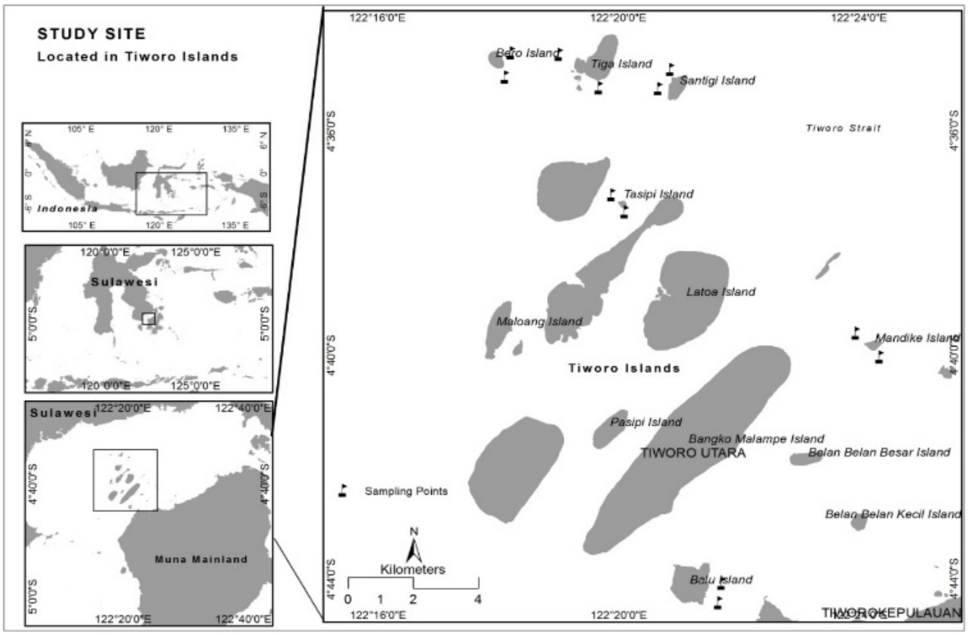

Fig. 1: Research site in Tiworo Archypelago.

cated in Nusa Tenggara Barat Province. Absolutely, activities of resorts also resulted in increasing liquid and solid waste containing pollutants that can be impacted to the water quality (Laapo 2010, Baoying & Yuanqing 2007). These conditions are very influential to the water quality in the surrounding environment of small island.

Water is a resource having an important role in supporting the sustainability of marine living biota (Karr & Dudley 1981, Bilotta & Brazier 2008). Activities utilizing waters such as marine aquaculture is highly depended on the water quality standards fulfilling the standard of eligibility (Boyd & Tucker 1998). Occurring of water quality standard change in the small islands is often caused by several factors. According to Mallin et al. (2000) and Liyanage & Yamada (2017), the change of water quality standard has a correlation with human settlement activities living within small island. An increase of pollutant concentration that comes from settlement activities excessively resulted in the inability of waters to assimilate all organic materials entering into them, although, the water itself has a self-purification naturally (Effendi 2003). The resulted consequences from the water quality standard change in the small islands will be impacts on other activities like marine aquaculture, which highly depends on the water quality standards in requiring its eligibility for living.

The change of water quality standard due to the use of small islands is presumed also occurring in the Tiworo Archipelago Islands. The landuse activities in, both the waters and land, have taken place like other parts of Indonesia. The coastal areas are used for fishing grounds by local fishermen. When the waters of small islands are utilized for aquaculture activities like floating cage net, it will have the potential to be polluted by organic matters. Tovar et al. (2000) stated that the marine aquaculture activities affect the water quality parameter variability composing of dissolved oxygen, total suspended solids, and nutrients (ammonia, nitrate, nitrite and phosphate). Uplifting the organic pollutants is the potential to disrupt the existing coral reefs ecosystem. An existence of floating cage net activities at Penghu Taiwan island contributes on escalating nutrient enrichment in the waters and is surmised to decrease the extension of coral reef ecosystem (Huang et al. 2011). Nevertheless, occurring the pollution of organic materials in the floating cage net exhibits a relationship significantly on the variability of seagrass bed growth (Rountos et al. 2012).

Utilizing the mainland functioning as the human settlement is potentially impacted by organic pollution (liquid and solid wastes). The settlement that has occurred since decades naturally resulted in domestic waste accumulating in the water body. This accumulation is able to lower the water quality standard and influence the activity of aquatic organisms' metabolism activity (Islam & Tanaka 2004). An increase of population growth have a correlation with the concentrations of BOD, dissolved oxygen, and total coliform (Liyanage & Yamada 2017).

Based on the small islands uses phenomena above including the Tiworo Archipelago, this research is very interesting to analyse how is the connection among the number of population (current and future), the change of water quality standard, and the water carrying capacity. This research aimed to estimate the quality change and the water carrying capacity regarding the local population in the small islands that are able to be used as one of the inputs in formulating the space utilization model of Tiworo Archipelago.

MATERIALS AND METHODS

This research was carried out in January to April 2018 in the Tiworo Archipelago, Southeast Sulawesi Province. The sites and sampling points of waters are shown in Fig. 1.

The estimation of water carrying capacity in this research was conducted using a nutrient-load approach. This approach was based on an understanding that each individual or group of community living in the small islands continuously delivers an anthropogenic input-load to the waters. Data used in this research were the results of measured water quality consisting of the concentrations of nitrate (NO_3^-), phosphate (PO_4^{3-}), ammonium (NH_4^+) and BOD_5. These parameters were related to the decomposition of organic materials generated from settlement activities. The sampling sites were defined as many as 12 stations and distributed in six inhabiting small islands. Every small island composes of two sub-villages that are being a concentration of people in the each island. The intended small islands are Tiga Island, Tasipi Island, Santigi Island, Balu Island, Mandike Island and Bero Island.

The field observation was conducted to take the water samples that were then analysed in the laboratory. Sampling the waters was accomplished in inhabiting islands. The secondary data, like number of population living in those islands, was collected to seek the potency of organic pollutants. Estimating the total organic materials generated in each household applied a method of quality standard comparison (Pindyck & Rubinfeld 1998).

The gained results of water quality parameter measurement were then compared with the values of water quality standards for marine biota that had been issued through the Ministerial Decree of Environment No. 51 of 2014 on the Marine Water Quality Standards for Marine Biota. The comparison of these two value groups is called as a ratio. Data of total population in each island used to simulate the magnitude ratio concentration of water quality standard. The step for estimating the water carrying capacity was carried out by modifying the steps from Laapo (2010) as follows.

1. Estimating the number of local population living in the small islands.
2. Sampling waters and measuring the seawater quality parameters in forms of dissolved oxygen *in-situ* in each research station and laboratory testing for contents of nitrate, phosphate, ammonia and BOD_5.
3. Comparing the results of measurement for every water parameter with the water quality standard for marine biota (according to the Ministerial Decree of Environment No. 51 of 2014) per research location.
4. Categorizing the water quality parameter using a Principal Component Analysis (PCA).
5. Testing the effect of *x* variable (local population) on *y* variable (ratio value of quality standard) of each parameter using a probability linear regression test to generate the constant value, and regression coefficient. The regression test was applied to the clustered water quality based on the results of principal component analysis.
6. Estimating the water carrying capacity by using the model formula as follows (Pindyck & Rubinfeld 1998).

$$QSR = a + b\,(Pi)$$

Where, QSR = Quality Standard Ratio
Pi = Number of population at station i
a = Constant
b = Coeficient regresion

The results of probability linear regression test (the constant and regression coefficient) from the probability model then were simulated (estimated) for the magnitude of human population causing the concentration of water quality parameters was equal to the water quality standard for marine biota (ratio value = 1). The QSR value was an estimated value to figure out the magnitude of human settlement influence on the water quality standard ratio. The QSR optimum as high as 1 is the limit of water carrying capacity meaning that the existing water quality parameters generated from measurement is equal to the water quality standards. If the value ratio QSR > 1, means that it has exceeded the water carrying capacity, and reversely if the value ratio QSR < 1, means that it does not reach the water carrying capacity yet.

The changes, the water carrying capacity and the water quality standard ratio resulting in by changing of *x* variable, were analysed using a dynamic system method applying a STELLA 9.0.2 software. To seek the possibilities that are going to occur regarding to the water carrying capacity changes, some scenarios were set by intervening the number of population and domestic waste treatment. The causal loop diagram of the water quality is preserved in Fig. 2.

RESULTS

Overall values of water quality parameters in the Tiworo Archipelago Islands was still under the quality standard threshold issued by the Ministerial Decree of Environment No. 51 of 2014. The measured concentrations of ammonia, nitrate, phosphate and BOD_5 were in the range of 0.014-0.031 mg/L; 0.0038-0.0048 mg/L; 0.04-0.07 mg/L and 2.3-2.5 mg/L respectively. The comparison of results between the direct measurement and the quality standard of waters are illustrated in Fig. 3.

Fig. 3 exhibits that the concentrations of water quality parameters in Tiworo Archipelago Islands were below the water quality standard's thresholds. Nitrate was the highest ratio of quality standard and ammonia was the lowest one. The parameters of water quality such as BOD_5 had different values due to water quality analysis. BOD_5 showed a lower concentration in Tasipi Island than Tiga Island; although, the number of population in Tasipi Island was higher. This was presumed due to the topography condition in Tasipi Island that is lower than other islands. Furthermore, the ratio value of phosphate in Balu Island at Station I was the lowest compare to other islands; even though, this island has a higher human population. A low concentration of phosphate in this island was caused by current that was higher than other locations.

Based on the PCA, the concentrations of water quality surrounding Station II of Balu Island, Station II of Santigi Island, and Station II of Tasipi Island, acquired relatively similar for ammonia; while the nitrate concentration had a similar value in the Station I of Mandike Island, and Station II of Tiga Island. Phosphate and BOD_5 parameters did not have any similarity with other research locations. The pattern of relationship between each station and water quality parameters according to the PCA as can be seen in Fig. 4.

A regression test analysis between variable of population number and the variable of water quality parameter ratio showed a significant correlation. The value ratios of ammonia in three islands namely Station II of Tasipi Island, Station II of Santigi Island, and Station II of Balu Island indicated a significant influence on those two variables. While, the number of population in two islands namely Station I of Mandike Island, and Station II of Tiga Island did not have any correlation significantly towards the nitrate concentration in the waters. A summary of statistical test of both the water quality parameters is given in Table 1.

Based on Table 1, it was clearly seen that the population in Tiworo Archipelago has a significant effect on the ammonia concentrations in the waters. A regressional line equation of population number effects on the ammonia concentration as can be seen in Fig. 5.

The magnitude of QSR ammonia value highly depends on the values of the constant (a), regression coefficient (b), and number of population in each small island. The higher number of population, the bigger is the gained QSR value. The value of regression coefficient is about 2.34E-05 hav-

Table 1: A summary of probability linear regression test.

No.	Description	NO_3^-	NH_3
1.	R	0.55	0.99
2.	R^2	0.31	0.99
3.	Constant a	0.57	0.07
4.	Coefficient b	-0.00012	2.34E-05
5.	p value	0.62	0.05

Sources: Data Analysis, 2018

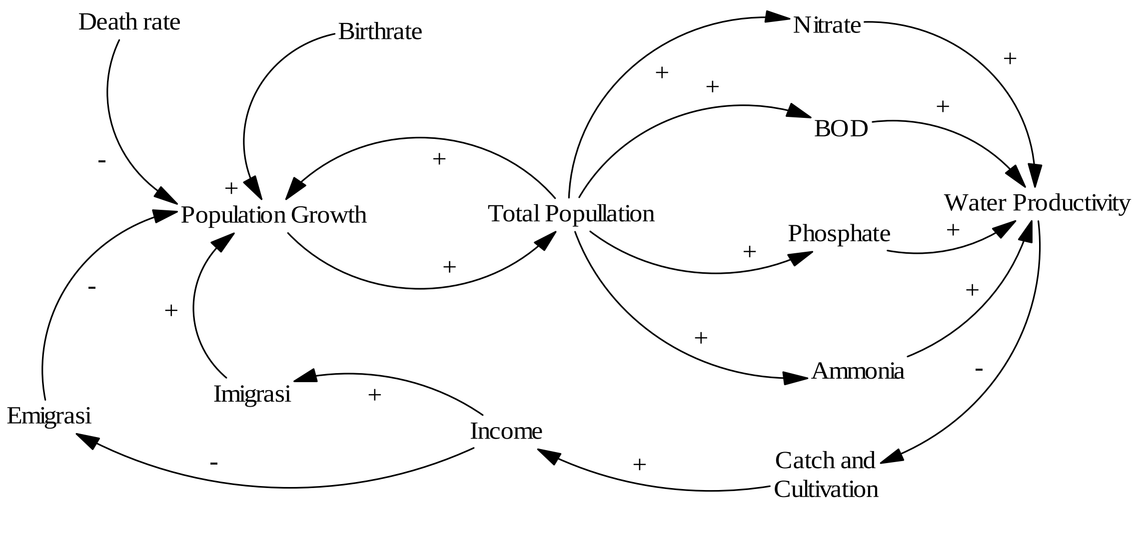

Fig. 2: A causal loop of relationship between population and the water quality.

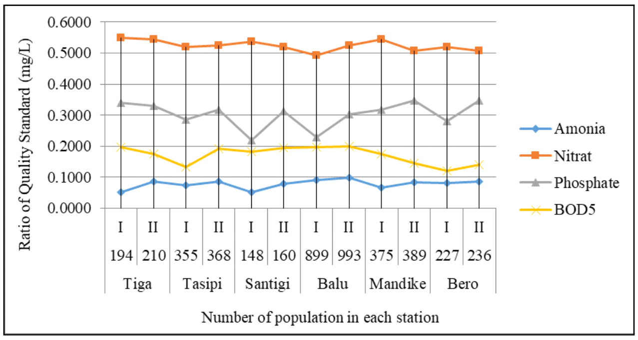

Fig. 3: The ratio value of water quality in each research station.

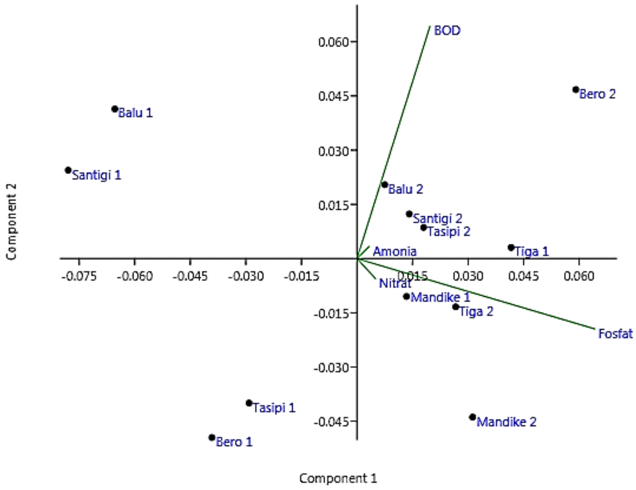

Fig. 4: A grouping of water quality paramaters.

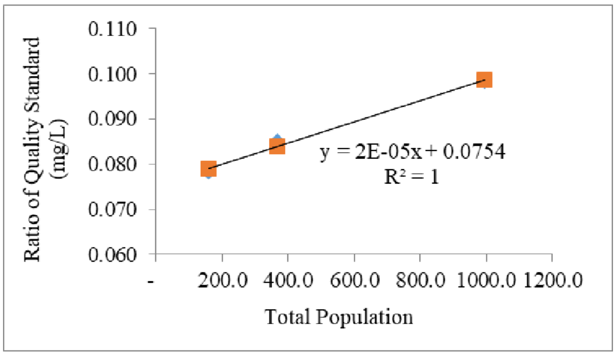

Fig. 5: A regressional line equation of total population on water quality.

ing a meaning that with every increased one individual, the concentration of ammonia was going to escalate as many as 2.34E-05. Based on the constant a, regression coefficient value, and number of population as many as 4,554 people, the QSR of ammonia currently was estimated as 0.18. The water quality change was illustrated as the flow diagram in Fig. 6.

The Fig. 6 is a flow diagram foreseeing the magnitude of the QSR ammonia value in a certain period of time based on the population growth rate. The growth rate of population in the Tiworo Archipelago currently was approximately 1.36% per year that will escalate the QSR value of ammonia starting from 0.18 to be a 1 (the limit of carrying capacity) in 160 years ahead. The estimated number of population reaching its carrying capacity limit was approximately 39,541 people. This estimation is based on the actual condition, without any sundry intervention or scenario on inputs of organic materials. An increased trend of QSR value and lowering of ammonia carrying capacity in a certain period of time is illustrated in Fig. 7.

The change of QSR value and ammonia carrying capacity was going to be occurred if various intervention efforts like decreasing or increasing the population growth percentage, or treating the waste coming from settlement activities. According to Aziz et al. (2004) administering the domestic waste using active carbon was able to deteriorate the ammonia concentration in the water as much as 40%. The scenario changes setting on the QSR value and carrying capacity of ammonia are presented in Figs. 8, 9 and 10.

DISCUSSION

The concentrations of organic matter in the Tiworo Archipelago commonly were still under their thresholds. The gained water quality parameter values are still under the water quality standard values issued by the Ministerial Decree of Environment No. 51 of 2004 on Water Quality Standard for Marine Biota. This indicates that the water quality in this island was in normal condition for the marine biota, including aquaculture activities. The water quality parameters in this island were relatively similar to the results of research conducted by Laapo (2010) in the Togean Archipelago. However, it was still lower compared to the results of research conducted by Patty (2015) in Lembeh Strait, Patty (2014) in the waters of Gangga and Siladen Island and Mustaruddin et al. (2011) in the waters of Aceh Jaya. Effendi et al. (2016) found the nitrate and phosphate compounds in some locations of Kepulauan Seribu that have exceeded the threshold of water quality standards.

The comparison of water quality parameters and the quality standard points out that the nitrate concentration in the water has the highest ratio value, while the lowest ratio value is of ammonia. This high ratio of nitrate depicts its concentration in the water has approached its quality standard. However, when this parameter was compared with other parameters, the nitrate concentration in the water was low.

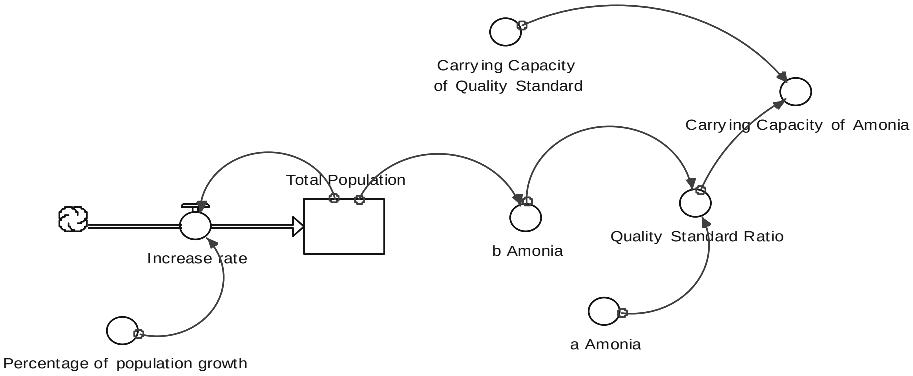

Fig. 6: A dynamic model flow diagram of the water carrying capacity.

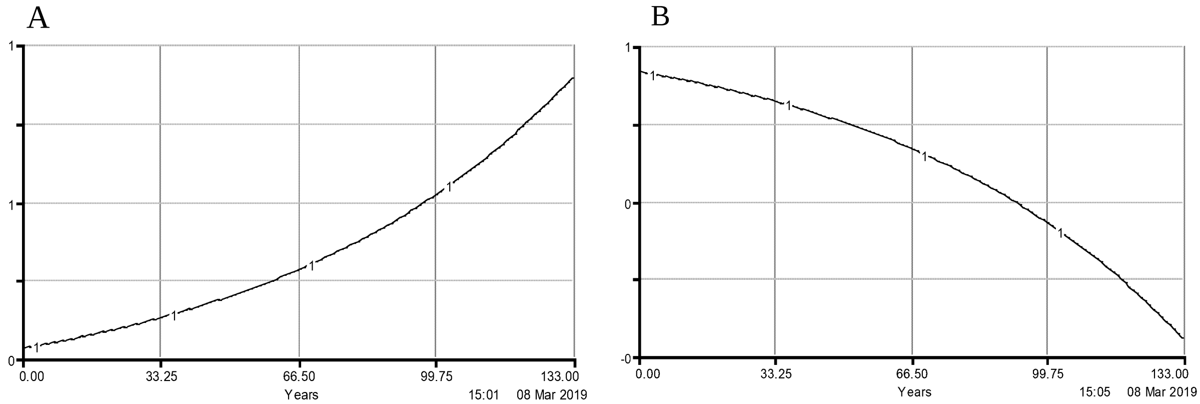

Fig. 7: (A) The ecalatating trend of QSR of ammonia, (B) The lowering trend of carrying capacity: (the assumption of normal population growth is about 1.36% per year).

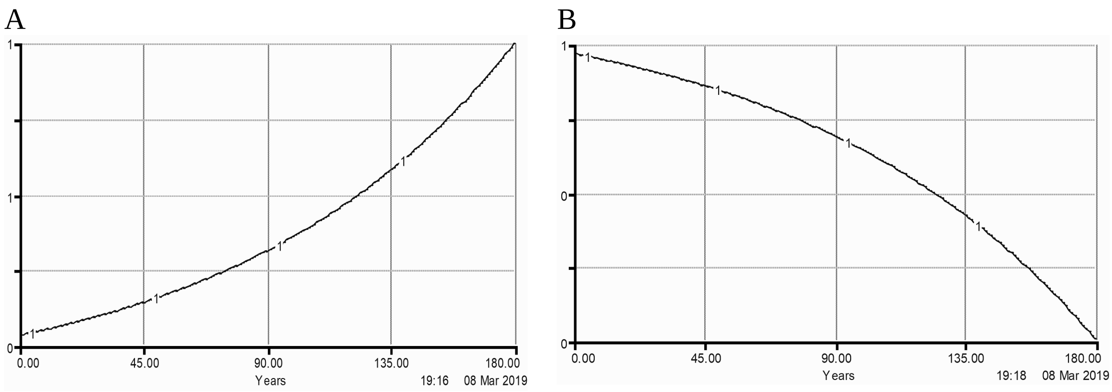

Fig. 8: (A) An incresing trend of QSR of ammonia, (B) A decreasing trend of carrying capacity (Assumed population growth of 1% per year).

In the natural waters, the concentration of nitrate never exceeds more than 0.1 mg/L (Effendi 2003). The concentration of nitrate in the water was often applied to categorize the water fertility level (Wetzel 1975). The high ratio of nitrate is caused by the nitrate quality standard value that was more stringent than other parameters of water quality standards. The Ministerial Decree of Environment No. 51 of 2004 defined the value of nitrate quality standard about 0.008 mg/L, which was lower than the standard issued by US-EPA (1973) at 0.07 mg/L. The reverse condition occurs for ammonia, where its gained ratio was lower than the ratio of nitrate and phosphate. The low ratio of ammonia was due

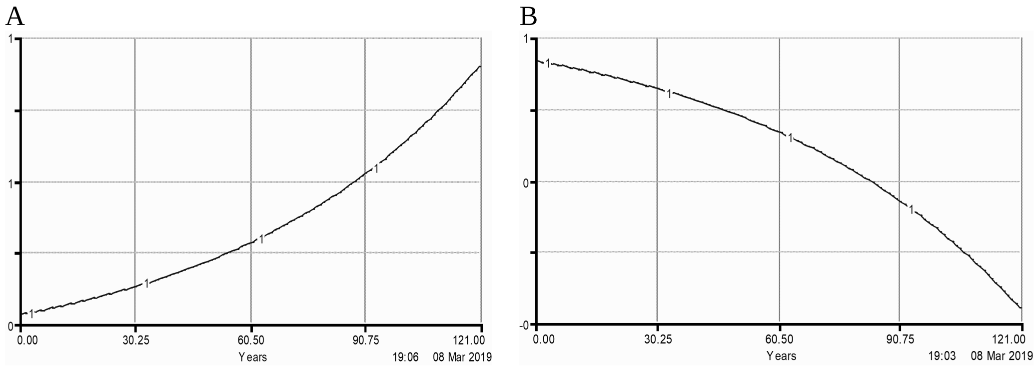

Figure 9: (A) An increasing trend of QSR of ammonia, (B) A declining trend of carrying capacity (Assumed population growth is 1.5% per year).

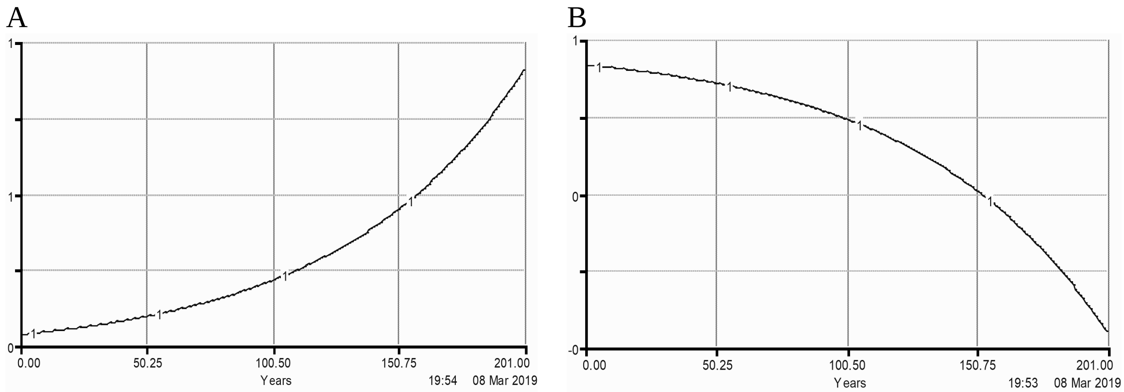

Fig. 10: (A) An increase trend of QSR ammonia, (B) a decrease trend of carrying capacity (Assumption: treating the domestic waste)

to its higher quality standard value than the nitrate and phosphate. The content of ammonia in the water was in a range of 0.016-0.026 mg/L that was higher than the concentration of nitrate and phosphate, which were in range of 0.0038-0.0044 mg/L and 0.0043-0.0073 mg/L, respectively.

The concentrations of dissolved organic materials in the Tiworo Archipelago were not merely characterized by human population of those small islands. Nevertheless, the concentrations of ammonia and nitrate had a similarity among one to other sites. A similarity of ammonia in three sites namely Station II of Tasipi Island, Station II of Santigi Island, and Station II of Balu Island, was related to the human population. The high concentration of ammonia in these locations was in line with the magnitude of human population living in these areas. Furthermore, the concentration of nitrate has a similarity in two locations such as Station I of Mandike Island and Station II of Tiga Island, even though, this similarity was not significantly related to the human population. While for two other parameters, BOD_5 and phosphate, their existence in the water was not distinguished by human population in the areas.

An existence of human population has a relationship with the concentrations of dissolved organic materials in the waters (Ahearn et al. 2005, Vega et al. 1998). In the case of Tiworo Archipelago, a linkage between human population and the existence of dissolved organic matters was reflected from a significant value of ammonia. The regression coefficient value of ammonia was approximately 2.34E-05, which evidences that every individual of population in the Tiworo Archipelago contributes on the ammonia concentration in the waters. The magnitude of ammonia concentration in the waters is also associated with the nitrification and denitrification process of organic compounds in the waters (Kemp et al. 2002). The existence of ammonia in the water is toxic for aquatic organisms (Ferrteti & Calleso 2011).

The population growth in the Tiworo Archipelago increases to as high as 1.36 % per year inflicting a decrease of water carrying capacity. Decreasing of the water carrying capacity was able to be looked at from an escalating QSR ammonia to as high as 0.1, which occurs in every 2-4 years. The increase of QSR ammonia lowers the water carrying capacity also to 0.1. Based on the growth rate of population, the QSR of ammonia will reach 1 within next 160 years, and at the time, the number of population in this islands is going to be 39,541 people. An increasing of QSR of ammonia indicates the escalating of domestic waste in the waters. The generated domestic waste will undergo oxidation process that declines the oxygen level in the waters (Effendi 2003, Kemp & Kodds 2002). Estimating the escalating QSR and carrying capacity of ammonia is an actual condition currently, where there is no intervention of human population number as one of organic material sources.

Conducting a scenario by lowering the population growth rate exceeding 1% per year, increasing QSR of ammonia to as high as 0.18, and within 218 years ahead, the carrying capacity of the water will reach within 1 (Fig. 8). An approximation of population number within this period is going to be 39,852 people. Conversely, when the growth rate of population increases to 1.5%, the QSR of ammonia will experience a rapid increase, starting from 0.18, and within 146 years ahead, the carrying capacity will be reached, and the expecting number of population will go to 40,034 people (Fig. 9).

A scenario with the growth rate of population rise to be 1.5% per year that was presented in Fig. 8, the QSR of ammonia will swell rapidly, and the QSR of ammonia is expected to be 1 will occur within next 146 years and the number of population will go to 39,852 people. Reversely, when the growth rate of population can be pressured to 1% per year, the QSR of ammonia will be exceeded longer, and the expected QSR of ammonia will be 1 within 218 years ahead, and the number of population will go to 40,034 people. By treating the generated local domestic waste from settlement activity has a more effective range in declining the waste concentration in the waters. According to Aziz et al. (2004), the domestic waste treatment using active carbon was able to bring down the ammonia concentration in the waters to 40%. The option of domestic waste management utilizing this method is going to be more effective in deflating the ammonia concentration in the waters. Based on the scenarios above, the domestic waste treatment might be conducted in the Tiworo Archipelago, the concentration of ammonia will be exceeded its carrying capacity within next 228 years, and the estimation of population number in these islands will go to 99,078 people. Although, occurring scenarios changes, the increase graphics of QSR ammonia in Figs. 7, 8, 9 and 10 follow the patterns of population growth that shape exponential curves. Within those spans of years, the concentration of ammonia in the water might be lower than its quality standards.

CONCLUSIONS

The water carrying capacity in the Tiworo Archipelago on the number of population is still big enough. The gained water quality parameter values are lower than the water quality standard for marine biota, which has been issued by the Ministerial Decree of Environment No. 51 of 2004. The current number of population has affected significantly the concentration of ammonia in the water, however, this parameter is still in a normal condition for the life of marine biota. In a perspective of management, the concentration of ammonia in the water becomes a postulate in defining the magnitude of the water carrying capacity.

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