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Chapter in book:

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Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th Annual Symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.) Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

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Analysis of lead (Pb) levels in water, sediment and mollusks in secondary irrigation channels in Gorontalo Province, Indonesia

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Abstract. *Tahir IA, Lamondo D, Baderan DWK. 2021. Analysis of lead (Pb) levels in water, sediment and mollusks in secondary irrigation channels in Gorontalo Province, Indonesia. Intl J Bonorowo Wetlands 11: 1-6.* This study was conducted in July-August 2020 in the secondary irrigation channels of Gorontalo Province aimed to determine the lead content in the water, sediment, and gastropods in the channels. The sampling points were located in four sub-districts, i.e., North Bulango Sub-district, Sipatana Sub-district, Central City Sub-district, and Hulonthalangi Sub-district. The samples were analyzed using Atomic Absorption Spectrophotometer (AAS). The data were analyzed qualitatively by comparing them with the contamination thresholds set by the government of Indonesia. The results showed that the levels of lead in water in the four stations were 0.37 mg/L, 1.30 mg/L, 1.69 mg/L, and 0.38 mg/L, respectively, in the sediment 1.1268 ppm, 0.9719 ppm, 0.7602 ppm, and 0.5290 ppm, respectively, and in each mollusk species, i.e., *Bellamnya* sp. 0.2924 mg/kg, *Pomacea canaliculata* 0.2413 mg/kg and *Pomacea canaliculata* 0.1873 mg/kg. The lead levels in the water, sediment, and gastropods in the study sites exceeded the contamination thresholds set by the Indonesian government.

Keywords: Lead, mollusks, secondary channels, sediment, water

INTRODUCTION

Irrigation channels are built to distribute and supply water to agricultural areas, especially rice fields, to maintain high agricultural production. According to the Government Regulation of the Republic of Indonesia Number 20 of 2006, irrigation channels are divided into 3, namely, primary, secondary, and tertiary irrigation channels. A secondary irrigation channel is a channel that carries water from the primary irrigation channel to the tertiary irrigation channel.

The secondary irrigation channels from the Lomaya dam are 25,733 meters long (Biahimo et al. 2015), passing through settlements and houses. Some residents who live along the secondary irrigation channels dispose of household waste, such as liquid waste, batteries, children's toys, wall paint, and plastic food or beverage packaging, to the irrigation channels. The materials discharged into this irrigation channel are likely to contain heavy metal lead (Pb), as Lamondo (2020) stated that batteries, children's toys, wall paint, and plastics contain lead. Eshmat et al. (2014) also reported that heavy metal pollutants, i.e., lead (Pb) and cadmium (Cd), that occurred in Ngemboh waters were caused by the disposal of resident waste originating from organic and inorganic materials.

The secondary irrigation channels become a place for liquid waste disposal from motor vehicle washing businesses and workshops. This liquid waste is likely to contain lead as research by Nadeak et al. (2015) showed that the liquid waste in motorized vehicle workshops in the city of Tanjungpinang observed at 3 small workshops with 3 sampling points had lead levels exceeding the threshold of more than 0.1 mg/L.

The secondary irrigation channels also receive waste from agriculture in the form of fertilizers and pesticides, which are likely to contain lead. Research conducted by Sukarjo et al. (2018) showed that applying fertilizer to rice plants could increase the metal content of lead and cadmium in soil and rice plants.

The secondary irrigation channels are also close to highways with heavy traffic of motor vehicles that produce smoke containing Pb. This smoke will crystallize in the air, and when it rains, the lead will be carried away with rainwater and enter the waterways. Pratama et al. (2012) showed that the lead metal content in Tapak River water ranged from 0.01 to 1.11 ppm. This was thought to have come from the motorized vehicle pollutants in the water bodies and smoke from the factories around the river.

The secondary irrigation water is also used to irrigate rice fields. Suppose this irrigation water is polluted and used to irrigate rice fields. In that case, the lead will accumulate in agricultural crops, and it will accumulate in the fish and gastropods, which will cause metabolic and respiratory disorders.

Suppose humans consume animals and plants that have been contaminated with lead. In that case, the lead will accumulate in the body, causing health problems such as weakness, headaches, fatigue, tingling hands, anemia, renal dysfunction, physiological dysfunction, liver dysfunction, and decreased fertility. Research by Lamondo et al. (2015) on male reproduction showed that lead could cause apoptosis in spermatogenic cells.

Heavy metals in the water will settle and accumulate in the sediment, so sediment is often used to indicate environmental pollution. Wicaksono et al. (2016) state that as the heavy metal content in the water settles in the sediment, the concentration of lead in the water will decrease. This is supported by Saputra's research (2018) which showed that the lead content in the sediment was 2.95 ppm, more significant than that in the water, i.e., 0.0183 ppm. This can occur because heavy metals entering water bodies will experience deposition and dilution, then accumulate in aquatic biota.

Besides water and sediment, biota can also be used as a bio-indicator of lead pollution in secondary channels. Baderan et al. (2019) state that gastropods that live on the bottom of waters can be used as bioindicators of pollution because filter feeders have low mobility and a high tolerance for environmental pollution.

MATERIALS AND METHODS

Study area

This study was conducted from July to August 2020 in Lomaya irrigation secondary channels, Gorontalo, Indonesia, with a length of 25.733 m. Samplings were done in 4 observation stations (Figure 1). (i) Station I is the entry point for the secondary channel (Inlet) river water; the location is at the Lomaya dam, Lomaya Village, North Bulango Sub-district, Bone Bolango District. (ii) Station II is a secondary channel for receiving household waste and washing motor vehicles; the location is at Jalan Tondano, Bulotadaa Barat Village, Sipatana Sub-district, Gorontalo City. (iii) Station III is a secondary channel for receiving household waste, workshops, agricultural waste, and washing motor vehicles; the location is at Jalan Arif Rahman Hakim, Dulalowo Village, Kota Tengah Sub-district, Gorontalo City. (iv) Station IV is where water comes out from the secondary channel (outlet) at Jalan Yos Sudarso, Tenda Village, Hulonthalangi Sub-district, Gorontalo City.

Procedure

Preparation of samples

Water test sampling for lead inspection: (i) the sampling point area was determined, (ii) the jerry cans were rinsed 2-3 times with sample water, (iii) water sample was taken using a 600 mL jerry can (Kitong et al. 2012).

Sediment sampling for lead examination: (i) the sampling area point was set, (ii) sediment was taken using a paralon pipe vertically, (iii) the sediment obtained was separated, cleaned from other objects, and inserted into the plastic (Rangkuti 2009).

A sampling of golden snails for lead examination: (i) the sampling area was determined by plotting the size of 1 m x 1 m, (ii) the snails were taken and put into a plastic container that had been labeled and put into a coolbox (Nur et al. 2015).

Water sample preparation (SNI 6989.8:2009)

Fifty milliliters of water were put in a 100 mL Erlenmeyer, added 5 mL of concentrated HNO_3 then covered using a funnel. Then, it was heated slowly until the remaining volume was 15-20 mL until it formed a slightly white precipitate or the solution became clear. Then the funnel was rinsed, and the rinsing water was put into a beaker. The solution was then transferred into a 50 mL volumetric flask, added with distilled water to the mark, and then homogenized. Then the solution was ready for analysis using AAS.

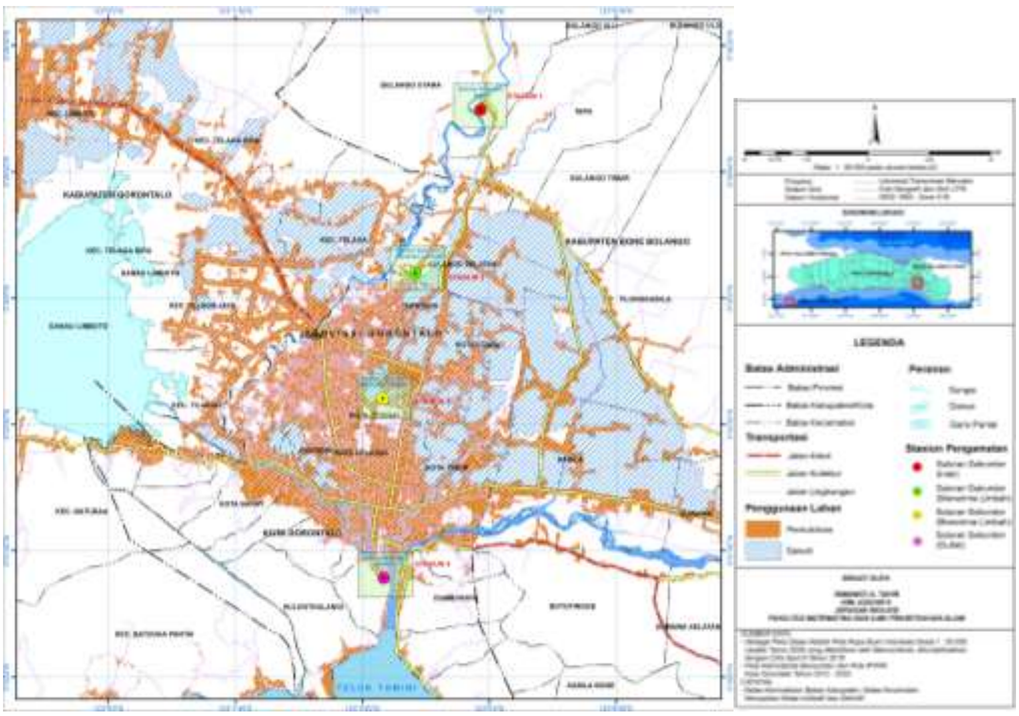

Figure 1. Research sampling locations

Sediment sample preparation (SNI 06-6992.3-2004)

The dry sediment as much as 3 grams was weighed and put in the Erlenmeyer, then added with 25 mL of distilled water and stirred using a stirring rod. Next. 5-10 mL of concentrated HNO_3 was added, stirred, then added with 3-5 boiling stones, and then closed using a watch glass. Then Erlenmeyer was heated on a hot plate at a temperature of 105°C-120°C until the volume of the remaining solution was 10 mL. It was then added with 5 mL of nitric acid, 5 mL of concentrated HNO_3, 3 mL of perchloric acid, 3 mL of concentrated $HCLO_4$. Then it was reheated in an electric bath until the lead smoke was white and the test sediment solution became clear; then, it was heated again for 30 minutes, then the sediment sample was cooled and filtered with filter paper with a pore size of 8.0 m. Furthermore, the sediment sample filtrate results were put into a 100 mL volumetric flask, and distilled water was added to the mark. Then it was ready to be tested using AAS.

Snail sample preparation (SNI 2354.5-2011)

The snail was weighed as much as 5 grams. Then, a spiked solution of 0.05 mg/kg (the result of a mixture of snail and 0.25 mL of standard Pb solution) was made, then evaporated on a hot plate with a temperature of 100°C until dry. The sediment and spiked were inserted into the ash furnace in stages from 100°C-450°C every 30 minutes to 18 hours. Then it was cooled at room temperature and added with 1 mL of HNO_3 65%; then, the solution was homogenized, then it was evaporated again on a hot plate at 100°C until dry. Next, the snail and Spiked samples were put back into the ashing furnace, and the temperature was gradually increased to 100°C every 30 minutes until the temperature reached 450°C, and maintained for 3 hours. After the ash turned white, the snail and spiked samples were cooled to room temperature. As much as 5 mL of 6 M HCL was added to each snail sample, spiked was homogenized until the ash dissolved in the acid. Then it was reheated on the hot plate at 100°C until dry. Then 10 mL of 0.1 M HNO_3 was added and chilled for 1 hour; then, the solution was transferred to a 50 mL polypropylene. Modifier matrix solution was measured and added to the limit mark. The sample was ready to be tested using AAS.

Data analysis

The concentrations of lead in the water were compared with the quality standards set in Government Regulation no. 82 of 2001 concerning water quality management and water pollution control, which is 0.03 mg/L, the concentrations of lead in sediments were compared with quality standards set in the Decree of the Minister of Environment No. 51 of 2004. The lead concentrations in snails were compared with the quality standard set in SNI 7387: 2009 regarding the maximum limit of heavy metal contamination in food.

RESULTS AND DISCUSSION

Lead levels in water

The lead levels in the water were different among stations (Figure 2). The water in station III had the highest level of lead, i.e., 1.69 mg/L, while the water in the station I had the least, i.e., 0.37 mg/L.

Levels of lead in sediment

The lead contents in the sediment were different among stations. The sediment in the station I had the highest level of lead, i.e., 1.1268 mg/kg, while the water in station IV was the least, i.e., 0.5290 mg/kg (Figure 3).

Levels of lead in mollusks

Mollusks were found only in stations II and III. In station II, 2 species of gastropods were discovered, namely *Bellamnya* sp. and *Pomacea canaliculata*, and in station III, only *Pomacea canaliculata* was found. The lead levels of each species at station II were 0.2924 mg/kg and 0.2413 mg/kg, respectively, and at station III, 0.1873 mg/kg (Figure 4).

Environmental parameters

The water temperature at 4 stations ranged from 24°C to 30°C with an average of 27.5°C. The pH of the water was the same for all stations, i.e., 7. Dissolved oxygen levels differed among the four stations: at the station I, it was 4.8 mg/L, station II 3.1 mg/L, station III 1.3 mg/L, and station IV 4.0 mg/L (Figure 5). The average value of dissolved oxygen level at the four stations was 3.3 mg/L.

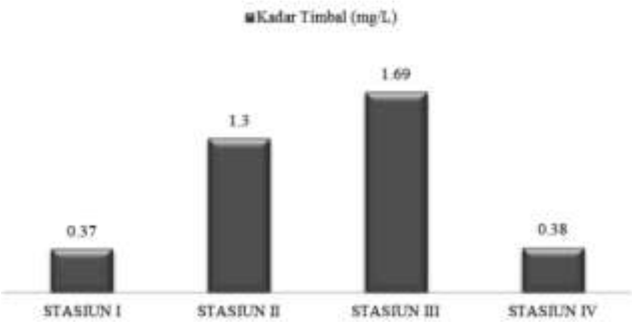

Figure 2. Lead content in water

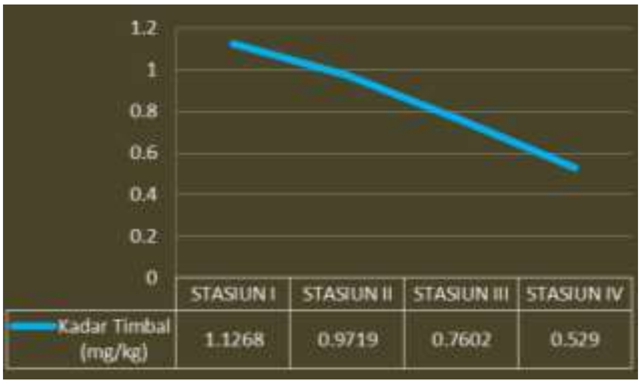

Figure 3. Concentrations of lead in sediment

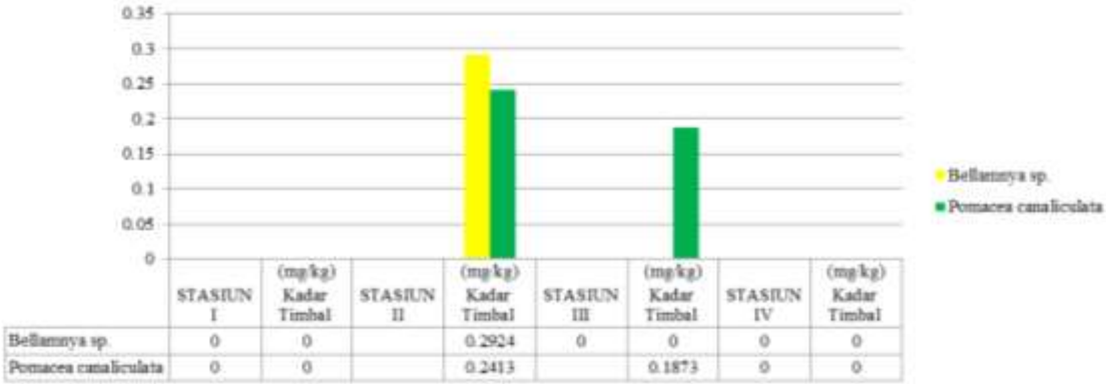

Figure 4. Lead levels in mollusks

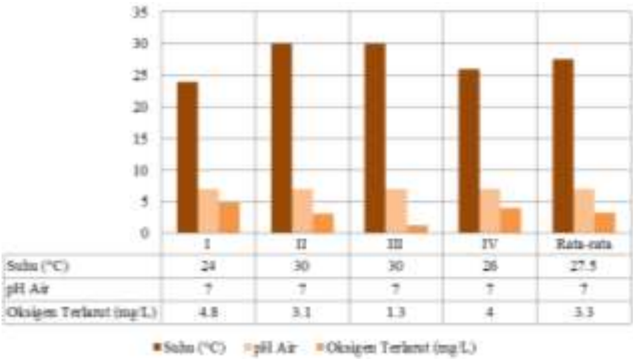

Figure 5. Environmental factors in the secondary irrigation channels

Discussion

The lead content in water in the secondary channel at the station I was 0.37 mg/L, the lowest among the four stations. However, this level exceeds the threshold level set in the Government Regulation number 82 of 2001 concerning the quality standard for the level of lead in water, which is 0.03 mg/L. The low level of lead at the station I was caused by pollutants from household waste only.

Household waste suspected of containing lead are batteries, children's toys, washed paint, and plastic food or beverage packaging (Lamondo 2020). Eshmat et al. (2014) also reported that the contamination of lead (Pb) and cadmium (Cd) in Ngemboh waters were caused by the disposal of resident waste originating from organic and non-organic materials. Budiastuti et al. (2016) also argue that household waste has a significant role in the presence of lead in waters.

Stations II and III had the highest levels of lead in the water, namely 1.30 mg/L and 1.69 mg/L. Apart from receiving household waste, this canal also receives waste from motorized vehicle workshops and washing businesses. There are 15 workshops and 7 car washes discharging waste to the channel. It is suspected that the waste disposed of at secondary channels contains lead. Research conducted by Nadeak et al. (2015) found the lead level in the sample of liquid waste at 3 small workshops in Tanjungpinang City were 0.6633 mg/L, 0.3423 mg/L, and 0.2744 mg/L, exceeded the threshold level.

The secondary irrigation channels at stations II and III also receive agricultural waste such as fertilizers and pesticides which contain lead. Research conducted by Sukarjo et al. (2018) found that applying fertilizers to rice plants can increase the content of lead in soil and rice plants.

The secondary irrigation channels at stations II and III are also close to roads with high motor vehicle mobilization producing smoke from the combustion engine, which crystallizes in the air, is carried away by the rain, and then enters the waterways. Research conducted by Reffiane et al. (2011) found that the concentration of lead in the air in the Semarang, which is densely populated with vehicles, as around 2-4 $\mu g/Nm^3$, whereas, in rural areas where the cars were less dense, it was less than 0.2 $\mu g/Nm^3$. The high concentration of lead in city air is due to the use of fuel that still contains tetraethyl lead (TEL) as an additive to increase the octane value of the fuel (Eshmat et al., 2014). Pratama et al. (2012) reported that the lead content in Tapak River ranged from 0.01 to 1.11 ppm, which was thought to come from motorized vehicle pollutants in water bodies.

The lead content in water at station IV was low, i.e., 0.38 mg/L, due to the large channel size and the high current speed. High current velocity can cause dilution, which affects lead levels in the waters (Happy et al. 2012)

The lead content in gastropods, water, and sediment were higher than the lead content found in secondary data from DLHK Gorontalo province. The secondary data shows that the lead level in the water in the Bolango river, which is the source of water for irrigating the secondary irrigation channel, is <0.002 mg/L. The high lead content in this study is thought to be caused by waste disposal into secondary irrigation channels. Environmental parameters also affect the levels of heavy metal lead in water. The highest temperature occurred at station II, and station III, which was 30 °C, and both stations also had the highest levels of lead in the water, namely 1.30 mg/L-1.69 mg/L.

The lowest dissolved oxygen levels were found at stations II and III, namely 3.1 mg/L and 1.3 mg/L, respectively, while the highest DO was found at stations I and IV, namely 4.8 mg/L and 4.0 mg/L, respectively. A low DO concentration value can indicate that the waters are polluted. Yunitawati's (2012) research reported that dissolved oxygen in the Cantigi river ranged from 1.11-4.1 mg/L, indicating moderately polluted the Cantigi river.

Lead measurements were also carried out in the sediment because sediment is widely used to indicate the environment contaminated with metals in water (Ali et al., 2016). Research on heavy metals in sediment and water can measure the impact of metals produced by industry, households, and activities that can cause water pollution. The lead levels in the secondary channels ranged from 0.5290 mg/kg to 1.1268 mg/kg, exceeding the threshold set by the Minister of Environment Regulation number 51 of 2004, which is 0.07 mg/kg.

Generally, the lead content in the sediment is higher than in the water because the heavy metals will settle in the sediment. Cahyani (2017) found that the levels of lead in water ranged from 0.042-0.104 mg/kg while in the sediment ranged from 1.56-1.98 mg/kg. Environmental factors, namely temperature, influence the concentration of lead in the sediment. Happy (2012) states that the drop in water temperature will cause metals to settle into the sediments easily. Parallui (2013) also states that an increase in seawater temperature can reduce the absorption of heavy metals in fine particles from the pollution that settles on the bottom of the water. When the water temperature rises, heavy metal compounds will dissolve due to the decrease in settlement velocity into the particles. The lowest temperature in the secondary irrigation channel occurred at the station I, namely 24°C.

Gastropods can be used as bioindicators of environmental pollution because they have low mobility characteristics, live in the bottom of the waters, and are filter feeders. Generally, *Pomacea canaliculata* and *Bellamnya sp.* filter the food around them. Widowati et al. (2019) state that golden snails get food by filtering food to accumulate lead.

Gastropods were found only in 2 observation stations, namely at stations II and III. At station II there were 2 species of Gastropods, namely *Bellamnya* sp. and *Pomacea canaliculata* and at station III, only 1 species, namely *Pomacea canaliculata*. Gastropods were found in only 2 stations because these stations have muddy substrates, which gastropods prefer, and are close to rice fields. Isnaningsih et al. (2011) state *Pomacea canaliculata* can be found in rice fields, lakes, or swamps, and these snails like muddy substrates. Sari et al. (2011) also state that *Bellamnya* sp. likes muddy substrates and running water.

The lead levels in gastropods ranged from 0.1873 mg/kg to 0.2924 mg/kg, much lower than the threshold set in SNI 7387: 2009 regarding the maximum limit of lead contamination in food, which is 1.0 mg/kg. The lead content in gastropods was lower than the lead content in water, which was 0.37 mg/L to 1.69 mg/L. This is in contrast with the results of research conducted by Wulandari et al. (2012) that the lead content in *S. glomerata* oysters was higher than in water, namely 0.505 mg/kg-2,960 mg/kg, and in water only 0.0035 mg/L-0.0470 mg/L. Physiological processes probably cause a lower lead level in the gastropods than in the waters in the snail's body. The body of the snail has the protein metallothionein (MT), which can bind lead in the body. The MT residual thiols. There are 2 domains that function to bind different metals, namely α- and β- (Smith et al. 2015)

Metallothionein is divided into 4 groups: MTI, MTII, MTIII, and MTIV. Metallothionein can be found in all living things such as bacteria, mammals, vertebrates, and invertebrates. MT can also be found in various body tissues such as kidneys, liver, testes, muscles, intestines, gills, blood, epithelial cells and urine. The MT concentration will increase if the organism accumulates more heavy metals in its body. After being detoxified, heavy metals will be excreted in the urine (Engel 1984).

The low level of lead in the snails' body compared to the level of lead in the water may also be caused by the small size of the snail, so the possibility of contact between the snails and the lead in the water was low. This was confirmed by Wulandari et al. (2012) who stated that the high Pb content in *S. glomerata* oysters was influenced by the width, height, and length, and so, a large oyster was able to accumulate more metal than the small one. This study concluded that the lead levels in water, sediment and gastropods in the study sites exceeded the threshold set by the government.

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Effect of climatic and non-climatic factors on fishing activities in Lake Victoria, Kisumu County, Kenya

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Abstract. *Akoth AJ, Mahiri OS, Obiero K. 2021. Influence of climatic and non-climatic factors on fishing activities in Lake Victoria, Kisumu County, Kenya. Intl J Bonorowo Wetlands 11: 7-17.* This study aimed to determine the impact of climatic factors like dry spells, rainfall, wind strength, and non-climatic factors like overfishing, water hyacinth, and predators on fishing activities on the shores of Lake Victoria in Kisumu County. The research used a descriptive survey design. The study area comprised thirty-two beaches, of which eight were chosen to represent Kisumu County as a whole. The eight beaches were sampled using a systematic sampling technique. The data was collected using a sample size of 362 respondents. Over the past ten years, fish landing data was collected at the beaches and the Kenya Marine and Fisheries Research Institute (KEMFRI), while climate data was received from the Kisumu Airport Regional Meteorological Department. Primary data was collected from the beaches using questionnaires and interviews, whereas secondary data was collected from KEMFRI using document analysis guidance, books, and publications. The results were processed and analyzed with the help of the Statistical Package for Social Sciences (SPSS) application, which assisted in the calculation of frequencies, means, and percentages. The study discovered a linkage between climatic factors and fishing activity. According to the study, climatic factors and fishing activities have a substantial relationship. The amount of rainfall affected fish captures, albeit the effect differed by fish species; *Oreochromis* (r =.260), *Lates niloticus* (r =.130), and *Protopterus* (r =.184) had positive correlations with rainfall, whereas *Rastrinoebola argentea* and *Claras gariepinus* had negative correlations. Overall, the findings showed a positive correlation coefficient (r =.079) between rain and total fish catch. Fish numbers in the lake have decreased due to a dry season accompanied by high temperatures. A strong wind had a negative impact on fishing activities, whereas mild to moderate wind favored fish catch. Non-climatic factors had a significant detrimental effect on fishing activity in Lake Victoria, according to the study. The researcher came to the following conclusions based on the findings: there was a relationship between climatic elements and fishing activities; non-climatic factors primarily influenced fishing activities negatively; however, fishers implemented mitigation strategies to help address non-climatic factors. Policymakers should regulate fish harvesting as dictated by climatic and weather variations, assess the impact of non-climatic elements in fish production, and recommend appropriate mitigation measures. Finally, regulations should be enhanced to save endangered fish species from extinction, according to the findings.

Keywords: Climatic elements, fishing, Kisumu, Lake Victoria, non-climatic factors

INTRODUCTION

Fishing is one of the oldest activities of civilization, and it is practiced for both sustenance and commercial purposes throughout the world. It is highly commercialized in developed countries while primarily carried out for subsistence in developing countries. Fishing occurs along the coast, in sheltered seas, and inland freshwaters (Kimathi et al., 2013). The primary fishing grounds of the world, on the other hand, are found in the chilly waters of the Pacific and Atlantic coasts in the northern hemisphere's temperate latitudes. Each contributes 40% of global yearly fish catches, with the Indian Ocean accounting for roughly 4% and aquaculture accounting for about 15%. (Aloo-Obudho 2010). In many regions of the world, fish has been a significant element of people's diets since time immemorial. Because of advances in technology, such as more powerful engines and advanced equipment, fish catches have increased dramatically during the last century.

Although fishery resources are renewable, they can also be depleted depending on how they are utilized, or an optimal benefit cannot be realized due to the industry's numerous problems. In the realm of fisheries, decline and variety in fish catch are a fact of life. Many climatic and non-climatic factors can have an impact on fishing activities. For example, the Intergovernmental Panel on Climate Change (IPCC) (2001), as reported by Muthama et al. (2007), stated that oscillations in fish abundance are increasingly being viewed as biological reactions to medium-term climatic variations, as well as overfishing and other anthropogenic influences.

Lake Victoria, the world's second-biggest freshwater lake by surface area (68,800 km^2), houses a large community of fishermen who rely on the lake for their livelihood (Karsin 2001). Tanzania, Kenya, and Uganda share the lake's borders. It is 1,134 m asl., has a volume of 2,760 km^3, and average and maximum depths of 40 and 80 meters, respectively (Andjelic, 1999). The threat to Lake Victoria's biodiversity continues to grow, with fisheries being the most visible example. Ochieng (2012) studied the Lake Victoria aquatic system for nearly ten years and discovered that a significant section of the cichlid fauna formerly thought extinct is still alive. He also found that Lake Victoria's Nile perch standing stocks declined while the small pelagics increased. Overfishing, illicit fishing gear, and environmental degradation in the catchment areas contribute to the loss of Nile perch. Because of nutrient levels, different parts of the lake produce varied amounts of fish. *Clarias gariepianus*, *Protopterus aethiopicus*, *Ovechromis* spp., and *haplochromines spp*. have all boosted their captures due to the growth of water hyacinth. The herb provides a safe haven, nesting grounds, and food sources (Njiru et al., 2012). Higher construction along the coastline combined with increased rainfall can generate run-off, alter water flows, and cause sedimentation in coastal waters, according to a report released by the Wildlife Conservation Society (WCS) on August 12th, 2011 (WCS 2011). Unsustainable levels of fishing and the effects of global climate change, according to the report, are the greatest dangers to the country's marine ecosystems, both of which have wreaked havoc on the Indian Ocean coral reefs. Inland fishing grounds in Kenya, such as Lakes Turkana, Naivasha, Victoria, and significant rivers like the Tana and Nzoia, are witnessing fish population declines due to climate change and other factors (Ochieng 2012).

Earlier studies have found that climatic and non-climatic factors impact fishing operations in the areas where they were conducted (LVEMP 2011; Okonga 2010); this has yet to be proven in Kisumu County. As a result, this research aimed to identify the relationship between climatic factors and fishing activities, specifically regarding the different types of fish caught and the number of fish caught throughout the rainy and dry seasons. It also looked at how non-climatic factors affected the volume and variety of fish captured.

The objective of this study was to (i) to determine the relationship between climatic elements and fishing activities, (ii) to determine the relationship between non-climatic factors and fishing activities, (iii) to examine fishers' mitigation measures for dealing with the influence of climatic elements and non-climatic factors on fishing activities.

MATERIALS AND METHODS

Research design

The descriptive survey research design was utilized in this study to acquire information from the sample population on the impact of climate variability on fish production using both quantitative and qualitative methodologies. According to (Muganda 2010), the purpose of a descriptive study is to provide the researcher with a profile or to describe relevant features of the phenomena of interest from an individual, organization, industry, or another perspective. The descriptive survey design was adopted for this study because it allowed the researcher to describe elements that influence fishing activity in Lake Victoria in great detail.

Study area

This research was carried out on the beaches of Kisumu County, Kenya, which are located along the Lake Victoria shoreline (Figure 1). Kisumu County is located in the Lake area. It is bordered on the south by Lake Victoria, on the north by Siaya County, Vihiga County, and Nandi County. On the northeast by Kericho County and the south by Homa-Bay County. With a surface area of 69,000 square kilometers, Lake Victoria is the world's second-largest lake. Tanzania holds 49% of the lake's area, Uganda 45%, and Kenya 6%. Lake Victoria dominates Kenya's fishing sector. It accounted for 94% of the entire catch of 193,789 tonnes of fish in 1995, while marine fishing accounted for 3%. (Omwenga et al. 2004).

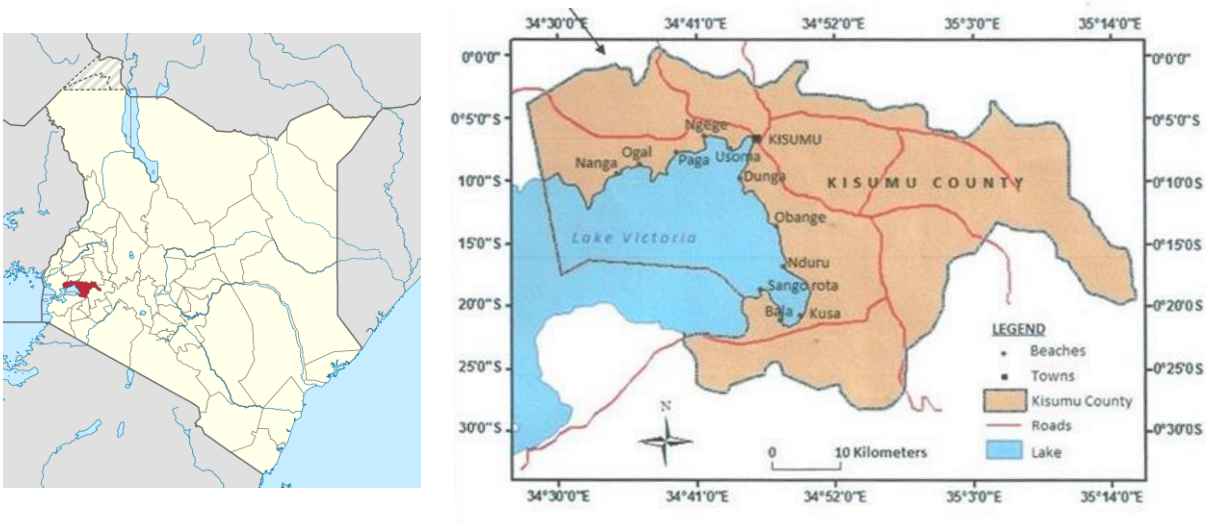

Figure 1. Some beaches along the shoreline of Lake Victoria, Kisumu County, Kenya

Kisumu County is located between latitudes 00^o 00,‟ and $00^0$30‟S and longitudes 34^0 28‟ E and $35^0$15‟E. Kisumu County has a total area of 2,085 km^2, 20% of which is covered by water, primarily Lake Victoria. The research was carried out on the beaches of Kisumu County, which run along the shore of Lake Victoria. Kisumu County is divided into six districts. However, the shoreline only stretches over three of them: Kisumu West, Kisumu East, and Nyando. In these three districts, there are thirty-two beaches. In Table 1, the names of the beaches are listed.

Climate

Kisumu County enjoys various climate conditions between Lake Victoria’s north and south coasts (GoK 2008a, 2008b, and 2008c). The northern side, which includes both the Kisumu East and Kisumu West districts, has an average yearly temperature of 20^0C to 35^0C degrees Celsius. The annual rainfall pattern in the County (Figure 2) is bimodal, with long rains falling between March and May and short rains falling between September and November. As documented at the Maseno Agricultural Training Centre, some locations endowed with hills, such as Maseno Division and Muhoroni, receive considerable rainfall ranging between 1500mm and 1800mm yearly (GoK 2008a) (ATC). Low-altitude areas, such as the Kano lowlands and Kombewa Division, receive less yearly rainfall, ranging from 600 to 1280 mm.

Socio-economic activities

Kisumu County's socio-economic activities are influenced by various circumstances, including rainfall consistency and closeness to Lake Victoria (GoK 2008a, 2008b, and 2008c). Fishing is the primary source of income for people who live on Lake Victoria's shoreline, while agriculture is the primary source of income for those who live further away. *Restrineobola argentea*, *Oreochromis spp.*, *Lates niloticus*, *Protoptrerus spp.*, *Clarias gariepinus*, *Haplochromine spp*., and *Synodontis spp*. are economically exploited fish species in Lake Victoria, Kisumu County, according to Omoro (2011). According to him, sugarcane is the principal cash crop farmed in Kisumu County, especially in Muhoroni, Miwani, Kibos, and sections of Nyando District. Rice is another cash crop cultivated along the Nyando and Awach rivers banks near Miwani and lower Nyakach, respectively. The County is home to the Ahero and West Kano irrigation schemes used for rice cultivation.

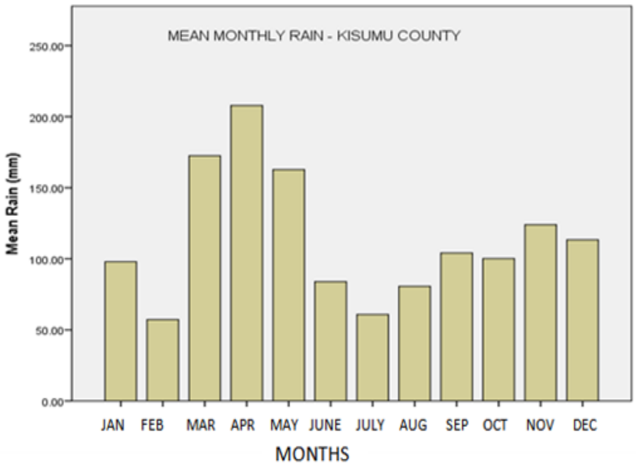

Figure 2. Mean monthly rainfall distribution over Lake Victoria, Kisumu County (2009- 2011). Source: Kenya Meteorological Department-Kisumu Airport (2014).

Table 1. Beach Management Units in Kisumu County, Kenya

Kisumu West	Population of fishermen	Kisumu East	Population of fishermen	Nyando District	Population of fishermen	Total Population
Asat	183	Paga	173	Singida	109	
Arongo	70	Usoma	76	Kusa	230	
Nanga	155	Nyandiwa	52	Kombewa	230	
Kihanja	55	Oseth/Obange	126	Bala	120	
Nyamarwaka	149	Kaloleni	61	Sangorota	270	
Kobudho	123	Rare	201	Koguta	220	
Kagwel	36	Ugwe	55			
Othany	98	Ochok	68			
Kaloka	91	Ongenya	84			
Bao	252	Usare	141			
		Nduru	86			
		Ogal	60			
		Ngege	83			
		Dunga	393			
		Kichinjio	233			
		Mawembe	110			
Total	**1, 212**		**2, 002**		**1, 179**	**4, 393**

Source: GoK (2008a, 2008b, 2008c)

Food crops such as maize, beans, sorghum, cowpeas, and fruits have great promise in high-altitude locations like Maseno, Muhoroni, and Upper Nyakach, which receive consistent rainfall. In the high-altitude areas of Koru, Muhoroni, and Maseno, livestock rearing is done, particularly dairy cattle. Other economic activities like trade and industry predominate in the county's metropolitan centers. Sugar factories in Kibos, Chemelil, and Muhoroni and rice milling in Ahero and Kibos are among them (Okonga 2010).

Target population

This research focused on all 32 landing beaches along Lake Victoria's shoreline in Kisumu County. Ten of the 32 beaches are in the Kisumu West District, 16 in the Kisumu East District, and six in the Nyando District. A total of 4,393 registered fishers make up the target population (Table 1). This is based on the GOK District Development Plans (2008).

Sampling technique and sample size

According to Cohen and Manion (2006), A study of social science nature requires the selection of at least a quarter of the sampling units. Because this is a social scientific study, 8 beaches were sampled using a systematic sampling technique, accounting for 25% of the 32 beaches in Kisumu County on Lake Victoria. Table 2 demonstrates how Cohen and Manion's 25% rule was used to estimate the sample size (2006). Kisumu County was chosen from neighboring counties around the Lake Victoria shoreline using a purposive sample strategy. The most appropriate sampling technique utilized to determine the visited beaches was systematic random sampling due to the minimal landing beaches. Furthermore, the researcher provided all of the beaches that took part in the study an equal opportunity. The 8 beaches were identified by selecting every 4th beach in Kisumu West District, then Kisumu East, and finally Nyando District, starting with the first one listed alphabetically in Kisumu West District. According to Kombo and Tromp, this procedure was fair because it was not biased (2006). A sample size of 354 fishers and 8 beach managers from the sampled beaches were utilized as respondents to acquire data from the study region, representing 25% of the total population of the examined 8 beaches. As a result, there were 354 responders in the research region (Table 2).

Data collection

Questionnaires were distributed to the sampled respondents in the 8 selected beaches within Kisumu County to obtain primary data.

Questionnaire

According to Orodho (2012), A questionnaire is used to acquire information and viewpoints about a phenomenon from knowledgeable persons about the subject. Questionnaires are by far the most widely utilized data collection tool. A questionnaire was used to collect data from both teachers and students in this study. According to Musungu and Nasongo, the questionnaire was an appropriate form of data acquisition because it allowed the researcher to reach many people in a short amount of time (2008). It also ensured secrecy, allowing for more candid and objective data to be acquired. Questionnaires were utilized to collect primary data from fishers, including fish species and daily catch amounts, the impact of climatic and non-climatic conditions on fish activities, and potential mitigation methods. Two portions were divided into the questionnaires. The first half comprised questions about the background of fishers, while the second portion contained questions concerning beach fishing practices. The return rate for fishers' questionnaires was 84.2% (298 fishers).

Interview guide

According to Keith (2006), An interview schedule is a guide that an interviewer adopts when conducting a structured interview. It consists of two parts: a list of questions that must be answered precisely as written and guidelines for the interviewer on how to answer the questions. The questions are listed in the order that they will be asked. The questions are constructed to be administered literally, word by word. Not only must the questions express what information is being requested of respondents, but they must also indicate the form or manner in which respondents are to respond to the questions. Interviews are used to follow up on questionnaire results in depth with smaller samples, according to Orodho (2008). The researcher interviewed the beach managers in-depth, mostly asking open-ended questions about factors impacting fishing operations. Keith stated that an in-depth interview was selected since it was both rich in contextual information and profound incomprehension (2006). It was also deemed perfect because the researcher was looking for personal interpretations and perspectives of beach managers. The researcher made personal notes during the interview process with the beach managers as a method for later coding and analysis.

The interviews focused on factors such as species and monthly fish landings from 2001 to 2011, which is the most current ten years period. Given that the beach managers provided information based on their recall, this period was appropriate. The study also employed interviews with beach managers to learn more about the impact of climatic and non-climatic elements on fishing activities. Beach managers who have been fishing for the past ten years regularly between 2001 and 2011 were deemed significant informants for the study. The researcher spoke with beach managers who stated that they had been active in fishing activities in the area for at least ten years before 2011.

Table 2. Selected beaches and sampling grid (GOK 2008)

Beach name (n = 8)	Beach manager	Registered fishermen	No. of fishermen	Sample size (%)
Kihanja	1	55	14	25.45
Othany	1	98	25	25.51
Usoma	1	76	19	25.00
Rare	1	201	50	24.87
Usare	1	141	35	24.82
Dunga	1	393	98	24.94
Kusa	1	230	58	25.22
Koguta	1	220	55	25.00
Total	8	1, 414	354	25.04

Document analysis guide

According to Kombo (2006), Document analysis is a social research method and a vital research instrument in and of itself and an essential component of most triangulation methods. Documentary research utilizes outside sources, such as documents, to support the viewpoint or thesis of academic work. Documentary research frequently entails some or all of the following steps: conceptualizing, using, and evaluating documents. In documentary research, the records are either quantitatively or qualitatively analyzed (or both). All researchers who utilize documents in their research must consider the specific issues surrounding types of documents and their ability to use them as credible sources of evidence in the social world.

Document Analysis Guide was utilized to obtain secondary data from the Kenya Marine and Fisheries Department, Kisumu County; the Kisumu Meteorological Station in the current study, which used two types of datasets, namely climatic and fisheries data. The researchers used documented data on monthly fish landings for the past 10 years from 2001-to 2011. This was available from the Kenya Marine and Fisheries Department in Kisumu and visited the beaches. By evaluating information provided by the Kenya Marine Fisheries Department, data on the number of fish collected on the beaches was established. The weight of fish or fish landings (in kilograms) in Kisumu County beaches were utilized as the fishing data. Monthly data on the volume and fish species was available from 2005 to 2011, while annual statistics were available for regions from 2001 to 2011. This data was obtained from a document analysis guide. Secondary data on meteorological factors such as rainfall and temperature, on the other hand, was acquired from Kisumu's Meteorological Department to establish the trend of these variables during the same period (2001 to 2011). The data were collected daily. Rainfall and temperature data were reliable. However, the data about wind speed and direction provided by Kenya Meteorological Department was limited.

Data analysis

Data were analyzed using both quantitative and qualitative methods. Before being grouped into the numerous topics of the research objectives, the qualitative data was edited, paraphrased, and summarized for easier understanding. The researcher presented the data in direct verbatim or narrative form. This helped to complement the findings from the quantitative data. The researcher employed descriptive and inferential statistics to analyze the quantitative data. Tables, charts, and graphs were utilized to display the findings, while descriptive statistics such as mean, frequencies, and percentages were employed to summarize the data. To form inferences and draw conclusions, inferential statistics were used. Pearson's product-moment of correlation, which was used to analyze the association between yearly rainfall and fish abundance, was the most common inferential statistic utilized. All significance tests were performed with a significance level of 0.05. Because of its versatility and ability to manipulate vast amounts of data, the Statistical Package for Social Sciences (SPSS) version 20 was used to analyze the data.

Data management and ethical considerations

All respondents were adequately informed about the purpose of the study and the consequences of participating. On the other hand, the researcher kept all respondents' identities private, and the information gathered from them was used for no other purpose than the research. All of the sources used in this study were credited correctly.

RESULTS AND DISCUSSION

Demographic characteristics of the respondents

Age, degree of education, marital status, other sources of income, experience in fishing activities, and average fishing income were among the demographic features of the respondents discussed. These factors were significant in the study because they influenced fishing activity.

Age of respondents

Table 3 shows that 90.6% of the respondents (fishermen) were over the age of 20, compared to 9.4% between 15 and 19. The majority of the fishers were adults, indicating that they were legal age to engage in fishing activities. Class 8 and Form 4 leavers who had recently taken up fishing as a source of income were identified as those between 15 and 19.

The educational level of respondents

Table 4 shows that the majority of the sampled fishermen (69.46%) had completed primary school, 23.15% had completed secondary school, and the remainder, 7.39%, had only completed nursery school. This indicates that primary education was the highest degree of education for the majority of the sampled fishers. There was no respondent among the sampled fishers who had received any college education. This is attributable to the fact that fishing operations do not necessitate any specific knowledge; most fishers are apprentice graduates.

Marital status of respondents

The study's findings suggest that 70.1% of the sampled fisherman were married, 24% were single, and 4% were widowers/widowers, as shown in Figure 3. The majority of the fisherman interviewed were married, according to the findings. Because of the lower levels of education (Table 4), many young people begin their family lives soon after dropping out of school. This was most likely the reason why, despite their youth, the majority of the fisherman polled had already married.

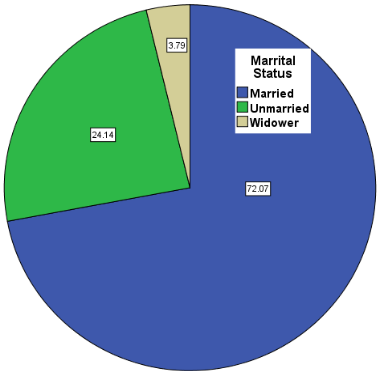

Figure 3. Marital status of the fishermen

Table 3. Age of respondents

Age category (years)	Frequency (n=298)	Percentage (%)
15-19	28	9.40
20-25	69	23.15
26-30	63	21.14
31+	138	46.31
Total	298	100.00

Table 4. Educational levels of the respondents.

Level of education	Frequency (n=298)	Percentage (%)
College Level	0	0.0
Secondary	69	23.15
Primary	207	69.46
Nursery	22	7.39
Total	298	100.00

Table 5. Availability of other sources of income among the fishers.

Availability of other sources of income	Frequency (n=298)	Percentage (%)
Yes	96	32.21
No	202	67.79
Total	298	100.00

Table 6. Other sources of income among the fishers.

Another source of income	Frequency (n=96)	Percentage (%)
Business	59	61.46
Farming	29	30.21
Pension	8	8.33
Total	96	100.00

Other sources of income

Only 32.2% of fishers were involved in other income-generating activities, as shown in Table 5, while the remaining 67.8% relied only on fishing for their livelihood. These findings suggested that fishing was the sole source of income for the majority of the fishers. As a result, the fishing activities in Lake Victoria, Kisumu County, were economically significant to the residents. Those fishermen who answered they had other sources of income were asked to specify what type of source they got their money from, and the results are shown in Table 6.

Table 6 illustrates that the fishers earned money through various activities other than fishing. 61.5% of fishers had other sources of income, 30.2% were farmers, and 8.3% were retirees who relied on pensions. This could indicate that the revenue generated by the sampled fishers' fishing operations was insufficient, necessitating the need to augment it with other sources of income. These findings were supported by results from the interviews, which revealed that weighted fish captured at the eight beaches only ranged from 1000 kg to 6,000 kg each month on average. According to the beach manager, only one of the beaches had a monthly weighted fish catch of 45,000 kg. In terms of monetary worth, these proved insufficient to adequately support families whose breadwinners were only engaged in fishing operations, as indicated in Table 8.

Experience of fishing among fishermen

The fishers were questioned about their experience in the fishing industry. Given that fishing abilities are acquired informally through apprenticeship, it was thought that their responses would allow the study to measure the level of fishing knowledge among the fishers. The fishers' responses are listed in Table 7.

Table 7 revealed that most of the sampled fishers (57.1%) had more than ten years of fishing experience. As a result, the majority of the fisherman polled had sufficient fishing experience. This data was judged to be relevant since it revealed that the responses provided by the sampled fishermen were reliable, based on their extensive experience fishing in Lake Victoria. This information is consistent with that gathered from the interviews with the beach managers, which revealed that seven of the eight managers had served in the same role at the same beach for periods ranging from one to seven years.

The average income per month from fishing

Having established the existence of other sources of income among the fishers, the study sought to determine how much income the fishers realized on average from their fishing activities per month. The researcher explored the fishers' income from fishing activities to gather responses to this question. The average monthly income per fisherman is summarized in Table 8.

Table 8 shows that 38.6% of the sampled fishers had a monthly average income of Kshs.3,000 or less, while 38.6% had a monthly average of Kshs.3,001-Kshs.7,000. As a result, it is evident that the bulk of the sampled fisherman had a very low average income, with only roughly 22% having an average income of more than Kshs.7,000. These statistics explain why most fishers may need to supplement their income from fishing with other sources of income such as farming and business. One of the reasons the fishers had no other sources of income was a lack of capital to diversify into other income-generating enterprises.

Table 7. Experience among the fishermen

Fishing Experience	Frequency (n=298)	Percentage (%)
10 years & below	128	42.95
11-15years	58	19.46
16+ years	112	37.59
Total	298	100.00

Table 8. Fishers' average income from fishing per month.

Average income (Ksh.)	Frequency (n=298)	Percentage (%)
1-1,000	8	2.68
1,001-2,000	70	23.49
2,001-3,000	37	12.42
3,001-4,000	0	0.00
4,001-5,000	57	19.13
5,001-6,000	0	0.00
6,001-7,000	58	19.46
Above 7,000	68	22.82
Total	298	100.00

Table 9. Average annual weight and value of fish catch from Lake Victoria, Kisumu County.

Type of Fish	Weight (kg)	Value (Ksh.)	Value per kg (Ksh)
Oreochromis spp.	268,361	21,222,638	79.10
Lates niloticus	359,223	29,732,933	82.80
Rastrinoebola argentea	408,427	14,984,296	36.70
Clarias gariepinus	135,140	7,957,835	58.90
Protopterus spp.	57,809	3,205,514	55.50
Others	68,981	2,465,803	35.80
Total	1,297,941	79,569,019	

Source: Compiled from Kisumu County Fisheries Department (2014)

Type and amounts of fish caught in Lake Victoria

The researcher conducted a documentary examination of the records of fish caught by species and the monetary worth annually to determine the kind and number of fish caught. *Rastrineobola argentea, Lates niloticus, Clarias gariepinus, Oreochromis spp., Protopterus spp., Haplochromine spp., Schilbe spp., Labeo spp.,* and *Synodontis spp.* were among the principal fish species found in Lake Victoria, according to the findings. The most common fish captured were *Oreochromis spp., Rastrineobola argentea, Clarias gariepinus, Protopterus spp.*, and *Lates niloticus.* Table 9 shows that the weight and value of the five most prevalent varieties of fish taken in Lake Victoria vary significantly. The weight of the fish caught was recorded in kilograms, and the value was calculated using the market price paid at the landing beach.

Table 9 shows the annual average volume and value of several types of fish collected from 2001 to 2011, as calculated from Kisumu County Fisheries Department records.

Annually, 1,297,941 kg of fish worth Ksh.79,569,019 were taken in Kisumu County's Lake Victoria. *Lates niloticus* brought in the most money (Kshs. 29,732,933) annually, followed by *Oreochromis* spp. at Ksh.21,222,638 and *Rastrinoebola argentea*, which had the most significant weight (almost 4 tonnes annually) and generated Ksh.14,984,296 on an annual basis. This investigation shows that, although having the largest catchweight, *Rastrinoebola argentea* has a poor value compared to *Oreochromis spp.* and *Lates niloticus.*

Relationship between climatic elements and fishing activities

One of the research problems addressed in this study was the association between climatic conditions and fishing activity in Kisumu County's Lake Victoria. Winds (both strong and mild), rainfall, and dry spells were among the meteorological conditions evaluated in this context. The responders responded by describing how each climatic aspect had affected their Lake Victoria fishing operations.

Effects of winds on fishing activities in Lake Victoria

During the discussions with the beach managers, it became clear that the winds that blow over Lake Victoria are diverse. The fisherman divided the winds into two categories: strong and mild. However, the study's findings demonstrated that mild or strong wind could influence fish behavior and, ultimately, fishing operations. According to the study, winds affected fishing in Lake Victoria in diverse ways (Table 10). Mild breeze has been proven to have a favorable impact on fish catch because it stimulates fish movement in the water, allowing fishers to catch fish that would otherwise hide deep in the lake bed. According to the study's findings, mild winds block the penetration of the sun's rays into the water, creating a favorable environment for fish growth and development. Winds also freshen the water by mixing it, providing a healthy environment for fish to flourish.

Table 10 summarizes the fishers' responses to the impact of wind on their fishing activities in Lake Victoria. The study discovered that moderate wind speeds were adequate for boat movement on the water and that mild winds generated a more favorable atmosphere for fishing activities than severe winds. Strong winds were shown to have a greater negative impact; for example, 30.9% of fishers claimed they couldn't sail on the lake effectively during strong winds, and 3.7% said strong winds hindered the fish passage because water weed stuck to the water surface. Fishers identified other difficulties in response to strong winds, including boat accidents in the lake (44.30%). Losses of bait and already caught fish were reported by 11.4% and 9.7% of the fishers, respectively. 43.3% of fishers stated they slowed down their movement during fishing in the water during mild winds, while 56.7% claimed they saw greater fish productivity during mild winds.

Table 10. Effect of winds on fishing activities.

Effect of strong winds	Frequency (n = 298)	Percentage (%)
Hinder the fishers from sailing in their boats	92	30.87
Sticking water weeds blocks the way of fish	11	3.69
Accidents to the fishermen	132	44.30
Loss of fish already caught	29	9.73
Loss of baits used by the fishermen	34	11.41
Total	298	100.00
Effect of mild winds	Freq. (n=29 8)	Perc. (%)
Slow down movement of fishermen	129	43.29
Increased fish production	169	56.71
Total	298	100.00

The beach managers have noticed that little fish rise to the water's surface as the wind strength lowers. As a result of these findings, mild winds had a greater positive impact on fishing activities than severe winds, negatively affecting fishing activities. As a component of the climate, this means that wind impacts fishing activities. These findings supported the postulation of Ogutu-Ohwayo that wind speed and direction, among other things, can drastically alter fish population abundance, dispersion, and availability. The association between wind and fishing activity was also validated in oral interviews with beach managers, which agreed with the fishers' comments. One of the beach managers at one of the beaches in the research area, for example, said: "Mild winds, such as Kus and Matarae, are known for bringing a lot of rain and fish. This promotes fishing by facilitating fish feeding, boat movement, and mixing the water in the lake. There is very little fishing when these two breezes do not blow. Strong winds such as Nyamranga and Nyamaseno, on the other hand, can be extremely dangerous and can blow at any time. Such hazardous winds reduce fishing activity by causing fish to hide in the mud, breaking boats, and potentially killing fisherman in accidents."

Effects of rain on fishing activities

Table 11 shows that most fishermen (58.4%) said that fish were swept away by floods after heavy rains, whereas 5% said that fish died due to the severe downpours. However, 35.2% of respondents stated their fish harvest increased as the rain increased, while 1.4% of fishers said they became ill after extreme downpours. According to these data, heavy rains had various consequences on fishing in Lake Victoria. Brander (2007) concluded that rainfall event frequency and intensity were expected to significantly impact future fisheries productivity in both inland and marine systems. Although Brander (2007) did not specify how the frequency and intensity of rainfall affected fish productivity, this study found that fish catch was higher for several types of fish when there were significant rains. This was proven through an interview with beach managers, who ascribed the increase of *Lates niloticus* and *Protopterus spp.* to heavy rains.

The hypothesis that climate factors have no substantial influence on fishing activities in Lake Victoria, Kisumu County, was evaluated using bivariate Pearson moment correlation to establish the association between climatic elements and fishing activities in Lake Victoria, Kisumu County.

A Pearson correlation analysis was undertaken after preliminary investigations to establish that the assumptions of normality, linearity, and homoscedasticity were not violated. Table 12 summarizes the findings of a bivariate Pearson moment correlation between the amount of rain and the number of fish caught by a fisherman in Lake Victoria, Kisumu County. The correlation data demonstrated a relationship between heavy rains and the amounts of fish caught by fishers; there is a direct relationship between rainfall intensity and the amounts of fish caught (Table 12). The findings of a correlation analysis of rainfall data and fish capture records revealed that rainfall had a significant positive relationship with fish catches for several types of fish (Table 12). This suggested that rainfall affected fish catches in Lake Victoria, Kisumu County, even though the effect varied by fish type. While *Tilapia* (r =.260; sig. level =.033), *Lates niloticus* (r =.130; sig. level =.022), and *Protopterus spp.* (r=.184) showed a positive connection with rainfall; the amount of rainfall negatively correlated with *Rastrinoebola argentea* (-.786; sig. level=.051) and *Claras gariepinus* (r=-.012; sig. level =.014). Overall, the findings demonstrated a weak but positive correlation (r =.079, sig. level.025) between the rainfall and the total amount of fish caught. Based on these findings, it was concluded that, while rainfall intensity had both a negative and positive impact on fish caught in the lake, it was clear that, in general, the higher the amount of rain, the more fish caught.

Table 11. Effect of heavy rains on fishing activities

Effects of heavy rains	Frequency (n = 298)	Percentage (%)
Floods carry fish	174	58.38
Death of fish	15	5.03
Higher fish catch	105	35.24
Illness to fishermen	4	1.35
Total	298	100.00

Table 12. Correlation between fish catch and annual rainfall amount

Type of fish	Amount of rainfall	
	Pearson correlation	Sig. level (2-tailed)
Oreochromis spp.	.260	.033
Lates niloticus	.130	.022
Rastrinoebola argentea	-.786	.051
Clarias gariepinus	-.012	.014
Protopterus spp.	.184	.002
Overall	.079	.025

Note: *. Correlation is significant at the 0.05 level (2-tailed).

These connections can be explained by considering how rainfall re-distributes nutrients for fish in the lake, which impacts the fish's spawning time. Because Lake Victoria is an inland lake, our findings support Brander's (2007) claim that precipitation and water management changes impact inland fisheries. Heavy rains send silt and other debris into the lake, reducing the capture of *Nile perch* and *Tilapia*, but increasing the catch of indigenous fish such as lungfish and catfish, designed to survive without oxygen for short periods. This finding is similar to that of Barthem and Goulding (1997). They discovered that catfish are adapted to live in the muddy water because they have a highly developed organ called the Weberian apparatus that connects the inner ear, swim bladder, and lateral line system, making them sound specialists capable of preying in muddy areas.

As demonstrated in Table 12, the statistical non-significance (P.V =.051) was only recorded in the occurrence of Rastrinoebola argentea, which showed a negative correlation (r =-.786) with rain. However, it was also noticed in the conversation with the fishers that with severe rains, the fish catch normally increases. As a result, rainfall as a climatic component altered Lake Victoria’s fishing activities.

Effects of a dry spell on fishing activities in Lake Victoria

According to Table 13, 86.6% of fishers indicated a fish shortage during the dry spell; just 6.4% thought the fish catch rose during the dry period, and 7.04% said there was no change in fish caught. As a result, most of the fishers interviewed reported a fish shortage during the dry spell. These findings echoed those of Mackenzie and Koster (2004), who found that variations in water temperature impacted fish harvest in the Baltic and the Black Sea. In North Carolina, they discovered that sprat catches were substantially higher than usual during warm years than cold years (Baltic Sea).

The researcher interviewed the beach managers to remark on the effect of the dry spell on fishing activities in Lake Victoria to corroborate this finding with their perspectives, and this is what one of them said: “During a dry period, the fish catch decreases because the water along the coast is warmer, which inhibits fish occurrence. As a result, most fish migrate to the middle of the lake in search of cooler water. Because most fish species do not like warm water, the fish catch can drop to as low as 200kg per day and 1,800kg per month during this time. This means that beach managers confirmed that fish catch decreases during dry spells, a phenomenon they blame for rising water temperatures along the coast, which discourages fish occurrence; most fish swim deeper into the lake in search of calmer waters beneath. They claim that this drastically reduces the volume of fish caught. As a result of these data, it can be concluded that dry spells have a negative impact on fishing activities in Lake Victoria, Kisumu County.

Relationship between non-climatic factors and fishing activities in Lake Victoria

The effects of non-climatic factors were crucial to the researcher in this study because they would find other factors that they believed affected fishing activities in Lake Victoria. Non-climatic factors such as fishing gear theft, a lack of good technical skills, bad infrastructure, and a lack of sufficient finance, among others, were thought to have a substantial impact on Lake Victoria’s fishing activities. The fishers’ were asked to indicate factors that they believed influenced fishing activities in Lake Victoria; they were not limited to choosing just one factor but were free to choose all of the factors they believed influenced fishing activities. As a result, their responses in Table 14 had numerous responses to the identified factors. The proportion of respondents who identified each item as a factor affecting fishing activity in Lake Victoria is shown in the percentage column. Water hyacinth, lack of engine boats, theft of fishing gear in the water, lack of refrigeration facilities, limited capital, insecurity, predation, overfishing, and poor marketing, all of which led to overexploitation by individual businessmen, were some of the significant challenges faced by the fishers who took part in the study. Among all the non-climatic factors that the fishermen mentioned as affecting their fishing activities in Lake Victoria, water hyacinth stood out as the most influential factor, with a frequency percentage occurrence of 64.8%.

This is supported by Keteregga and Sterner's (2007) findings that water hyacinth was a significant threat to fishing and directly impacted fishing activity. According to the fishers, the hyacinth infestation in Lake Victoria has a lot of social and economic consequences for fishing. It has been discovered that its rapid development causes physical obstruction of streams and water abstraction units, obstructing water transit and obstructing fishing activities. It also produces a high number of long-lived seeds that can survive for an extended period, as well as a weed population that swiftly doubles. The weed creates a permanent floating vegetation cover over the highly productive open water surface, affecting the food web and ecological diversity. It was also discovered that the plant provided ideal breeding grounds for mosquitoes and other insects, leading to an increase in illness outbreaks among fishers. Furthermore, the weed suffocates aquatic life by deoxygenating the water, depletes nutrients for juvenile fish in sheltered bays, and disrupts local subsistence fishing by limiting access to beaches.

Table 13. Effect of dry spell on fishing activities

Effect of dry spell	Frequency (n = 298)	Percentage (%)
Shortage of fish	258	86.58
Increase in fish catch	19	6.38
No change in fish catch	21	7.04
Total	298	100.00

On the other hand, the presence of hyacinth was found to be more favorable to fish growth and development in a study by Njiru et al. (2012). Most fishers agree that the hyacinth mats should be left where they do not disrupt other economic activities. Whatever the case may be, it is critical to track the impact of water hyacinth on fisheries activities over time to understand better the linkages between fish population dynamics and hyacinth regrowth. According to an analysis of the fishers' responses, 36.9% of them believed that the presence of the Nile perch (Lates niloticus) in Lake Victoria had endangered other small fish. The aggressive predatory nature of the Nile perch wreaked havoc on the species composition of Lake Victoria. The Lake used to have a diverse range of fish species; however, once the Nile perch was introduced in the 1950s, this diversity was significantly decreased. This study's findings were similar to Ogari (2001) and Muthama et al. (2007). They found that Nile perch, as an invasive fish species, had a significant impact on the fish species composition of Lake Victoria. The presence of Nile perch, on the other hand, has contributed both negatively and positively to the Lake Victoria fisheries, according to this study. Improved export revenues, an increased supply of desirable protein food, increased fish productivity, and increased employment and earnings for fishers were all beneficial outcomes. According to the fishers, fishing activities in Lake Victoria have also been hampered by a lack of capital.

As shown in Table 14, security issues were another major factor affecting fishing activities in Kisumu County's Lake Victoria, with piracy (21.5%) and theft (28.5%) among the severe difficulties that needed to be addressed. The theft took place on two levels, including already caught fish and fishing equipment. The fishers would band together and sell fish in the lake before landing on the beaches, effectively cutting into the profits of the boat owners. Although piracy was not prevalent in Kisumu County's Lake Victoria, the study found a severe security issue that resulted in the loss of machinery, fish, and occasionally lives when fishers were attacked while on the lake. Another aspect that led to the exploitation of the fishers by middlemen was poor marketing (8.7%). It was discovered that middlemen would acquire fish from a fisher for a low price and then sell it for a higher price. Due to a lack of refrigeration, fish had to be sold as soon as caught, or they would decay. As a result, the fishers were willing to accept highly cheap rates because they were at the whim of the middlemen.

Finally, a lack of technical knowledge and relevant skills has been identified as a serious issue affecting the fishing business. Lack of technical expertise was cited by more than half of the respondents (56.7%) as a problem influencing fishing activities in Lake Victoria. The majority of fishers relied only on apprenticeship to learn the necessary skills. This was insufficient since the trainee fisherman would be taught by equally inexperienced instructors who, like the trainee fishers, relied solely on experience and lacked the necessary knowledge and abilities to back them up—mitigation measures to cope with the influence of climate and non-climatic factors on fishing activities in Lake Victoria.

Table 15 summarizes the procedures that fishermen in the studied area claimed they had put in place to deal with climatic and non-climatic factors influencing fishing activities in Lake Victoria. Table 15 shows that 24.2% of the surveyed fishers believed that increased security is one way to address safety concerns about fishing in Lake Victoria. It's worth noting that some of the respondents mentioned theft and piracy as some of the problems that affect their fishing activities. As a result, increased security may be able to help.

Table 15 shows that 66.1% of fishers believe that infrastructure development is better to address transportation problems they face while fishing. This indicates that most respondents believed a good road network around the beaches was necessary to increase lake fishing. The development of a strong road system could help with transportation within the fishing zone and open up the region to allow fishers access to necessary services such as health centers, schools for their children, and other social amenities. Because fish is a perishable product, better facilities such as electricity and large-scale refrigeration are required if fishers avoid significant losses and exploitation by middlemen. One approach to ensure this happened was to start road and electricity projects on these beaches; fostering a general improvement in the road network and electricity was crucial in fishing activity.

Table 14. Other factors affecting fishing activities in Lake Victoria

Another factor affecting fishing	Frequency (n = 298)	Percentage (%)
Water hyacinth	193	64.8
Pirates	64	21.5
Capital	145	48.7
Theft	85	28.5
Threat by other fish	110	36.9
Technical knowhow	169	56.7
Aquatic animals	52	17.4
Poor infrastructure	76	25.5
Poor marketing	26	8.7

Table 15. Mitigation measures on factors affecting fishing in Lake Victoria, Kenya

Mitigation measures	Frequency (n = 298)	Percentage (%)
Security	72	24.2
Development of infrastructure	197	66.1
Business	22	7.4
Farming	7	2.3
Total	298	100.00

In conclusion, according to the study findings, factors like mild winds, high rainfall, and cool temperatures all positively influenced fishing activities in Lake Victoria by resulting in high fish catches, as these created a conducive environment for fish to thrive. In contrast, other climatic factors like strong winds and high temperatures resulted in low fish catches, resulting in losses and reduced revenue. Non-climatic elements were shown to have a detrimental impact on fishing activity, according to the findings of the study. Fishing activities in the Lake were hampered by a lack of capital, theft among fishers, and water hyacinth. Although most of these non-climatic factors were outside the fishers' control because they were matters requiring county government intervention, the study revealed that the fishers had put in place some steps to help them avoid detrimental effects on their fishing business. They took deliberate action to strengthen security, clear the water hyacinth, restrict fishing locally, develop storage facilities, seek markets, and organize small fish cooperative societies to supply capital for better fishing equipment.

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Review: Economic impacts of the invasive species water hyacinth (*Eichhornia crassipes*): Case study of Rawapening Lake, Central Java, Indonesia

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Abstract. *Maulidyna A, Alicia F, Agustin HN, Dewi IR, Nurhidayah I, Dewangga A, Kusumaningrum L, Nugroho GD, Jumari, Setyawan AD. 2021. Review: Economic impacts of the invasive species water hyacinth (Eichhornia crassipes): Case study of Rawapening Lake, Central Java, Indonesia. Intl J Bonorowo Wetlands 11: 18-31.* Introduced species is defined as a conscious or unconscious effort to present a species of animal or plant into a new habitat. Introduced species have two pathways on their biogeographical distribution: becoming an invasive species or not becoming an invasive species. An introduced species that does not negatively impact the new habitat is not classified as an invasive species. In contrast, a species introduced that negatively impacts the new habitat is considered invasive. One problem that threatens freshwater ecosystems in Indonesia is the invasion of water hyacinth (*Eichhornia crassipes*). This introduced plant species can reproduce rapidly, both generatively and vegetatively, and form very dense masses in water bodies, such as swamps, lakes, rivers, and channels, including Rawapening Lake in Semarang District, Central Java Indonesia. This study is aimed to review the economic impacts of the invasive water hyacinth species in Rawapening Lake from two perspectives: the negative and the positive impacts so that feasible solutions can be developed. There are several negative impacts caused by water hyacinth in Rawapening Lake. The overgrown water hyacinth in the lake hinders the fishers in maneuvering the boats and fishing gears, reducing the fish catches. The extensive coverage of water hyacinth causes the reduction in soluble oxygen and blocks sunlight into the water, leading to the decline of the fish population. The rotten water hyacinth can obstruct the irrigation channels of the fields so that farmers cannot produce maximum rice harvests, and eradicating them would incur financial costs. On the other hand, there are also positive impacts of water hyacinth in Rawapening Lake. This plant can be used as raw materials to produce a variety of handicrafts in the form of bags, sandals, baskets, wallets, and furniture such as chairs and tables. Water hyacinth can also be processed in biogas production and organic fertilizers. Water hyacinth can remediate polluted water caused by heavy metals contamination with careful management. In short, economically, water hyacinth in Rawapening can be both beneficial and detrimental. Proper management of this species is necessary to maintain the sustainability of this aquatic environment.

Keywords: Economic impact, invasive plant, Rawapening Lake, water hyacinth

INTRODUCTION

Introduced species is defined as a conscious or unconscious effort to present a species of animal or plant into a new habitat. Introduced species have two pathways on their biogeographical distribution: becoming an invasive species or not becoming an invasive species. An introduced species which does not have a negative impact on the new habitat is not classified as an invasive species, while a species that is introduced and do have a negative impact on the new habitat is considered an invasive species (Caplat and Coutts 2011; van Wilgen and Richardson 2012; Gallardo et al. 2016; Schirmel et al. 2016; Courchamp et al. 2017; David et al. 2017; Thapa et al. 2018; Bartz and Kowarik 2019). The most noticeable impact of invasive species is the domination of habitat by the newly introduced species (Kumschick et al., 2015). The route of arrival and spread of invasive species can be caused by natural factors (e.g., storms, ocean currents, and climate change) and human factors, through the introduction and distribution, either intentionally (e.g., crops and pets) or unintentionally (e.g., trade, tourism, and transportation).

Nowadays, invasive species (either animals or plants) have spread to almost all types of ecosystems on earth, including mountain, lowland, terrestrial ecosystems, freshwater, and marine ecosystems, as well as archipelagic and continental realms (Mostert et al. 2013; Gallardo et al. 2015; Russel et al. 2017; Spatz et al. 2017). According to Llewelyn et al. (2011), in Australia found, the cane toad (*Bufo marinus*) is huge (up to 40 cm long), the so-called

"Toadzilla" (after the term Godzilla monster). These frogs were initially imported from Hawaii to deal with the overgrowth of local frogs. However, it turns out that introducing this species into an invasive species threatens diversity in Australia because the local frogs are depleted, the cane toad continues to exist, and even thrives because there are no predators such as crocodiles and snakes that can survive after eating it. In Europe, *Heracleum mantegazzianum*, *Lupinus polyphyllus*, and *Rosa rugosa* are all invasive plants that can produce dominant stands with a cover of more than 90% (Thiele et al. 2011). In the Americas, there are *Ampelopsis brevipedunculata*, *Cynanchum louiseae*, and *Ranunculus ficaria*, which have a high invasive rate because their growth is very fast, beating the native species (Buerger et al. 2016). Then, South Africa can spend a lot of money dealing with invasive species such as *Acacia mearnsii*, *Acacia saligna*, *Leptospermum laevigatum*, *Pinus halepensis Pinus pinaster*, and *Pinus radiata* that interfere with local biodiversity in the Nature Reserve (Gaertner et al. 2016).

As many countries face globally, Asia, especially Indonesia, has emerging invasive species problems. One of the problems facing Indonesia is the uncontrollable spread of introduced plants. These plants species are often considered as weeds, and the most dangerous weed species are those which have high reproductive abilities and cause devastating impacts both ecologically and economically (Essl et al. 2011; McConnachie et al. 2012; Mkumbo and Marshall 2014; Srivastava et al. 2014; Arp et al. 2017; Essl et al. 2017; Huang et al. 2018). One invasive species in Indonesia is water hyacinth (*Eichhornia crassipes*).

The invasion of water hyacinth occurs in many aquatic ecosystems across Indonesia, one of which is in Rawapening Lake. The presence of water hyacinth is becoming dominant nowadays and causes the Rawapening Lake ecosystem to become unbalanced. The Uncontrolled growth of water hyacinth poses a significant risk to the aquatic ecosystem in Rawapening Lake (Gichuki et al., 2012; Dereje et al., 2017; Gaikwad and Gavande 2017; Degaga 2019; Madian et al. 2019; Prasetyo et al. 2021). This phenomenon occurs because of eutrophication, a condition of increasing the nutrient content in water, especially phosphorus (P) and excessive nitrogen (N) (Clout and Williams 2009; Uwadiae et al. 2011; Zan et al. 2011; Arthaud et al. 2012; Coetzee and Hill 2012; Sood et al. 2012; Patel 2012; Chislock et al. 2013; Grasset et al. 2016; Guignard et al. 2017). The uncontrolled growth of water hyacinth will cover the water surface in the lake and block light from entering the lake, which causes biota such as fish to experience a lack of oxygen and nutrients, leading to death and population reduction (Bornette and Puijalon 2011; Mironga et al. 2011; Güereña et al. 2015; Kamau et al. 2015; Gupta and Yadav 2020). On the abiotic factor, the invasion of water hyacinth in Rawapening Lake also causes silting in the bottom of the lake.

The ecological impacts of water hyacinth invasion in Rawapening Lake can inflict negative consequences on the economy of stakeholders who rely on the lake, such as fishermen. The study on the economic impact of water hyacinth invasion in Rawapening Lake is essential for water hyacinth eradication or management solutions. Therefore, this study is aimed to review the economic impacts of the invasive water hyacinth species in Rawapening Lake from two perspectives: the negative and the positive impacts, so that feasible solutions can be developed.

THE CONTEXT OF STUDY AREA: RAWAPENING LAKE

The context of this study is in the Rawapening Lake area, Semarang District, Central Java, Indonesia (Figure 1). This is a semi-natural lake with about 2,607 hectares administratively located in the subdistricts of Ambarawa, Bawen, Banyubiru, and Tuntang (Sudjarwo et al. 2014). Rawapening Lake is located approximately 45 kilometers south of Semarang City and 9 kilometers northwest of Salatiga City, in the golden triangle between Semarang, Solo, and Yogyakarta. The lake geographically is located at 7°04’-7°30’ south latitude and 110°24’46’-110°49’06’’ east longitude, and it has an altitude of 460 meters above sea level.

Indonesia has ratified the Sustainable Development Goals (SDGs) and global communities for the 2015-2030 period (UNDP Indonesia 2015). One of the global agendas on the SDGs is to ensure the availability and sustainable management of water and sanitation for all. In line with this, Indonesia has developed the National Medium-Term Development Plan (RPJMN) for the 2020-2024 period, clearly stated in Chapter 7, namely building the environment, increasing disaster resilience, and climate change Rawapening Lake priority water ecosystems. This lake is protected explicitly in the maintenance, restoration, and conservation of natural resources and water ecosystems by Presidential Regulation No.18 (2020).

Rawapening Lake is utilized for various purposes, including water drinking sources, fisheries, agriculture, tourism, social and religious life, and hydroelectricity (Soeprobowati 2017). Historically, this lake was dammed by the Dutch Colonial Government in 1936 with a maximum water table area of 2,667 ha in the rainy season (November-April) and 1,650 ha in the dry season (May-October) (Sulastri et al. 2016). Currently, the lake is under intense pressures to exceed its capacity, which four prominent conditions can indicate, namely reduced fishery production, the rapid growth of aquatic plants, pollution of water sources and loss of endemic organisms, as well as silting and depletion of lakes area from its original state (Haryani 2013). Among such problems, the rapid growth of aquatic plants in Rawapening Lake is caused by the uncontrolled growth of water hyacinth.

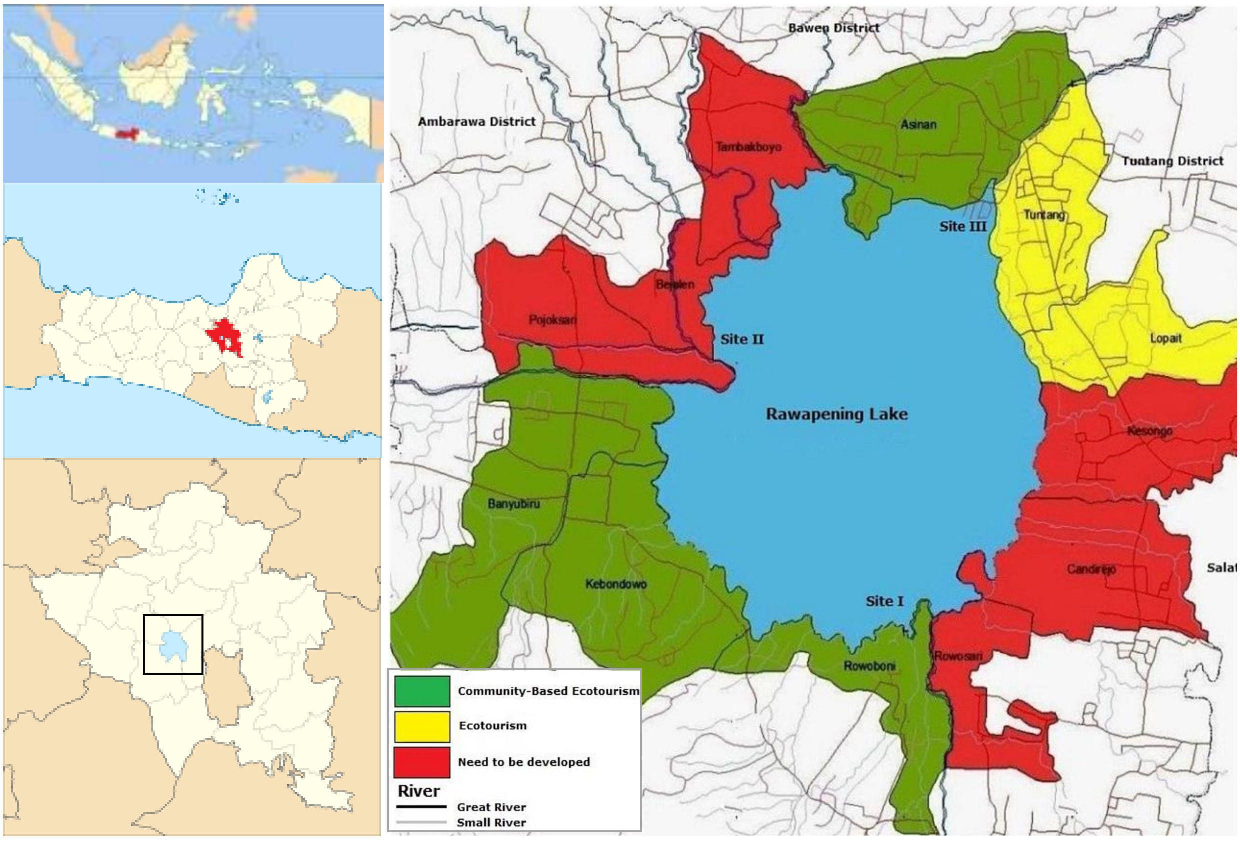

Figure 1. Map of the Rawapening Lake area, Semarang District, Central Java Province, Indonesia

INVASIVE PLANTS: A BRIEF HISTORY OF WATER HYACINTH IN INDONESIA

Flora is defined as a plant that grows and can spread from one area to another, which becomes its new habitat. A plant that historically grows in a particular area or habitat is known as native species. However, with the development of trade flows and transportation across countries and regions, there has been a change by allowing various species to move and cross long distances into new habitats as foreign species (Turbelin et al., 2017). In the context of Indonesia, the native flora is often so-called Flora Malesiana, and plant species other than Flora Malesiana are considered introduced or alien plant species.

The existence of introduced species can cause impacts in changes in the composition of local or native species. Introduced plants species can have a significant impact on an area, be it detrimental or beneficial (Kowarik et al. 2011; Lodge et al. 2012; Ricciardi et al. 2013; Simberloff 2013; Jeschke et al. 2014; Genovesi et al. 2015; Tanner et al. 2017; Hanley and Robert 2019). Several introduced plant species positively impact other species, ecosystems, and humans. Several other introduced plant species are invasive, potentially disturbing other species, ecosystems, and humans (Schlaepfer et al. 2011; Kapler et al. 2012; Blackburn et al. 2014; Roy et al. 2018; Epanchien-Niell 2017; Riley et al. 2018).

The difference between introduced and invasive species is that introduced species are not necessarily invasive species. However, all invasive species must be introduced (Gallardo et al. 2016; Schirmel et al. 2016; Courchamp et al. 2017; David et al. 2017; Thapa et al. 2018; Bartz and Kowarik 2019). Invasive species have several characteristics that make it easier for them to compete and over-dominates other species (Rakotoarisoa et al. 2015), including quick and mass reproduction biology, rapid growth and survival, ability to widespread, tolerance to a wide range of environmental conditions, ability to live with various types of food, and can cause damage to ecosystems (Pejchar and Mooney 2009; Vilà et al. 2011; Pyšek et al. 2012; Ricciardi et al. 2013; Gallardo et al. 2016; Schirmel et al. 2016; David et al. 2017; Foxcroft et al. 2017; Vilà and Hulme 2017). Invasive species can also cause socio-economic damages (Bacher et al. 2018) or affect infrastructure (Booy et al. 2017). Furthermore, invasive species management usually requires considerable financial and personnel resources (Hoffmann and Broadhurst 2016).

There are several processes in the invasion of introduced plants that influences natural communities, including competition, which affect the ecological processes in an ecosystem (Coetzee et al. 2011, 2014; Tollington et al. 2015; Solfiyeni 2016). According to Kumschick et al. (2012) and Blackburn et al. (2014), the competition is related to the interaction between two or more species in a habitat that occurs because of the exact needs, so that they compete for habitat, air, water, food, sunlight and so on. This competition will impact the underperforming species to die, be eliminated, or move to another place. Thus, a strong invasion of the invasive plant can lead to a decrease in the population of the native plants and, in some instances, may cause local extinction.

Water hyacinth is a freshwater plant species first discovered accidentally by a botanist from Germany, Carl Friedrich Philipp von Martius, when he was doing an expedition in the Amazon River, Brazil, South America, in 1824 (Chunkao et al. 2012). Generally, water hyacinths live and grow above the wetland water surface and can also be grown among agricultural crops cultivated in wetlands. In 1894, during the occupation of the Bataaf Republic in the Dutch East Indies (now Indonesia), water hyacinth plants were first brought to Indonesia as a collection of aquatic plants (Ratnani. 2012). General Governor Thomas Stamford Raffles, who governed the Bataaf Republic in Indonesia, exported water hyacinth from Brazil, South America, and cultivated it in a pond in the Bogor Botanic Gardens (Lestari et al. 2018).

At first, water hyacinth was in great demand by Indonesians as an ornamental plant because it has flowers with purple and blue colors that are pretty striking, making it suitable as an ornamental plant for ponds. After all, it resembles a lotus plant (Figure 2) (Arham 2013). Water hyacinth plants can reproduce incredibly fast, so the presence of water hyacinth in the Bogor Botanical Garden pond has covered several existing water bodies. Due to the rapid growth (about 3% per day), the water hyacinth was then dumped through the rivers around the Bogor Botanical Gardens, spreading into waterways, marshes, and lakes throughout Indonesia and Southeast Asia. The growth of water hyacinth is uncontrolled and very fast that this plant is considered an invasive weed (Patel 2012; Frezina 2013; Ilo et al. 2020).

Nowadays, water hyacinth has invaded many freshwater bodies across Indonesia, including lakes. Besides the biological traits related to the invasiveness of water hyacinth, the invasion of these plants is facilitated with the degraded conditions of biotic and abiotic factors of the lakes. The majority of lakes in Indonesia are currently facing environmental problems such as eutrophication, sedimentation, and a decrease in the lake area, one of the leading causes of which is the invasive growth of water hyacinth (Juma et al. 2014; Soeprobowati et al. 2016; Sulastri et al. 2016; Guignard et al. 2017; Sutadian et al. 2017).

THE BIOLOGY OF WATER HYACINTH

Water hyacinth (*Eichhornia crassipes* (Mart. and Zucc.) Solms; syn. *Pontederia crassipes* Mart.) belongs to the family Pontederiaceae. It is a floating weed in tropical and sub-tropical freshwater lakes and rivers, especially those enriched with organic matters. It grows in shallow freshwater wetlands and can create pure stands. An emergent perennial aquatic plant forms rosettes of thick and spongy leaves. Flowers appear on the spike-like flower stalks. Beneath the surface water, the plant has black, fibrous roots. Rosettes are often connected to the surface water by stolons roots develop at the base of each leaf and form a dense mass: usually 20-60 cm long, although it can extend up to 300 cm. Periodically, axillary shoots develop as stolons, growing horizontally 10-50 cm before forming daughter plants. Vast populations of interconnected shoots can develop rapidly, although the stolons eventually die (Gopal 1987; Zhang and Guo 2017).

Plant sizes vary widely; seedlings have leaves only a few centimeters wide or in height, while mature plants with a good supply of nutrients can reach a height of 1 m. Plants in an open habitat tend to have short, spreading petioles with marked swelling, whereas, in dense stands, they are taller, more erect, and with little or no swelling petioles. The plant system consists of individual shoots, each with ten broad leaves arranged in a spiral, separated by very short internodes. As individual shoots develop, older leaves die, leaving pieces of dead shoots with no leaves protruding downwards (Figure 2) (Gopal 1987; Zhang and Guo 2017).

The leaves are basal and straightforward, forming a rosette around the flower stalk. Leaves consist of petioles (often swollen, 2-5 cm thick) and blades (roughly round, kidney or ovoid-shaped, up to 15 cm). The petiole base and subsequent leaves are flanked by 6 cm long stipules. Each petiole is short and consists mainly of a bulging ball that helps the plant float in the open state. The petioles become longer, thinner, and less inflated in more shady conditions. Leaf venation is parallel, and leaf margin is smooth (Figure 2) (Gopal 1987; Zhang and Guo 2017).

The inflorescences are loose, spike-like clusters of tiny lavender, resting on the erect stalk. Each flower has 6 petals. The inflorescences are spikes that develop from the apical meristem but tend to emerge laterally due to the rapid development of the axillary shot as a 'renewal' or 'continuation' shoot. Each spike, up to 50 cm high, has two bracts below it and has 8-15 sessile flowers (4-35 rarely). The bottom 5 petals are a solid shade of lilac or lavender, but the topmost petal has a bright yellow dot surrounded by a bluish "halo." Each flower has a perianth tube 1.5 cm long, developing into six light purple or purple lobes up to 4 cm long. The main lobe has a bright yellow, diamond-shaped patch surrounded by deep purple. Once the inflorescences have fully emerged from the leaf midrib, all the flowers open together, starting at night, completing the process in the morning, and most often the following evening when the peduncle begins to bend. The flowers are tristylus. They have six stamens and one style. The fruit is a three celled capsules containing many tiny seeds. Each capsule can hold up to 450 small seeds, each measuring about 1 x 3 mm (Figure 2) (Gopal 1987; Zhang and Guo 2017)

Water hyacinth has a flexible morphology that easily adapts to habitats with specific physicochemical and biological characteristics, especially changes in root length, petiole length and shape, and shoot-root ratio. However, this macrophyte causes extensive damage due to its biology and function in aquatic ecosystems. Water hyacinth has morphological elasticity, speedy growth, changes in the chemical composition of various plant parts in multiple habitats, adaptive phenology for ecological invasion, and vegetative and sexual reproduction for persistent distribution. This aquatic perennial free-floating plant is a harmful, unique, useful, fast-growing, and constant invasive macrophyte. The root morphology plus the fast growth rate under suitable conditions allows one hectare of water surface to be covered entirely by water hyacinth every day (Penfound and Earle 1948; Zhang and Guo 2017).

Water hyacinth reproduces by seed, budding, fragmentation, and stolon production. Seeds may germinate within a few days or remain dormant for 15-20 years. They usually sink and stay dormant until periods of stress (drought). After re-flood, the seeds often germinate and renew the growth cycle (Gopal 1987; Westerdahl and Getsinger 1988; Barrett, 1989; Sharma et al. 2016; Mathur and Mathur 2017). Daughter plants grow from stolons, and doubling times have been reported to be 6-18 days. Water hyacinths multiply rapidly, float and spread easily, and quickly cover water bodies, resulting in poor water transparency. Therefore, water hyacinth competes with other aquatic plants (floating and submerged) and algae for mineral nutrients, sunlight, space, and other resources in natural waters (Masifwa et al. 2001; Villamagna and Murphy 2010).

WATER HYACINTH IN RAWAPENING LAKE

Rawapening Lake receives water from the springs of several mountains that flow through eight tributaries (UNEP 1999). The tributaries of the lake watershed flow through the catchment area, which is widely used for agriculture and urban development, is suspected as a source of increased sediment load and nutrient content in the lake. The land uses of water catchment area in Rawapening Lake include secondary forest (12,661.65 ha), primary forest (593.48 ha), agriculture (8,974.48 ha) which consists of irrigated and non-irrigated agriculture, settlements (3,304.44 ha), plantations (480.30 ha), shrubs (529.55 ha), and water bodies (1,517.46 ha). Non-irrigated agriculture for vegetable cultivation in water catchment areas has caused erosion and sedimentation in lakes (Wuryanta and Paimin 2012).

Water hyacinth is very easy to find in Rawapening Lake because the water hyacinth population in this lake is very abundant. The speedy growth and spread of water hyacinth plants are probably due to eutrophication in Rawapening Lake waters, which can be influenced by several causes such as high levels of nutrients (nitrogen and phosphorus) and pesticides from agricultural waste, feed waste from livestock, factory waste, domestic waste, etc., that flowed into the water bodies of Rawapening Lake (Knoll et al. 2003; Soeprobowati et al. 2012; Verma and Sivappa 2017).

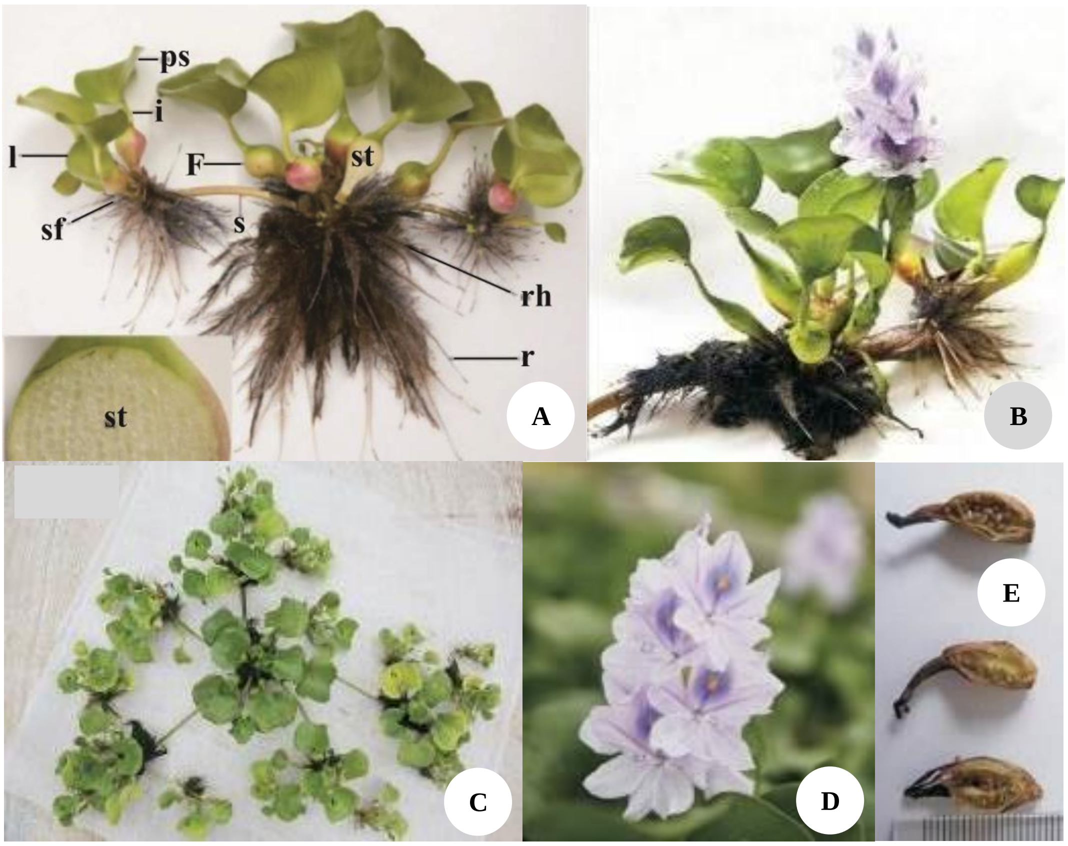

Figure 2. Morphological description of water hyacinth (*Eichhornia crassipes*). A. Young water hyacinth. l: ligule; sf: sub float; s: stolon; ps: pseudo-lamina; i: isthmus; f: float; rh: rhizome; r: root; st: sponge tissue. B. Mature water hyacinth, C. Vegetative reproduction, D. Water hyacinth in flower, E. Dehiscent capsules contain 63-153 seeds. (A-D. Photo by Lin Shang 2015; E. Photo by Ying-ying Zhang 2010)

Water hyacinth is also a significant problem that has the potential to reduce the environmental quality of Rawapening Lake, namely lake sedimentation, coverage of the lake surface by water hyacinth weeds, and increase in the volume of waste entering the lake area from several rivers that flow into the Rawapening Lake (Haseena et al. 2017; Salam and Salwan 2017; Ting et al. 2018; Yunindanova et al. 2020). Wind also affects nutrient dynamics in the lake, causing water hyacinth to float to new areas and triggering sediment resuspension that increases nutrient release in the lake (Worqlul et al. 2020).

In just a few decades, the water hyacinth invasion in Rawapening Lake has been severely increasing. In 1994, water hyacinth covered 18.45% of Rawapening Lake along with *Hydrilla verticillata* (7.69%) and *Salvinia* sp. (15.36%) (Goltenboth and Timothy 1994). In 2002, water hyacinth coverage in Rawapening Lake had reached 20-30% of the surface water areas or about 150 Ha (Utomo 2016). Between 2004 and 2005, the coverage of water hyacinth on the surface of Rawapening Lake increased from 60% to 70%, then increased again to 85% in 2006 due to the rapid growth rate of water hyacinth reaching 7.1% per year (Soeprobowati 2012).

In 2013, water hyacinth invasion reached 45% of the surface area of Rawapening Lake. This is caused by the water hyacinth growth rate being so fast, where the water hyacinth stems can produce new plants covering an area of 1 m^2 within 52 days (Utomo 2016). According to Hidayati et al. (2018), the area of water hyacinth in Rawapening Lake in 2012 was 775.49 ha, while in 2016, it increased to 990.53 ha. According to Soeprobowati (2017), one water hyacinth plant can reproduce and cover an area of water in Rawapening Lake, reaching an area of 1 m^2 within 22 days. Based on the research conducted by Prasetyo et al. (2021), the growth rate of water hyacinth must be considered so that the management of Rawapening Lake can be successful. The Relative Growth Rate (RGR) of water hyacinth in Rawapening Lake ranged from 6.40-7.26%/day. Meanwhile, water hyacinth propagation time (DT) ranged from 9.6-10.8 days. Then, 1 m^2 will be full of water hyacinth within 21 days to 28 days. The water hyacinth invasion in Rawapening Lake from year to year is getting out of control because water hyacinth is increasingly covering the lake area (Figure 3).

Figure 3. Condition of water hyacinth in Rawapening Lake in 2021 suggests that water hyacinth is everywhere in the lake

The uncontrollable water hyacinth invasion in Rawapening Lake can cause various negative impacts that affect the surrounding communities' social and economic aspects. The decrease in soluble oxygen in the water because water hyacinth blocks sunlight from entering the water causes a balance disorder in the Rawapening Lake aquatic ecosystem, leading to the decrease in fish production, the loss of endemic organisms, disturbance in irrigation, reduction in the beauty of the waters because the fallen roots will float and cause the water to look very dirty or cloudy, and others (Bornette and Puijalon 2011; Güereña et al. 2015; Kamau et al. 2015; Gupta and Yadav 2020).

The main factor that triggers the rapid growth of water hyacinth in Rawapening Lake is eutrophication due to the increase in the waters' nutrient content, especially phosphorus (P) and nitrogen (N). In addition, temperature and carbonate also significantly affect the growth of water hyacinth (Soeprobowati et al. 2016). Soeprobowati et al. (2012) stated that the eutrophic condition of Rawapening Lake has occurred since 1967, and it is tough to control the growth of water hyacinth because of its fast growth rate and ability to store seeds scattered by flooding (Júnior and Carvalho 2019). Water hyacinths also have seeds that have a dormancy up to 15 years, implying that the seeds have long-lasting regeneration ability (Ojo et al., 2019).

To eradicate the invasion of water hyacinth, biological control is most effective but can take several years to be successful (Van Wilgen and de Lange 2011; Fraser et al. 2016; Su et al. 2018). This involves using natural enemies, including plant pathogens (Dagno et al., 2012). There are several native enemies of water hyacinth, including two South American beetles (*Neochetina eichhorniae* and *Neochetina bruchi*) and two species of water hyacinth moth (*Niphograpta albiguttalis* and *Xubida infusella*) which have been effective in controlling water hyacinth populations in many countries, especially in Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea, and Benin (Williams et al. 2007; Venter et al. 2012; Gichuki et al. 2012; Dagno et al. 2012).

NEGATIVE ECONOMIC IMPACTS OF WATER HYACINTH IN RAWAPENING LAKE

The rapid growth and spread of water hyacinth in Rawapening Lake cause detrimental impacts to the economic conditions of the people around the lake, especially the farmers and fishers. In the agricultural sector, water hyacinth is a pest that disturbs agricultural crops. The bush from the water hyacinth plant becomes a nest for rats, which in the event of high tide, the bush pulls over to the agricultural land then eats up the agricultural crops (Ningsih et al. 2019). The spread of water hyacinth into drainages and sewages may cause clogging. The rotten water hyacinth plants can obstruct the irrigation channels of the fields so that farmers cannot produce maximum rice harvests (Chowdhury 2013; Kriticos and Brunel 2016). Water hyacinth that is not controlled will invade agricultural land and livestock grazing, making fodder plants and grasses lose their place of growth. Unfortunately, water hyacinth cannot be used as animal feed because it contains too much silica, calcium oxalate, potassium, and too little protein (Osumo 2001).

In the health sector, the overgrown water hyacinth provides an ideal habitat for disease carriers such as mosquitoes that cause malaria, inflicting the cost of health treatment when the surrounding community suffering the disease (Minakawa et al. 2012; Njuru et al. 2012; Honlah et al. 2019). In addition, certain bacteria can thrive in water hyacinth habitats. If left unchecked, this will have the opportunity to cause disease outbreaks for humans.

In fisheries sector, water hyacinths that covered the surface water of Rawapening Lake obstruct the activities of fishermen because water hyacinth makes it difficult and hinders the speed of the fishing boats, and disturbs fishermen when casting nets into the lake to look for fish (Ndimele et al. 2011; Patel 2012; Aloo et al. 2013). The large coverage of water hyacinths reduces the soluble oxygen in the water, causing aquatic organisms, especially fish, to find it difficult to get oxygen and eventually die, so that the fish population decreases and fishermen get only a few fish catches (Downing et al. 2012; Schultz and Dibble 2012; Witte et al. 2012; Degaga 2019). This condition is happening in Rawapening Lake which inflicts loss to the fishermen due to the decrease in fish catches (Genissa et al. 2018).

Economic losses suffered by the stakeholders of Rawapening Lake also come from the financial cost to suppress the growth of water hyacinth weeds. Because, the cost to eradicate and manage water hyacinth is expensive, there is a need for environmentally friendly efforts that incur low costs. If possible, the potentials utilization of water hyacinth can be developed to generate economic benefits.

POSITIVE ECONOMIC IMPACTS OF WATER HYACINTH IN RAWAPENING LAKE

Bioremediation

Despite the negatives economic impacts caused by water hyacinth invasion, some economic benefits have also been reported. It has been shown, for example, that water hyacinth is a good biosorbent for heavy metals contamination and it can improve the quality of water around the plant cover (Wang et al. 2012; Moyo et al. 2013; Ammar et al. 2014; Wanyonyi et al. 2014; Matindi et al.2014; Pusphe et al. 2016; Feng et al. 2017; Arenas et al. 2018; Ting et al. 2018; Sayago 2019). The remediated water that is not polluted by heavy metals can be used for various uses, for example for agricultural irrigation, so that in can increase economic income (Akinwade et al. 2013; Matindi et al. 2014; Canazart et al. 2017; Gogoi et al. 2017; Priya et al. 2018; Nash et al. 2019).

Handicrafts

Various products of handicrafts can be made of water hyacinth to generate economic value (Bruneckiene and Sinkiene 2014; Onyango and Ondeng 2015; Guna et al. 2017; Yan et al. 2017; Mitan 2019; Sianturi et al. 2019).

Communities around Rawapening Lake use the leaf stalks of water hyacinth to make various creative products that have functional value as well as environmentally friendly (Sudana and Mohamad 2020). Craft products produced by communities and enterprises around Rawapening Lake include bags, sandals, baskets, wallets, and furniture such as chairs and tables (Table 1).

The process of craft production with raw materials originated from water hyacinth begins with the drying of wet water hyacinth plants. In adding to the beauty value and economic value, it can use various methods such as embroidery (Putri and Prasetyaningtyas 2019). In its manufacture, the equipment used in the production of this craft consists of a sickle to take raw materials, a press for leveling the water hyacinth, a knife or scissors, a sewing machine to form and unite the supporting materials (cloth or leather). These art products made from water hyacinth are then can distributed either directly or through online media (with social media) so as to generate a number of profits.

Biogas

In addition, according to Bote et al. (2019), water hyacinth has a high hemicellulose content compared to other organic components, which will produce carbon dioxide and methane gas as biogas. The principle of making biogas is to use the anaerobic decomposition of organic matter, which is closed from free air to produce gas in the form of methane (CH_4). Several microorganisms, especially methane-producing bacteria, assist the anaerobic decomposition process. Anaerobic digestion is a process in which microorganisms break down biodegradable materials without oxygen (Yonathan et al. 2012). Manufacturing is done by preparing tools and materials. Tools and materials needed are biogas stove, gas generator, drum/gallon, galvanized pipe, hose. The ingredients are water, water hyacinth, cow dung. The mixture consisted of water hyacinth as a substrate, cow dung as a biostarter, and water as a nutrient.

Making biogas begins with water hyacinth chopped into small pieces measuring less than 1 cm, then water and cow dung are added according to the dilution variable. After the appropriate dilution variable, enter the mixed solution into the biodigester. The following process is to let it sit for a week for gas decomposition. Making biogas begins with water hyacinth chopped into small pieces measuring less than 1 cm, then water and cow dung are added according to the dilution variable. After the appropriate dilution variable, enter the mixed solution into the biodigester. The following process is to let it sit for a week for gas decomposition. Then, the gas produced is accommodated in a drum or gallon reservoir and the gas is flowed through a hose to turn on the stove and an electric generator. If the decay of the water hyacinth is good, the fire and electricity can continue to burn. If the decay of the water hyacinth is good, the fire and electricity can continue to burn.

According to Yonathan et al. (2012) who researched making biogas with water hyacinth with the composition of the ratio of water + cow dung: water hyacinth (2 : 1; 2: 1.5; 2: 2 ; 2: 2.5). The amount of substrate for each variable in a row are: 326.5gr; 420gr; 490gr; and 543.2gr. The amount of volume produced has increased from variable 2: 1 to variable 2: 2.5. The results obtained on the composition variable show the largest biogas production at 2:2.5 composition of 1162.97mL and the smallest biogas production at 2:1 at 12.85mL. The more the composition of the substrate, the higher the volume of biogas produced. From the results of the Gas Chromatography analysis, it was obtained, and after calculating the methane content formed was 0.03 mol of methane / 100gr of water hyacinth. From the results of this analysis, it can be concluded that biogas from water hyacinth can be used as a renewable energy source because it is proven that there is methane content in the biogas produced. However, from the results of this study, further research is still needed whether with the longer fermentation time and variations of other variables the methane gas content can still increase or not.

Biogas from water hyacinth is an environmentally friendly material at an affordable price. In that case, when we take advantage of the water hyacinth plants in Lake Rawapening, we can reduce the excessive water hyacinth population. Furthermore, utilizing water hyacinth as an ingredient for biogas is also very helpful for residents who have difficulty obtaining gas and electricity for their daily activities.

Organic fertilizer

Water hyacinth can also be processed into organic fertilizers that are marketable and also at the same time can reduce its population in Rawapening Lake (Fan et al. 2015; Yunindanova et al. 2020). In the community service activities carried out by Yunindanova et al. (2020) in the Rawapening Lake area and Kadirejo Village, Pabelan Sub-district, Semarang District, Central Java Province, they studied the practice of making compost using water hyacinth as the main raw material through the aerobic composting method. The fertilizer was made within one until two weeks with nutritional quality that meets the standards of organic fertilizers. The organic fertilizer produced from water hyacinth contains 18.93% C-organic, 1.78% total N, 1.10% P, and 1.26% K. The production of this fertilizer can generate profits from trade which can be trade enhanced by good packaging and with nutrient analysis (Sudhakar et al. 2013; Hernández-Shek et al. 2916; Goswami et al. 2017).

Table 1. Various handicraft products with raw materials originated from water hyacinth

Product category*)	Examples	Photographs
Household accessories	Baskets, tissue holder, coasters, placemats, tray box.	
Interior	Carpet, table and chair set, lamp, wall clock, rope.	
Decorative	Vase, photo frame, mirror, toys/miniature	
Fashion	Shoes, sandals, wallets, bags, necklaces	

Note: *) Based on Sianturi et al. (2019)

CHALLENGES ON THE UTILIZATION OF WATER HYACINTH IN GENERATING ECONOMIC IMPACTS

Alternative management of water hyacinth into goods that can be used as appropriate items is a good step to reduce water hyacinth populations and improve water quality. Making water hyacinth-based products can also be an opportunity for improving the community's economy. With the community around the Rawapening Lake area taking part in the production of making water hyacinth goods, this means that these people also have the right to benefit from the distribution of this water hyacinth processed product. Making handicrafts and organic fertilizer from water hyacinth is the best thing for the people around Rawapening Lake because of the cost of making it is relatively easy and does not require expensive technology.

However, there is a challenge in using water hyacinth to reduce/eliminate water hyacinth populations in Lake Rawapening while generating economic benefits. These challenges are: (i) lack of community resources because not all people can make various handicraft products whose raw materials come from water hyacinth, (ii) lack of interest in learning from the younger generation in utilizing water hyacinth so that utilization is not optimal and lacks innovation from products made from water hyacinth produced, (iii) the difficulty of constructing a series of biogas plants and the lack of research on effective biogas production and (iv) not yet comprehensive support provided by the Indonesian government in helping the community to make various handicraft products and fertilizers or other things whose raw materials come from water hyacinth.

Therefore, it is necessary to have a good relationship in establishing cooperation to reduce/eliminate the water hyacinth population in Lake Rawapening while generating economic benefits between the community and the Indonesian government so that human resources are more skilled, there is an increase in the quantity and quality of products, as well as promotion or marketing good product and reach every area.

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Interaction of soil-inorganic nitrogen in rice fields of Kilombero Floodplain, Tanzania

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Abstract. *Yobele AB, Kilasara M. 2021. Interaction of soil-inorganic nitrogen in rice fields of Kilombero Floodplain, Tanzania. Intl J Bonorowo Wetlands 11: 32-47.* At Ifakara Morogoro Region, a study was done to determine the effect of selected crop management interventions and hydrological conditions on soil NH_4^+ and NO_3^- concentration. The study chose Valley Middle and Fringe locations as distinct hydrological zones. Three repetitions of an experiment with six treatments were laid down: semi-natural vegetation (TR1), farmers practice (TR2), bunding alone (TR3), bunding + 60 kgN/ha (TR4), bunding + 120 kgN/ha (TR5), and bunding+Lablab green manure (TR6). As a test crop, the SARO 5 rice variety was employed. The trials took place during the pre-season of 2014/15 and the regular 2015/16. Data were gathered from a depth of 0-10 cm in the soil. Using the GenStat Program, two-way ANOVA and post hoc-Tukey HD test statistical analyses were done. Pre-season NH_4^+ concentrations followed three distinct patterns: an initial increase to peak levels within 3 and 6 weeks for the Fringe and Middle sites, a fall (7th to 9th week for the Middle, and 4th to 6th week for the Fringe), and an increase (from 7th, Fringe and 10th week, Middle). The Middle site had the highest peak NH_4^+ levels (TR6-0.007401, TR5-0.004776, and TR4-0.04525, g/kg soil, and TR4-0.004524, TR5-0.004595, g/kg soil, respectively). At the Middle and Fringe locations, peak NH_4^+ values varied considerably between treatments, following the trend TR6>TR5>TR3>TR4>TR1>TR2 and TR4>R6=TR5=TR3+TR2>TR1. Nitrate levels declined within 1-2 weeks at both sites, reaching their lowest levels between 4 and 7 weeks, and then gradually increased to 10. Rice cropping season NH_4^+ and NO_3^- variation followed a similar pattern for both locations, except a sharp increase in treatments with N input during weeks 8 and 10. Hydrological conditions had no significant effect on the NH_4^+ and NO_3^- levels (P = 0.05). The study advises that the experiment be repeated under controlled conditions.

Keywords: Crop management, hydrology, inorganic nitrogen, Kilombero Floodplain, rice fields

INTRODUCTION

Rice is a commercial crop whose productivity improves in the Kilombero Valley (Kato 2007). Mineral nitrogen fertilizer is becoming an increasingly important input in crop productivity, particularly in irrigated systems (Nascente et al., 2009). The mineral nitrogen in the soil is quite volatile (Becker et al., 2007). The processes that determine the dynamic nature of mineral N are highly dependent on a variety of soil conditions, the most critical of which is soil hydrological conditions (Reddy and De Laune 2008; Suryantini 2016; Njoroge et al. 2018), soil pH (Mokata and Takalapeta 2021), N input (Yeasmin et al. 2012), and crop husbandry (Lou et al. 2011; Susanto et al. 2018). The type of nitrogen applied and the rate at which it is used determine its usefulness for crop yield in wetland environments (Ngwene et al., 2013).

It is typical to compensate for mineral N deficit in wetland soils by boosting the organic or inorganic mineral N pool (endogenous and exogenous N sources), hence contributing to production increases (Yeasmin et al., 2012). Most plants acquire nitrogen in NO_3^- (Buresh et al. 2008). Rice is unique among plants in that it can absorb nitrogen in the NH_4^+ state (Wang et al. 1993). Additionally, both NH_4^+ and NO_3^- are highly active compounds highly dependent on the wetland hydrology, namely the amount of free water and redox potential (Pezeshki and Delaune 2012). As a result, the condition of NH_4^+ and NO_3^- in wetlands and their dynamics are critical for N management and paddy production (Buresh et al., 2008). In paddy rice production systems, N can be lost by a variety of mechanisms, including leaching (Kimetu et al. 2006), volatilization (Loomis and Connor 1992; Jones et al. 2007), denitrification (Brady and Weil 1999), and nitrification (Sahrawat 2010). Apart from resulting in net nitrogen loss, these processes contribute to detrimental environmental consequences and climate change (Reddy and DeLaune 2008). For example, it is well established that NH_4^+ N is harmful to aquatic life even at low concentrations in water (Reddy and DeLaune 2010). On the other side, NH_4^+ volatilization increases the likelihood of adverse effects of climate change (Audet et al., 2014). Under aerobic circumstances, NH_4^+, a byproduct of mineralization, is easily oxidized to NO_3^-. The latter travels downward from the oxidized zone into the anaerobic area, where it is converted to NO_2 and subsequently to N_2O and N_2 (Smil 2000).

Both contribute directly to global warming by degrading the ozone layer (Audet et al., 2014). Similarly, when NO_3^- N is leached from flooded soils, it raises the danger of groundwater pollution (Yeasmin et al., 2012). Therefore, it is vital to monitor the inorganic N status in wetland rice production for economic reasons, environmental protection for the well-being of wetland biodiversity, and minimize the impact of added N fertilizers on greenhouse gas emissions. Numerous variables affect the dynamics of mineral or inorganic N in wetlands. These include temperature (Wang et al. 2004), redox potential (Pezeshki and Delaune 2012), moisture regime (Wang et al. 2004; Reddy and DeLaune 2008), C: N ratio (Smith 2010), microbial activity, and biomass (Reddy and DeLaune 2008), electron acceptor availability (Sugihara et al. 2010 a,b). Paddy's nitrogen needs fluctuate according to crop growth or development (Muhammad et al., 2010).

It is crucial to understand the amount of mineral N present throughout the growing season under selected agricultural practices used by small-scale farmers in floodplains, particularly in the Kilombero valley, because no research on the mineral N dynamics in wetlands soils with adequate regard for hydrological conditions have been done so far. Studies According to Corstanje and Reddy (2004), soil drying after paddy production increases mineral N in the soil. Because the level of this nutrient is fluctuating, it has ramifications for both water quality and greenhouse gas emissions during the subsequent flooding period (Yeasmin et al., 2012). Therefore, it is critical to determine the mineral N content before the rainy season or the beginning of the following rice crop in a wetland. In the Kilombero flood plain, where information is scarce, a good understanding of the difficulties outlined above will permit economic and sustainable rice farming.

The objective of this study was: (i) To see how different crop management interventions affect the fluctuation of NH_4^+ and NO_3^- content before and after rice transplanting. (ii) To determine the impact of hydrological conditions on the levels of NH_4^+ and NO_3^- during the paddy growth season.

MATERIALS AND METHODS

Study sites

This research was carried out at the Kilombero Valley Floodplain Wetland, located in the Kilombero area of Morogoro (Figure 1). It has a total area of 7967 km^2 (Samora et al., 2013). The climate in the Valley is sub-humid tropical, with relative humidity ranging from 70 to 80% and annual rainfall ranging from 1200 to 1400 mm (MNRT 2004a). There are two rainy seasons in the Valley: a short rainy season known as Vuli that lasts from December to February and a long rainy season known as Masika that lasts from March to May/June. The temperature in the atmosphere varies between 20ºC and 30ºC (MNRT 2004b).

The flood plain is defined by fertile swelling shrinking soils inundated primarily throughout the long rainy season but develop cracks during the dry season, particularly between July and October (Samora et al., 2013). Agriculture, cattle husbandry, fishing, and business are the primary activities in the area (Kato 2007).

Site description of the study sites

Three experimental sites were established in three villages chosen for their distinct soil hydrological characteristics. These were Kantindiuka, Kiyongwire, and Kivukoni Villages, classified as Fringe, Middle, and Central zones, respectively, in terms of river flooding (Figure 1). These represent the study's three distinct hydrological conditions.

Thus, the locations' corresponding qualities are discussed. (i) The Center zone denotes the wetland's primary water flow center. It is defined by persistent circumstances of water saturation with a peak water flood height of 1 m and a flooding period of around 2-3 months during which water covers the ground surface. (ii) The Middle site is a transition zone between the floodplain's protracted inundated center zone and its least flooded portion (Fringe). It is defined by a flooding period of less than a month during which flowing water completely covers the land surface but leaves the root zone moist throughout the cropping season and is underlain by a saturated soil layer. (iii) The Fringe zone is saturated with water to the ground surface for less than two months. It has a significantly longer surface water saturation than the Middle site due to seepage water from the hills following rain that lasts longer than the major river flooding in the former. Therefore, the site located in the Center, Middle, and Fringe portions of the Kilombero River flood plain will be referred to throughout the paper as the Centre, Middle, and Fringe zone or site.

Experimental design

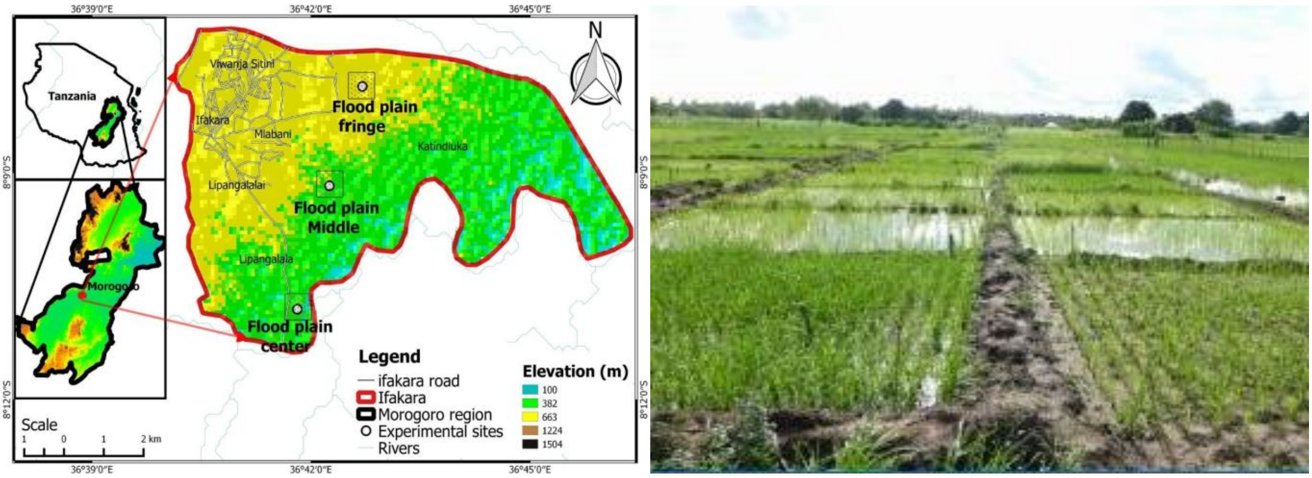
During the 2014/5 and July 2015/6 rain seasons, an experiment with six treatments duplicated three times in a completely randomized block design (CRBD) was conducted at three sites with varying hydrological conditions. The treatments included the following: (i) semi-natural vegetation that was previously planted but left without crop (TR1) (ii) Farmers' practices - rice crop grown without the addition of mineral N and the use of bunds (TR2). (iii) Rice crop + bunds but without mineral N application (TR3). (iv) Rice crop + Bunds + 60 kg/hectare of Urea (TR4). (v) Rice crop plus Bunds + 120 kg/hectare of urea (TR5). (vi) Rice + bunds + laboratory green manure devoid of mineral nitrogen (TR6). The former was put into the soil 45 days after germination in the lablab treatment. The amount absorbed into the soil was equal to 50 kg/ha of N.

In this study, the paddy (*Oryza sativa*) variety TXD 306, popularly known as SARO 5", was employed as a test crop. The experiment was conducted on 5 x 6 m^2 plots with 20 x 20 cm^2 plant spacing, as Kanyeka et al. (2007) advised. Throughout the cropping season, standard agronomic crop management practices were followed.

Determination of hydrological-based characteristics

Rainfall of the studied sites

An automatic weather station collected rainfall data at the study locations. Hourly measurements were taken and stored in a data logger. The distribution of rainfall for the 2015/16 cropping season is shown in Figure 2.



A B

Figure 1. A. Location map of the experimental sites in rice fields of Kilombero Floodplain, Tanzania. B. Fringe experimental site four weeks after paddy rice transplantation

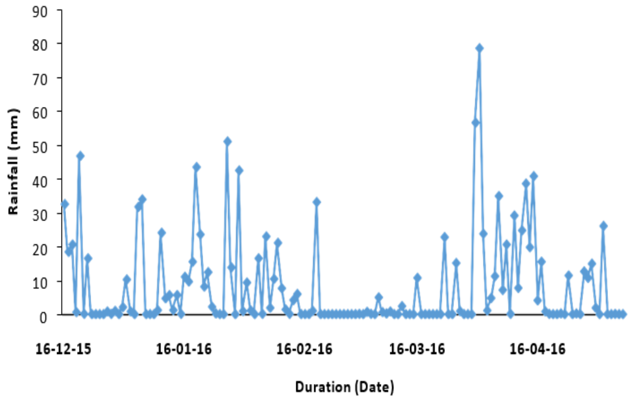


Figure 2. The rainfall during the 2015/16 rainy season

Soil moisture measurements

Virrib sensors were used to collect data on soil moisture. A Virrib sensor was mounted horizontally at a depth of 10 cm from each experimental site, with automatic measurements taking place every 15 minutes (Walker et al., 2004).

Redox potential measurement

The redox levels at each site were determined using the method established by Vorenhout et al. (2004). Daily values were recorded continuously using an Ag/AgCl electrode. A mobile PC was used to configure the system and collect data. A central PIC processor (PIC16F877) processed the data and stored it in a 256 Kbit ferroelectric non-volatile random-access memory (FRAM) serial memory. The data logger was configured and collected using the Hypnos Data Collector Version 1.4, written using LabView.

Determination of the soil characteristics

For laboratory characterization, soil samples were collected from the experimental sites. First, 18 soil samples were randomly obtained from the 0-30 cm depth at each experimental site and combined to form a composite sample. Next, composite soil samples were packed and transferred to the laboratory, where they were air-dried, crushed, and sieved using a 2 mm sieve.

Soil NH_4^+ and NO_3^- content data collection

The following data were collected from the experimental plots: NH_4^+ and NO_3^- concentrations. Before data collection, soil samples from each subject were obtained and prepared in the manner described below.

Soil sampling and sample preparation

During the 2015/16 rain season, soil samples for NH_4^+ and NO_3^- analysis were obtained from individual plots. Before and during the farming season, samples were taken. The pre-paddy growing season (dry-wet transition period) lasted from 16 December (the start of the 2015/16 short rainy season) to 4 March 2016, with weekly samples collected. The second data gathering season ran from 18 March until 8 July 2016. Every two weeks, soil samples were taken. Soil samples were taken randomly from each plot using a soil auger at depths ranging from 0-10 cm. Six soil samples from each treatment were combined thoroughly to create a composite sample.

Individual samples were then sealed in labeled plastic bags, placed in a cooling box filled with ice, and sent immediately to the laboratory for analysis. The samples were immediately frozen in the laboratory before extraction and subsequent NH4+ and NO3-analysis. Of the three study sites, sampling at the Valley Centre site was halted due to flooding shortly after the short rain season.

Data analysis

Soil characterization

The soil samples determined particle size distribution, bulk density, porosity, particle density, pH, total n, total carbon, and plant-available phosphorus. The hydrometer method was used to determine the particle size distribution of soil samples spread in sodium hexametaphosphate solution at 5% (Gee and Bauder 1986). Bulk Density was calculated using the procedure described by Blake and Hartage (1986). The particle was determined using the pycnometer method, which Blake and Hartage invented (1986). Porosity was estimated using the formula (1-BD/PD, where BD= bulk density and PD= Particle density).

The amount of organic carbon in the air was assessed using the Walkey-Black wet combustion method (Nelson and Sommers 1982). According to Bremner and Mulvaney's methodology, total nitrogen was determined using the micro-Kjeldahl method (1982). Olsen and Sommers (1982) described the approach was used to determine the available phosphorus. Finally, pH was determined using a soil: water suspension (1:2:5) following Mc Lean's procedure (1982).

Determination of NH_4^+ and NO_3^-

Before NH_4^+ and NO_3^- extraction, frozen samples were defrosted. Each analyzed plot's moisture content was determined using a different soil sample. To a consistent weight, these samples were defrosted and weighed before and after oven drying at 105ºC. Considering an analytical balance was used to determine the dry weight. After defrosting, around 20 to 25g of soil samples were weighed and immediately placed in the oven. The moisture content was expressed as a fraction of the sample's oven-dry weight. This was converted from the field weight to the oven-dry weight equivalent.

Fifteen grams equivalent of wet soil was shaken with 90 ml of 0.01 M $CaCl_2$ for 60 minutes at 189 rpm (Houba et al. 1986), filtered, and treated with one drop of 0.01 M sulfuric acid to prevent microbial development before being used to determine the concentrations of NH_4^+ and NO_3^- (Nascente et al. 2009). The NH_4^+ concentration in the soil extract was determined using the method established by Reardon et al. (1966). 0.01M NaOH was used to alter the pH of a 20 ml portion of the extract to 7. (Kunamneni et al., 2003). A 0.1 ml aliquot of the neutral (pH 7) extract was pipetted into 16mm cells and incubated for 20 minutes with a mixture of ammonia, salicylate, and cyanurate F5 powders. The NH_4^+ content was determined calorimetrically at a wavelength of 690nm using a photo flex photometer. NO_3^- was determined using Swinehart and Warren's technique (1953). Next, 1 mL of the soil extract obtained in the previous preparation was pipetted into 16 mm cuvette cells and incubated for 10 minutes with Vario nitrate Chromotropic powder. The NO_3^- the content of the extract was measured using spectrophotometry at a wavelength of 436nm. Both NH_4^+ and NO_3^- concentrations were expressed in g/kg soil.

Statistical analysis

GenStat Computer Software was used to conduct a post hoc Tukey HD test and two-way ANOVA analysis (Payne 2009). To compare the mean values of NH_4^+ and NO_3^- contents between treatments, the post hoc Tukey HD test was performed. In addition, the influence of the hydrological zone between the Middle and Fringe sites on NH_4^+ and NO_3^- concentration was investigated using a two-way ANOVA.

RESULTS AND DISCUSSION

Characteristics of the studied soils

Tables 1 and 2 summarize the physical and chemical characteristics of the soils tested. The soil textures of the investigated soils vary considerably. Clay concentration reduced as the distance from the river source increased. The Centre site has approximately 60% clay, while the Fringe site contains the least clay (30%). All sites had a high silt concentration, ranging from 26% in the Centre and Middle sites to 39% in the Fringe site. The porosity of the soil was 54% in the Center, 48% in the Middle, and 54% in the Fringe, respectively. The C/N ratio was 11.8% in the center, 12.4% in the middle, and 16.5% in the fringe. The ratio increased as the hydrological conditions deteriorated from the Center to the Fringe.

Table 1. Soils physical characteristics of the studied sites

Site name	Physical properties					
	Sand (%)	**Silt (%)**	**Clay (%)**	**BD (Mg m^{-3})**	**PD (Mg m^{-3})**	**Porosity (%)**
Fringe	29.61	39.61	30.78	1.22	2.66	54
Middle	40.34	26.87	32.44	1.34	2.66	49
Center	12.00	26.54	61.47	1.21	2.66	54

Table 2. Soils chemical characteristics of the studied sites

Site name	Chemical properties				
	Organic C (%)	**Total N (%)**	**C/N**	**Extractable P (mg kg^{-1})**	**pH**
Fringe	1.82	0.11	16.5	49.98	6.1
Middle	0.87	0.07	12.4	16.52	5.8
Center	1.88	0.16	11.8	5.51	4.9

With a pH of 4.9, the Center was the most acidic. The soil pH climbed steadily from the Centre to the Fringe site, reaching 5.8 and 6.1 in the Middle and Fringe locations, respectively. All sites have a relatively low organic carbon content. It was approximately 1.8% at the Centre and Fringe locations, but only 0.8% at the Middle location. The total nitrogen level was comparable in the Centre and Fringe sites (0.16 and 0.11%) but was relatively low at the Middle site (0.07%). At the Center, Middle, and Fringe, the equivalent C: N ratios were 11.7, 12.4, and 16.5, respectively.

Variation of soil moisture in the root zone of the studied soils during the pre-paddy growing season

The soil's moisture level between 0 and 10 cm changed throughout the season, as indicated in Table 3. It varied between 12.3 and 31.6% at the Middle site and 16.2 to 46.4% at the Fringe location. Between the two sites, the pattern of moisture content fluctuation was distinct.

During the first four weeks, the Middle site was significantly drier than the Fringe zone, with moisture content varying between 12 and 22%, compared between 41 and 46%. It was noteworthy that soon following the first rains in early December, the Fringe zone became wetter due to surface water flow from surrounding mountain slopes. At the Middle location, this phenomenon did not occur. Due to the inadequacy of the data for assessing the extent of soil aeration, a phenomenon associated with redox processes in the soil (Lin and Doran 1984), the data were converted to a percentage of water-filled pore spaces to interpret their relationship with the redox-related characteristics of the studied soils.

As illustrated in Table 4, the percentage of WFP varied significantly within and between the two sites. It varied between 22.7 and 53.9% at the Middle site for nine out of ten weeks of the trial period and peaked at 64.3% at week twenty. It fluctuated between soils at the Fringe site over the first four weeks, ranging from 76. 5 to 86.0% WFP. During weeks 4 and 7, the WFP percentage varied between 27.4 and 31.1%. This was the site's dry phase. Between weeks 9 and 10, the percentage of WFP began to grow again (55.0 to 56.8%). These are later described in detail concerning the change in NH_4^+ and NO_3^- concentrations at these sites.

Variation of the redox potential in the root zone of the studied soils

Variation of redox potential at the Middle and Fringe sites during the pre- paddy cropping season

The Middle site's redox potential values fluctuated significantly during the changeover period. They were between +341.5 and +394.7 mV. A comparable situation existed between weeks 0 and 7 at the Fringe location. From week 7 to week 10, elevated Eh values (more than +600 mV) were seen. The potential redox values within the root zone for both the Middle and Fringe locations during the primary cropping season are shown in Table 5. Again, there were significant differences between the two sites. Eh varied between +121.6 and +394.2 mV at the Middle site.

Variation of redox potential at the Middle and Fringe sites during the paddy cropping season

The lowest readings (121.6 to 237.0 mV) were obtained during the first 3 weeks, while between 348.1 and 478.0 mV were obtained between weeks 6 through 16. At the Fringe location, a similar tendency was seen, though with some variance. By and large, the soils investigated at the Middle and Fringe locations had greater redox levels toward the end of the cropping season (Table 6). For example, this began at the Middle site during week 6, but it started at the Fringe location.

Table 3. Variation of soil moisture content in the root zone (0-10cm) in the studied soils during the pre-paddy growing season

Site	Soil moisture content (%)										
	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Middle	15.1	12.3	13.1	22.7	26.4	24.2	17.5	17.7	19.5	14.4	31.6
Fringe	43.4	46.4	43.1	41.3	16.2	14.9	16.8	14.7	22.7	29.7	30.6

Table 4. Water-filled pore space at the Middle and Fringe sites during the pre-paddy growing season

Site	Percentage water-filled pore space (%WFP)										
	Week0	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10
Middle	30.8	25.1	26.7	46.4	53.9	49.4	35.7	36.2	39.9	29.5	64.6
Fringe	80.5	86.0	79.8	76.5	30.0	27.7	31.1	27.4	42.1	55.05	56.8

Table 5. Variation of Redox potential (eh) at the Middle and Fringe sites during the pre-paddy cropping season

Site	Redox potential (mV)										
	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Middle	392	383.7	341.3	344.5	349.3	350.9	361.9	365.6	363.6	371.8	394.7
Fringe	358.7	349.6	345.3	351.1	348.1	341.6	346.2	350.3	672.7	676.7	688.9

Table 6. Variation of redox potential at the Middle and Fringe sites during the paddy-cropping season

Site	Redox potential (mV)								
	Week 0	Week 2	Week 4	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16
Middle	237.0	204.8	121.6	348.3	394.2	347.3	478.0	349.0	349.4
Fringe	195.3	209.2	352.3	242.9	403.7	295.5	408.3	350.2	357.5

Effect of crop management interventions on the variation of NH_4^+ content

The data illustrating the fluctuation in the NH_4^+ concentration of the examined soils are divided into two seasons: the dry-wet transitional (pre-paddy growing season) and the paddy cropping season.

NH_4^+ variability during the pre-paddy growing season

The data presented below consists of 2 sites: The Middle and the Fringe sites.

NH_4^+ content at the Middle site

The results indicated a range of NH_4^+ concentrations and a four-stage process. The initial NH_4^+ content at the start of the rainy season, the subsequent increase in NH_4^+ to a peak value, the subsequent fall in NH_4^+ content to 0 g/kg soil, and finally, the following increase NH_4^+ content (Figure 3). At week 0, the Middle site's NH_4^+ content was greatest in TR6 (0.00215 g/kg soil) and lowest in TR2 and TR5 (0.000698 and 0.000958 g/kg soil, respectively). At (P = 0.05), these values were statistically different (Table 7). The remainder of the treatments had intermediate values.

From week 0, NH_4^+ grew gradually to reach a peak value between weeks 4 and 6 (Figure 4). The peak readings for NH_4^+ were as follows: TR6>TR5>TR3>TR4>TR1>TR2. Between weeks 4 and 6, depending on the treatment, NH_4^+ levels gradually decreased to their lowest levels at week 9 before increasing progressively at week 10 (Figure 4). At week 10, this increase reached considerably different values (Table 7), with TR3 reaching the most significant value.

At week 6, significant differences in NH_4^+ content were observed between treatments, which can be classified into four categories: TR6 had the highest NH_4^+ content (0.00720 g/kg soil), followed by TR4 and TR5 (0.004525 and 0.004325 g/kg soil, respectively), and TR3 (0.002058 g/kg soil). In contrast, TR2 and TR1 had the lowest NH_4^+ content (0.000514 and 0.00020 g/kg soil, respectively). These categories were statistically distinct (Table 7). Between weeks 9 and 10, practically all treatments experienced a significant increase in NH_4^+. At week 10, TR 5 and TR3 had the most critical and lowest NH_4^+ contents (0.005478 and 0.004212 g/kg soil, respectively).

NH_4^+ content at the Fringe site

The fluctuation in NH_4^+ concentrations at the Fringe site changed throughout time, as illustrated in Figure 4. On the first day following the initial rainstorm, the NH_4^+ content differed significantly between treatments. TR2, TR3, TR4, and TR5 treatments included considerably more NH_4^+ (above 0.003 g/kg soil) than TR1 and TR6 treatments contained (0.001 and 0.002 g/kg soil, respectively) (Table 8). NH_4^+ content varied significantly across all treatments throughout the pre-paddy growing season. Regardless of the imposed management intervention, the NH_4^+ content changed predictably, demonstrating three separate periods. These were: an initial period that corresponded to the start of the rains, during which the NH_4^+ content was relatively high and showed a tendency to increase to a peak value, followed by a second period during which the NH_4^+ content decreased over time to zero, and finally a period of NH_4^+ increase over time (Figure 4).

During the initial phase of NH_4^+ growth, discrepancies in the peak value and the time necessary to reach it existed. For example, in TR4 (60 kg N + bunds), NH_4^+ nearly quadrupled in a week (0.003 to 0.005 g/kg soil). TR6 (Green manure + bunds) had a similar trend, increasing from 0.01 g/kg soil in week 0 to 0.004 g/kg soil in week 3 (Table 8). The subsequent treatments increased NH_4^+ less effectively and differed in the time required to attain peak NH_4^+ content. TR3, TR4, and TR5 reached their highest NH_4^+ values in week 1, TR1 and TR2 in week 2, and TR6 in week 3.

The reduction pattern in NH_4^+ from the peak to the lowest value varied significantly between treatments, as illustrated in Figure 4. The reduction began in week one for TR2, TR3, TR4, and TR5; week two for TR2, and week three for TR6. The lowest or absolute 0 results were obtained at various times: week 4 for TR4 and TR5, and week 5 for the remaining treatments.

The period during which no NH_4^+ was detected varied according to treatment: 4 weeks (weeks 4-7) for TR4 and TR5; 3 weeks (weeks 5-7) for TR2 and TR3 (weeks 5-7); and 2 weeks (weeks 5-6) for TR1 and TR6, respectively.

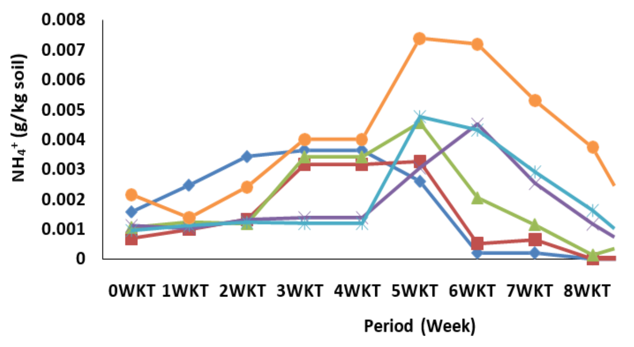


Figure 3. Pre-rice growing season NH_4^+ variation at the Middle site. WKT: Week before Transplanting Rice (Dry -wet transition weeks)

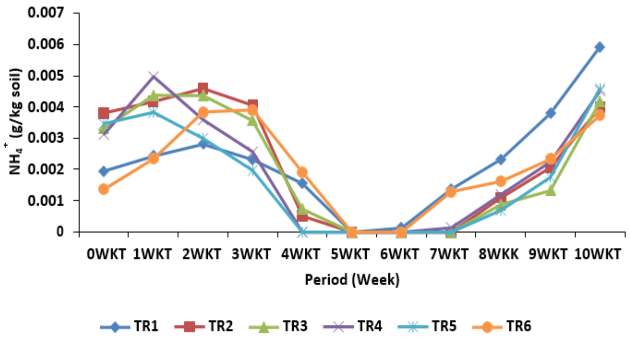


Figure 4. NH_4^+ content during the pre-paddy growing season at the Fringe site. WKT**:** Week before transplanting rice (dry-wet transition weeks)

Additionally, the increase in NH_4^+ throughout the final period varied amongst regimens. At week 10, the biggest increase (0.006 g/kg soil) was reported in TR1, whereas the smallest (0.003 g/kg soil) was observed in TR6. At week 10, the difference between treatments was statistically significant (P = 0.05) (Table 8).

The duration of mineralization required to reach maximal NH_4^+ was as follows: RT4>TR6=TR5=TR3=TR2>TR1. These findings indicate that the lablab green manure treatment was the most effective at increasing peak NH_4^+ turnover, followed by the urea-treated treatments (TR4 and TR5) and finally, the control. The treatment with bunds behaved similarly to those receiving mineral N. The amount of injected urea did not affect the peak NH_4^+ level.

NH_4^+ variability during the paddy cropping season

Content of NH_4^+ in valley Middle

The fluctuation in NH_4^+ concentrations at the Middle site across the rice-cropping season is depicted in Figure 5. At week 0 (shortly after rice planting), the NH_4^+ content differed modestly between treatments.

TR5 had the highest concentration (0.02731 g/kg soil), and TR2 had the lowest (0.00993 g/kg soil). TR4, TR5, and TR6 levels at week 0 were significantly greater (P = 0.05) than the values for the other treatments (Table 9). Additionally, it is critical to highlight the significant differences in NH_4^+ concentrations that occurred between treatments even during the following phases of the rice cropping season.

In general, the NH_4^+ content decreased over the 16 weeks in the majority of the treatments. TR4 and TR5 behaved differently at week 8 (0.009733 and 0.03038 g/kg soil) but then followed a similar trend of declining NH_4^+ concentration until week 16. The greatest drop in NH_4^+ concentration throughout the 16 weeks was observed in TR5 (0.024746 g/kg soil), while the smallest decrease was observed in TR3 (0.007912 g/kg soil).

While TR1, TR2, and TR3 had significantly lower NH_4^+ levels throughout the early phases of the rice cropping season, TR1 had significantly greater NH_4^+ levels by week 16 compared to the other treatments (Table 9).

Content of NH_4^+ in valley Fringe

The variance in NH_4^+ concentrations at the Fringe site is illustrated in Figure 6. At week 0, TR5 (0.02987 g/kg soil) had the greatest NH_4^+ content (0.01841 g/kg soil). TR1 and TR2 had the lowest values, while TR3 had the highest. These differences from the rest were statistically significant (P = 0.05). TR2, TR3, and TR5 continued to exhibit the same tendency throughout the cropping season, as demonstrated by weeks 8 and 16 (Table 10). Nevertheless, similar to the Middle site, TR1 maintained much higher NH_4^+ values during the same period.

The NH_4^+ content of TR4 and TR5 soils increased significantly at week 8 (0.009513 g/kg soil from 0.003032 g/kg soil at week 6 for TR4 and 0.027823 g/kg soil from 0.003032 g/kg soil at week 6 for TR5, respectively) (Figure 6). Statistics indicated that these peak values were statistically significant (P = 0.05). Apart from the unique phenomena observed at week 8 for TR4 and 5, the general trend for the remaining treatments was a drop in NH_4^+ content from week 0 to week 6 or 8, a minor increase in the same at week 10, and stagnation for the remainder of the cropping season until week 16.

Table 7. Effect of crop management interventions on the NH_4^+ content during the pre-paddy growing season at the Middle site

Treatment	NH_4^+ content (g/kg soil)			
	Week 0	**Week 1**	**Week 6**	**Week 10**
TR1	0.00158ab	0.002476a	0.000204a	0.002154ab
TR2	0.000698a	0.000992a	0.000514a	0.002836ab
TR3	0.001058ab	0.001242a	0.002058ab	0.004212bc
TR4	0.001121ab	0.00102a	0.004525b	0.001955ab
TR5	0.000958a	0.001121a	0.004325b	0.005478d
TR6	0.002158b	0.001383a	0.007207c	0.00361abc
Mean	0.001262	0.001135	0.00314	0.00337
F statistics	0.019	0.1	0.001	0.002
L.S.D	0.0007662	0.000663	0.001666	0.00141
CV(%)	5.3	14.4	5.3	24.7

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05).

Table 8. Effect of crop management interventions on the NH_4^+ content at selected periods during the pre-paddy growing season at the Fringe site

Treatment	NH_4^+ content (g/kg soil)			
	Week 0	**Week 1**	**Week 6**	**Week 10**
TR1	0.001955ab	0.002431a	0.00013286a	0.005934b
TR2	0.003805c	0.004176a	0a	0.003988a
TR3	0.003314c	0.004379a	0a	0.004174a
TR4	0.003126bc	0.004973a	0a	0.004524a
TR5	0.003471c	0.003836a	0a	0.004595a
TR6	0.001371a	0.002349a	0a	0.003742a
Mean	0.00284	0.00369	0.000022	0.00449
F statistic	0.9	0.097	0.465	0.158
L.S.D	0.000871	0.002115	0.000171	0.001713
CV (%)	0.9	8.4	21	4.4

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

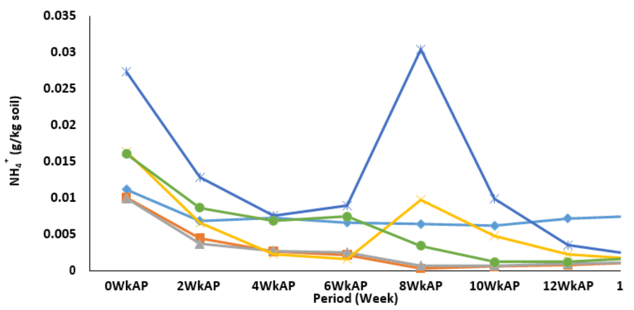


Figure 5. NH_4^+ content during the paddy-cropping season at the Middle site. WKAP: Week after transplanting rice

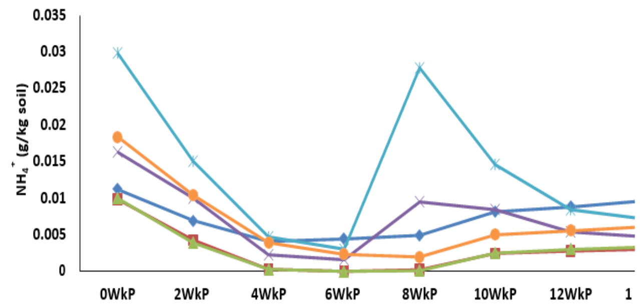


Figure 6. NH_4^+ content during the paddy-cropping season at the Fringe site. WKP: Week after transplanting rice

Table 9. Effect of crop management interventions on the NH_4^+ content during the paddy-cropping season at the Middle site

Treatment	NH_4^+ content (g/kg soil)		
	Week 0	Week 8	Week 16
TR1	0.01112a	0.0064bc	0.008739b
TR2	0.01003a	0.000289a	0.001486a
TR3	0.00993a	0.000669a	0.001465a
TR4	0.01633b	0.009733c	0.002018a
TR5	0.02731c	0.030381d	0.002914a
TR6	0.016b	0.003369ab	0.002564a
Mean	0.01512	0.00847	0.0032
F statistic	0.001	0.001	0.001
L.S.D	0.001891	0.002127	0.001252
CV (%)	3	1.5	1.9

*Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Table 10. Effect of crop management interventions on the NH_4^+ content during the paddy-cropping season at the Fringe site

Treatment	NH_4^+ content (g/kg soil)		
	Week 0	Week 8	Week 16
TR1	0.01123a	0.00492b	0.010551d
TR2	0.00987a	0.000213a	0.003653a
TR3	0.01002a	0.000083a	0.003627a
TR4	0.01633b	0.009513c	0.005379ab
TR5	0.02987c	0.027823d	0.008084c
TR6	0.01841b	0.001975ab	0.007236bc
Mean	0.01595	0.00742	0.00642
F statistic	0.001	0.001	0.001
L.S.D	0.001966	0.001805	0.001361
CV (%)	2.2	1.9	4.6

*Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Effect of crop management interventions on the variation of NO_3^- content

The data illustrating the changes in NO_3^- content in the examined soils are divided into two time periods: the pre-paddy growing season and the paddy cropping season.

NO_3^- content during the pre-rice cropping period

The NO_3^- the content of both the Middle and Fringe locations is included in the results reported here.

NO_3^- content at Middle site

At the start of the rainy season, the NO_3^- concentration varied slightly between treatments, with TR6 and TR2 having the highest and lowest levels (0.002951 and 0.002324 g/kg soil), respectively (Figure 7).

The NO_3^- level in all treatments fell to 0 g/kg soil within two weeks. Depending on the individual treatment, there was a beneficial shift in NO_3^- content between weeks 3 and 5.

This increase persisted from week 0 to week 10. However, the pattern varied according to treatment. However, these increases in NO_3^- were not statistically significant (P = 0.05), except at week 10, when the NO_3^- value in TR1 (0.000621 g/kg soil) was statistically considerably lower than the value observed in the other treatments (Table 11).

NO_3^- content at the Fringe site

Figure 8 illustrates the NO_3^- concentration at the Fringe site during the pre-paddy growing season. TR6 had the maximum concentration (0.002104 g/kg soil) in week 0 (0.002104 g/kg soil). The remainder of the treatments contained almost no NO_3^-.

Between weeks 1 and 7, except TR6, hardly any NO_3^- was detected in the root zone for most imposed treatments. An increase in NO_3^- occurred differentially between weeks 7 and 10. The differences, however, were not statistically significant (P = 0.05) (Table 12). Thus, by week 10, the root zone NO_3^- concentration ranged between 0.000453 (TR 4) and 0.0010683 (TR5) g/kg soil.

NO_3^- content during the paddy cropping season

NO_3^- content at Middle site

The following qualities can be seen in these results: Initial relatively high NO_3^- values that vary among treatments, dividing the latter into three categories that are statistically significantly different (P = 0.05) (Table 13), a decline of NO_3^- to achieve absolute or close to 0 g/kg soil from week 8 to the rest of the cropping season (except for TR4 and TR5, which showed a remarkable rise in NO_3^- at week 8) (Figure 9).

TR5 (0.010681 g/kg soil) had the greatest NO_3^- the level at week 0, followed by TR4 (0.005722 g/kg soil). The two treatments were statistically different from the others

(P = 0.05) (Table 13). The NO_3^- level in TR5 increased dramatically at week 8, reaching 0.011948 kg/kg from 0 g/kg at week 6. TR4 showed a similar trend (0.00675 g/kg soil at week 8 compared to 0 g/kg soil at week 6).

Following that, the NO_3^- levels dropped to near 0 g/kg soil in both cases by week 12 and stayed nearly constant until week 16. From week 6 to week 16, TR1 experienced a small but considerable increase in NO_3^-.

NO_3^- content at the Fringe site

With two exceptions: a considerably higher (P = 0.05) TR1 value than the other treatments at week 16 and an abrupt increase in NO_3^- content in TR3 at week 10, the NO_3^- fluctuation during the rice cropping season approximated that of the Middle site (Figure 10).

TR5 had the greatest NO_3^- value (0.009302 g/kg soil) at week 0, followed by TR6 (0.005841 g/kg soil), and TR 2 had the lowest NO_3^- value (0.00242 g/kg soil) (Table 14).

Effect of hydrological conditions on the NH_4^+ and NO_3^- variation during the paddy growing season

This section discusses the findings of NH_4^+ and NO_3^- content measurements as a function of both imposed treatments and hydrologic conditions. These are the aggregated results from the hydrological conditions examined (Middle and Fringe sites). Due to the similar magnitudes and trends in the content of both NH_4^+ and NO_3^- values in the treatments between the pooled values (Middle and Fringe combined) and those from individual sites (Middle or Fringe), as presented previously, then this will demonstrate the effect of hydrological conditions on NH_4^+ and NO_3^- content.

Effect of hydrological conditions on the content of NH_4^+

NH_4^+ values for a given week are shown in Figure 11 at both the Middle and Fringe sites. Tables 15 and 16 illustrate statistical comparisons of the NH_4^+ concentrations at the two sites. Throughout the 16-week study period, there was no significant difference between the sites with varying hydrological conditions.

Thus, regardless of the treatment used, there was no statistically significant change in NH_4^+ concentration between the Middle and Fringe sites during the rice-growing season. As a result, these findings imply that the site's hydrology had no discernible effect on the NH_4^+ condition.

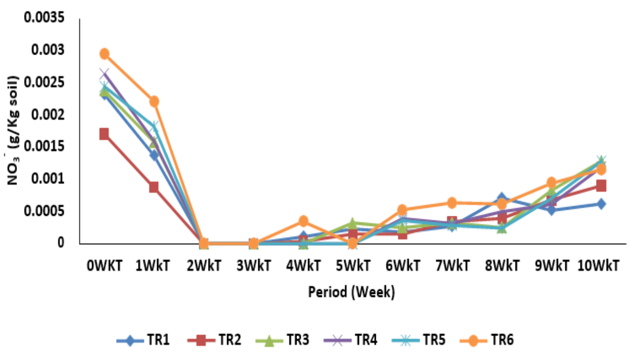


Figure 7. NO_3^- content during the pre-paddy growing season at the Middle site. WKT: Week before transplanting rice (dry-wet transition weeks)

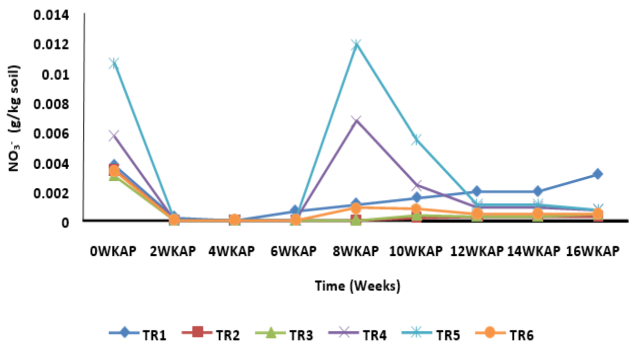


Figure 9. NO_3^- content the rice paddy-cropping season at the Middle site. WKAP: Weeks after transplanting rice

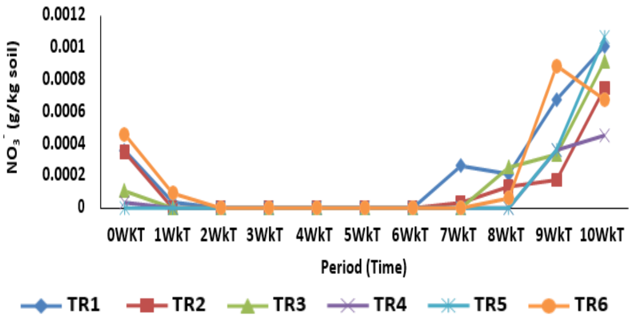


Figure 8. NO_3^- content during the pre-paddy growing season at the Fringe site. WKT. The week before transplanting rice (dry-wet transition weeks)

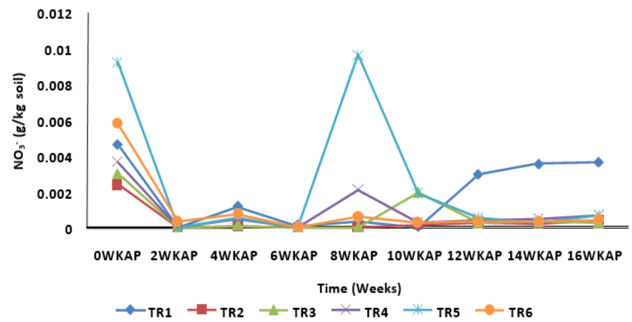


Figure 10. NO_3^- content the rice paddy-cropping season at the Fringe site. WKAP: Week after transplanting rice

Table 11. Effect of crop management interventions on the NO_3^- content during the pre-paddy growing season at the Middle site

Treatment	$NO3^-$ content (g/kg soil)		
	Week 0	**Week 6**	**Week 10**
TR1	0.002324a	0.0001821a	0.000621a
TR2	0.001706a	0.000153a	0.000903ab
TR3	0.002383a	0.0002505a	0.001285b
TR4	0.002645a	0.0003933a	0.001195ab
TR5	0.002448a	0.0003612a	0.001283ab
TR6	0.002951a	0.0005301a	0.001159ab
Mean	0.00241	0.000312	0.001075
F statistics	0.101	0.08	0.023
L.S.D	0.000822	0.000271	0.000396
CV (%)	9.2	10.3	5.3

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Table 12. Effect of crop management interventions on the NO_3^- content during the pre-paddy growing season at the Fringe site

Treatment	$NO3^-$ content (g/kg soil)		
	Week 0	**Week 6**	**Week 10**
TR1	0.0003604a	0a	0.0010126a
TR2	0.0003482a	0a	0.0007507a
TR3	0.0001057a	0a	0.0009195a
TR4	0.0000337a	0a	0.000453a
TR5	0a	0a	0.0010683a
TR6	0.00004594a	0a	0.0006769a
Mean	0.000492	0	0.000814
F statistic	0.001	0	0.155
L.S.D	0.0003849	0	0.000509
CV (%)	30.3	0	17.3

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Table 13. Effect of crop management interventions on the NO_3^- content during the rice-cropping season at the Middle site

Treatment	$NO3^-$ content (g/kg soil)		
	Week 0	**Week 8**	**Week 16**
TR1	0.00378a	0.001113a	0.0031145b
TR2	0.003474a	0a	0.0002873a
TR3	0.003075a	0a	0.000463a
TR4	0.005722b	0.00675b	0.0007468a
TR5	0.010681c	0.011948c	0.0007007a
TR6	0.00336a	0.000852a	0.00047a
Mean	0.00502	0.00344	0.00096
F-Statistic	0.001	0.001	0.001
L.S.D.	0.000997	0.001291	0.000985
CV (%)	2.2	3.8	14.9

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Table 14. Effect of crop management interventions on the NO_3^- content during the rice paddy-cropping season at the Fringe site

Treatment	$NO3^-$ content (g/kg soil)		
	Week 0	**Week 8**	**Week 16**
TR1	0.004646a	0.000354a	0.003662b
TR2	0.00242a	0a	0.000408a
TR3	0.003047a	0a	0.000238a
TR4	0.003686a	0.002085a	0.000663a
TR5	0.009302b	0.009691b	0.000691a
TR6	0.005841ab	0.000643a	0.000402a
Mean	0.00482	0.00213	0.00101
F statistic	0.001	0.001	0.001
L.S.D	0.002291	0.001988	0.001029
CV (%)	13.4	20.6	22.9

Note: Means in the same column followed by the same letter(s) are not significantly different according to the Tukey test (P = 0.05)

Table 15. Two-way ANOVA for NH_4^+ content comparison between the Middle and Fringe sites at week 0.

Variate: NH_4^+ source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Treatment	5	2.991E-03	5.983E-04	81.13	<.001
Block (site)	1	4.382E-06	4.382E-06	0.59	0.448
Treatment Block	5	1.641E-04	3.283E-05	4.45	0.005
Residual	24	1.770E-04	7.374E-06		
Total	35	3.337E-03			

Table 16. Two-way ANOVA for NH_4^+ content comparison between the Middle and Fringe sites at week 6.

Variate: NH_4^+ source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Replicate stratum	2	2.166E-05	1.083E-05	2.04	
Treatment	5	2.050E-04	4.100E-05	7.71	<.001
Block (site)	1	1.538E-10	1.538E-10	0.00	0.996
Treatment Block	5	7.124E-06	1.425E-06	0.27	0.926
Residual	22	1.170E-04	5.317E-06		
Total	35	3.507E-04			

Effect of the hydrological conditions on the root zone NO_3^- content

The fluctuation in NO_3^- concentration between the Middle and Fringe locations across the 16-week study period is depicted in Figure 12. There was no significant variation in NO3- content for the trial duration. This is illustrated in Table 17.

The statistical study results on NO_3 indicated no significant differences between the Middle and the Fringe in the latter periods (Week 0 to Week 16). However, the interaction between blocks and treatments was statistically significant in certain weeks. As a result of these findings, it is concluded that the site's hydrology had no discernible effect on the NO_3^- status.

Table 17. Two-way ANOVA for NO_3^- content comparison between the Middle and Fringe sites at week 0

Variate: NO_3^- source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Replicate stratum	2	2.465E-06	1.233E-06	1.26	
Treatment	5	2.023E-04	4.046E-05	41.24	<.001
Block (site)	1	3.309E-07	3.309E-07	0.34	0.567
Treatment.Block	5	2.077E-05	4.154E-06	4.23	0.008
Residual	22	2.158E-05	9.810E-07		
Total	35	2.474E-04			

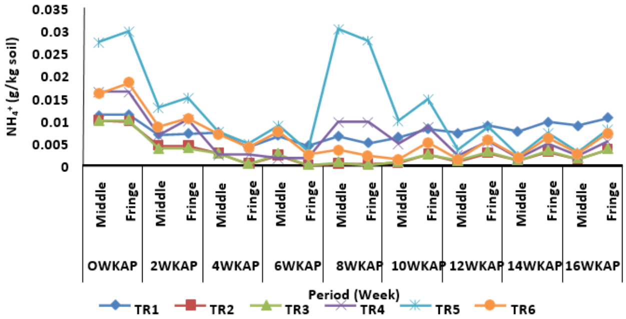


Figure 11. NH_4^+ content in the different treatments at the Middle and Fringe sites during the paddy-growing season

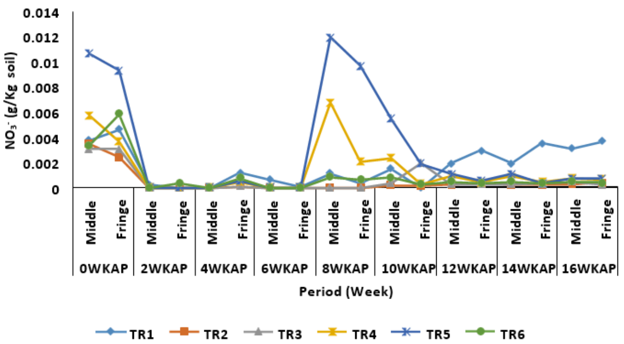


Figure 12. NO_3^- content in the different treatments at the Middle and Fringe sites during the paddy-growing season

Discussion

Effect of crop management interventions on the Variation of NH_4^+ content

Variation of NH_4^+ during the pre-rice growing season (dry-wet transition period) at both sites; Middle and Fringe sites

These results are described independently for each of the analyzed locations and then compared to one another. Additionally, a comment is made on the seasonal fluctuation between the pre-rice growing season (wet-dry transitional period) and the protracted rain season, also known as the paddy cropping season.

The primary characteristics of the NH_4^+ variation during the wet-dry transitional season were an increase in NH_4^+ during the initial period following the first rainfall to a peak value; a decline in NH_4^+ to a value of 0 g/kg soil NH_4^+ content; and a subsequent rise near the season's end. This pattern is typical of both locations during the wet-dry season.

The increase in NH_4^+ concentration following initial rains is related to mineralization, a process generally connected with the degradation of organic matter and the release of nutrients in their mineral form, including NH_4^+ (Nziguheba et al. 2005; Sugihara et al. 2010 a,b). Therefore, differences in peak values across treatments can be interpreted as measuring the amount of mineralizable nitrogen in the substrate soil organic matter (Wang et al., 2004; Nziguheba et al., 2005).

Mineralization will often continue as long as the prevailing conditions, including the presence of a substrate, permit. The pH, C: N ratio, redox potential, microbial activity and biomass, electron acceptor availability, cation exchange capacity, amount and nature of clay, nature and amounts of salts, inputs and nature of organic materials, soil organic matter content, and quality, and supply of nutrients such as phosphorus (P), among others, all play a role in ammonium production in submerged rice soils (Deenik 2006; Inamura et al. 2009). Except for the organic matter content and perhaps the C/N ratio, most of these variables were similar, if not identical, among treatments. It is self-evident that treatments fertilized with N, organic or inorganic, should have generated more biomass than those that were not, resulting in significantly more mineralizable N and a significantly longer duration of obtaining the peak NH_4^+ concentration (Kimetu et al. 2006). This appears to be the case at the Middle site, where TR6, TR5, and TR4 had some of the highest peak NH_4^+ values compared to the other treatments. It is critical to note that mineralization happened equally in the Fringe and Middle sites, with significantly less pronounced differences between the treatments. The inconsistency in the peak NH_4^+ content and the time required to reach it cannot be adequately explained. This may be partly explained by the much more significant percentage of water-filled pore space during the first three weeks. Additionally, changes in the rate of water loss by natural drainage following a rain occurrence were seen among treatments, a phenomenon that was not previously described. Between weeks 0 and 3, the soil at the Fringe site was drier, with percentage WFP values of 80.51% at week 0, 86.05% at week 1, and 79.85 and 76.55% at weeks 2 and 3, respectively. These conditions are suboptimal for organic matter decomposition (Gilmour et al. 1977) and ammonification (Pal and Broadbent 1975). This may explain why the Middle site's percentage WFP values peaked at 53.89% during the period of peak mineralization. Linn and Doran (1984) demonstrated a linear relationship between microbial activity and WFP levels between 30% and 60%, often the optimal moisture level for microbiologically regulated processes like mineralization.

These results indicate that the mineralization period for peak NH_4^+ production at the Middle site was between 3 and 6 weeks and between 1 and 3 weeks at the Fringe site. The difference is most likely due to changes in soil moisture conditions. The latter is more humid and has a percentage water saturation of greater than 60% during the first four weeks of the rain season. Additionally, mineralization occurred over a more extended period with a substantially higher peak NH_4^+ in treatments with a greater biomass incorporation rate the previous season.

The parallelism in the decrease in NH_4^+ levels between the Middle and Fringe sites suggests the presence of similar impacting variables. The decline can be attributed to a variety of processes, including plant uptake, leaching (where conditions permit) (Kimetu et al. 2006), volatilization (Jones et al. 2007), nitrification (Reddy and DeLaune 2008; Sahrawat 2010), deamination (Reddy and DeLaune 2008), decomposition (Reddy and DeLaune 2008), and decline in decomposable organic matter (Marschner 2008). The phenomenon is generally attributable to nitrification and plant uptake of both NH_4^+ and NO_3^- in the first instance. The reason for linking the drop with nitrification is reinforced by the aerobic conditions prevalent during this period, as indicated by the elevated redox potential readings (Table 5). Numerous earlier investigations have linked redox levels greater than + 300 mV to aerobic circumstances (Pezeshki and Delaune 2012) conducive to nitrification (Reddy and DeLaune 2008). The time of the NH_4^+ drop coincided with a significant decrease in soil moisture content (Table 3).

The percentage of water-filled pores (% WFP) varied between 35.7% (week 6) to 29.57% during this period (Table 4). Under low soil moisture content conditions, microbial-mediated processes such as organic matter decomposition and mineralization occur at a low rate (Pal and Broadbent, 1975; Gilmour et al., 1977; Linn and Doran, 1984). Linn and Doran (1984) reported that at a concentration of 30% WFP, microbial activity is significantly decreased.

The rapid increase in NH_4^+ concentration in all treatments between weeks 9 and 10 is related to increased soil moisture. At week 10, the soil moisture status increased from 14.49% moisture content, or 29.57% WFP, to 34.67% (64.63% WFP). Linn and Doran (1984) concluded that the% WFP value at week 10 is close to ideal for microbial-mediated processes like mineralization. At week 10, the NH_4^+ turnover reflects the soil's capacity to produce NH_4^+ before rice crop transplantation. This is consistent with previous discoveries that dry circumstances are optimal for the soil microbial biomass, which serves as both a nutrient sink and a source of nutrients in tropical ecosystems ahead of the following rain season (Sugihara et al. 2010a). At the Middle site, TR5 and TR3 outperformed the other treatments in terms of NH_4^+ supply capacity, whereas TR1 outperformed the other treatments in terms of NH_4^+ supply capacity.

NH_4^+ variability during the paddy cropping season at both sites; Middle and Fringe site

Except for the treatments that received urea at week 7 after rice plant transplantation, the NH_4^+ concentration decreased with time during the rice cropping season in this study. The drop in NH_4^+ over time is comparable to the decrease seen by Carmona et al. (2012) over a 91-day timeframe. The decline could be attributed in part to rice crop uptake (Ghosh and Bhat 1998) and possible leaching (Kimetu et al. 2006). Meng et al. (2014) observed significant NH_4^+ losses beyond the 50cm soil depth in both conventional and organic rice cultivation systems.

The observed reduction in NH_4^+ from the first week onwards coincided with the presence of reducing soil conditions, as shown by the low (+ 300 mV) redox values at both sites. Under these conditions, NH_4^+ accumulates in the soil environment (Kimetu et al. 2006; Reddy and Delaune 2008), unless other factors such as NH_4^+ volatilization due to high pH (Loomis and Connor 1992), or leaching or displacement by runoff (Eder et al. 2015) have an effect. However, the pH values of the soils studied were low (5.8 and 6.1 for the Middle and Fringe sites, respectively). This is outside of that range. The most likely explanation for the observed low NH_4^+ concentrations is slow nitrogen mineralization and/or leaching rate. It is widely established that low redox potential inhibits mineralization because only anaerobic or facultative anaerobic bacteria are capable of respiration (Pezeshki and Delaune 2012). This group of microorganisms has a limited capacity for carbon absorption and high energy requirements (Pezeshki and Delaune 2012). The limit for aerobic respiration is regarded to be redox levels greater than + 300 mV. (Rostaminia et al., 2011; Pezeshki and Delaune 2012). As a result, the rate of N mineralization is likewise low (Kimetu et al. 2006). This may account for the relatively low NH_4^+ values observed during the season's first four to six weeks at the Middle and Fringe sites, respectively.

The abrupt increase in NH_4^+ in TR4 and TR5 at week 8 was attributed to the application of ammonium fertilizer in week 7. In actuality, urea hydrolyzes to become NH_4^+ within 5-7 days (Dharmakeerthi and Thenabadu, 1996). This could account for the increased NH_4^+ recorder values in TR4 and TR5 during week 8. Meng et al. (2014) measured NH_4^+ fluxes in leached nitrogen following DAP (di-ammonium phosphate) and urea topdressing.

However, the level of NH_4^+ in the treatment with 120 kg/ha additional urea (TR5) was not significantly greater than in the treatment with 60 kg/ha added urea (TR4). The former was thrice greater, indicating that other factors may have influenced the NH_4^+ content over the period under consideration. These, however, remain unaddressed in this work. Given that the redox potential in the soil (root zone) was greater than +300 mV for the majority of the rice cropping season at the Middle site, these conditions were favorable for the oxidation of NH_4^+ to NO_3^- (Pezeshki and Delaune 2012). This could account for not just the study's overall low NH_4^+ levels but also the abrupt fall in NH_4^+ in TR4 and 5 after week 8.

Although Meng et al. (2014) previously observed the release of NH_4^+ in paddy paddies during the late cropping season, the fairly considerable accumulation of NH_4^+ in TR1 warrants additional investigation to ascertain the causal reasons.

The addition of organic 60 kg of inorganic nitrogen to the soil following lablab green manure incorporation (TR6) appeared not to affect the NH4+ concentration. These findings contradict numerous earlier research (Becker et al. 1995). Lablab decomposes into NH_4^+ around four to six weeks after being incorporated into the soil under aerobic circumstances (Pereira et al., 2016). Under anaerobic conditions, ammonification of lablab would take significantly longer and give far less NH_4^+ (Becker et al. 1995). The lack of reaction in NH_4^+ could be attributed to the low redox potential that prevailed throughout the early stages of rice cropping, as illustrated in Table 6. Mineralization becomes a negative process in this case (Toure et al., 2009). This may account for the low level of NH_4^+ production during the rice-cropping season. One could anticipate detecting some variations between TR6 and the other treatments, particularly those without additional nitrogen.

The pattern of NH_4^+ variation at the Fringe site was strikingly similar to that at the Middle site. This is demonstrated by the overall drop in initial NH_4^+ concentration and the abrupt increase in NH_4^+ content at week 8 for treatments with increased mineral N. Thus; these findings can be explained similarly to those from the Middle site, except a considerable rise in NH_4^+ content in TR5 and TR6 toward the end of the rice-cropping season (week 12-16) at the Fringe site. The given data cannot explain this discrepancy; more research is required. This controversy warrants additional investigation.

The significantly elevated NH_4^+ levels seen in treatments with additional urea can be attributed only to N intake. Previous research has demonstrated increased ammonium generation during the decomposition of agricultural wastes from fields that received mineral N fertilizer (Kimetu et al. 2006). The absence of a difference in NH_4^+ concentrations in the treatment group that received lablab green manure contradicts earlier research (Becker et al. 1995; Yadvinder-Singh et al. 2005). The decrease in NH_4^+ content during the first six to eight weeks of the rice cropping season could be attributed to crop growth requiring mineral N (Nascente et al., 2009).

Effects of crop management interventions on the variation of NO_3^- content

NO_3^- variability during the pre-rice cropping season at both sites; Middle and Fringe site

At both sites, the variation in NO_3^- content across the research period followed a similar pattern indicating some similarities in the environmental factors that determined the soil's NO_3^- state. At the Fringe and Middle sites, the NO_3^- level rapidly decreased to 0 g/kg soil within 1 and 2 weeks, respectively. Surprisingly, this occurred under a wide variety of moisture conditions. At the Middle site, soil moisture was relatively depleted, whereas it was relatively abundant at the Fringe location (Linn and Doran 1984). This pattern does not represent the comparatively high ammonium levels produced in the Middle and Fringe sites during the 2 - 4 and 1- 3 weeks, respectively. There is an obvious distinction between the two. Assuming that the conditions, particularly at the Middle site, were aerobic, as indicated by the potential redox values for the period under discussion, one would expect spontaneous oxidation of the existing ammonium and hence a corresponding increase in the NO_3^- level. The same was expected for soil moisture and, more specifically, redox potential at the Middle site. The disparity between these two characteristics cannot be accounted for. These findings contradict Zaman et al. (1999), who observed the highest nitrification rates in soil treated with NH_4Cl compared to other treatments without additional ammonium.

The extremely low or absent NO_3^- levels between weeks 2 and 6 at the Fringe site and between weeks 2 and 5 at the Middle site cannot be well explained by current data. During this period, ammonium was abundant, particularly at the Middle site (Figure 3), and the moisture and redox potential were favorable for nitrification. It would be good to conduct a similar study that completely characterizes the destiny of N. Increases in NO_3^- content from week 4 (Middle) to week 6 (Fringe site) matched to the process of nitrification (Kimetu et al. 2006). The distinction between treatments was observed only in TR1 and TR3 at week 10 when the NO_3^- level was much higher than in the other treatments.

NO_3^- variability during the paddy growing period at both sites; Middle and Fringe site

NO_3^- tended to accumulate during the dry season at both sites. The increase in NO3 demonstrates this$^-$ content toward the conclusion of the pre-rice cropping season and the accompanying relatively high readings at the start (week 0) of the rice cropping season. This is most likely due to the conversion of NH_4^+ to NO_3^- in aerobic conditions (Smith 2010). It has been demonstrated that alternate rainy and dry seasons result in the production of ammonium and its subsequent oxidation to NO_3^- (Pande 2005).

The accumulated NO3- rapidly decreased to 0 or close to 0 g/kg soil within two weeks regardless of the treatment or site. This decrease in NO_3^- levels could be attributed to denitrification as a result of the low redox potential of the soil (Table 6). From week 0 to week 2, the redox potential changed from 237.0 to 204.8 mV at the Middle site and from 195.3 to 209.2 mV at the Fringe site. These redox values are within the range where O_2 is scarce, supporting denitrification (Reddy and Patrick 1975).

The consequent low nitrate content at the Middle site from week 2 to week 10 in the treatments that did not receive mineral nitrogen (TR2, TR3, and TR6) would negatively affect the crop. The need for N is often strong during this time, notably during the booting stage, which corresponds to weeks 8 and 10 (Kimetu et al. 2006). TR4 and TR5, which received 60 and 120 kg N/ha, respectively, were the only treatments with significantly higher nitrate levels at the booting and grain filling stages. During the late cropping stage (weeks 12-16), all rice crop treatments

(TR2, TR3, TR4, TR5, and TR6) exhibited almost minor NO_3^-. The low NH4+ content could partly explain this and the possibility of the crop absorbing any available NH_4^+ during the booting period (Olk et al. 1996; Nascente et al. 2009).

At the Fringe location, there was almost no NO_3^- in any of the week 2 treatments. During the tillering and booting stages, the same thing happened to all treatments without added mineral N (TR1, TR2, TR3, and TR6) (week 2 to 8). As was the case with the Middle site, the treatments with rice crops (TR2, TR3, TR4, TR5) experienced a general fall in NO_3^- content to nearly 0 g/kg soil during the late cropping stage (week 12 to 16). This was mainly due to the soil's low NH_4^+ level, particularly in treatments that did not get mineral N. This can be explained by the site's normally low NH_4^+ concentration, which could have been transformed to NO_3^-. (Pande 2005; Reddy and Delaune 2008).

Contribution of hydrological conditions on the NH_4^+ and NO_3^- variation

The two locations were chosen because the three primary floodplain hydrological zones, Valley Central, Valley Middle, and Valley Fringe, have distinct hydrology (Reddy and DeLaune 2008), which significantly affects N status. The Valley Central zone was submerged for the length of the experiment and so abandoned. The remaining two locations shared a high degree of hydrological similarity, as indicated by their redox potential.

Throughout the rice cropping period, both sites demonstrated reducing conditions for three weeks at the Middle site and two weeks at the Fringe site, followed by occasional variations between moderately reduced and reduced soil conditions between weeks 6 and 10, as illustrated in the Figures 11 and 12. Between weeks 12 and 16, both sites' soils reverted to aerobic conditions. This close-in redox potential is critical in explaining the similarities between the two sites in root zone NH4+ and NO3- levels. Numerous results from N dynamics studies conducted over time demonstrate the effect that hydrological conditions can have on wetland N dynamics. NO_3^- removal has been measured in wetlands agricultural fields in the United States of America, New Zealand's Scotsman Valley, and Denmark's Rabis Bk (Brusch and Nilsson 1993). Devito et al. (1989) discovered that while there was no significant net retention of nitrogen inside five wetlands on the Canadian wetland, there was the transition of inorganic nitrogen to organic nitrogen, which influenced NH_4^+ and NO_3^- dynamics under various hydrological conditions.

Additionally, Cai et al. (2002) observed a loss of NH_4^+ content in lowland wetland soils under various hydrological conditions. Despite this, Asante (2015) showed no significant association between NO_3^- status in wetland soils in Ghana's inland valleys under distinct hydrological zones. This is consistent with Yameogo's (2017) findings, who found that the NO_3^- level was not significantly different between treatments in an inland valley in the West African Savanna Zone with varying hydrological conditions.

As a result of these findings, the NH_4^+ and NO_3^- concentrations in the Valley Middle and Valley Fringe zones did not differ considerably. As a result, the presumed difference in NH_4^+ and NO_3^- status between the two sites due to hydrologic changes cannot be validated. As a result, the null hypothesis is supported.

In conclusion, the pre-rice growing season observed three distinct periods of change in NH4+ content. The initial phase of increasing NH_4^+ content occurs between the first and sixth weeks of therapy, followed by a period of NH_4^+ drop between the fifth and ninth weeks and an increase in NH_4^+ level between the tenth and thirteenth seasons. The peak NH_4^+ concentration in the first phase varied between treatments. Peak NH_4^+ production was significantly increased (P= 0.05) in both Middle Fringe sites in treatments with external N input (TR4, TR5, and TR6). Significant variations (P= 0.05) in NH_4^+ were also observed at the Middle site during the early stages of the fall in N (Week 6), with the following trend: TR6>TR5=TR4>TR3=TR2=TR1.

The initial NH_4^+ concentration at the start of the rice cropping season varied significantly between treatments, with the highest values mainly occurring in treatments receiving external N input during the 2014/15 season. TR4 and TR5 were located at the Middle site, while TR4, TR5, and TR6 were located at the Fringe site. NH_4^+ tended to decline constantly from week 1 to the start of the cropping season's end (week 16) for practically all treatments at the Middle site that lacked exogenous mineral N. At the Fringe site, the drop in NH_4^+ followed a similar pattern between weeks 4 and 8, then stabilized or increased somewhat regardless on the treatment.

During the pre-rice cropping season, the initial (beginning) NO_3^- content ranged from 0.001706 (TR2) to 0.002951 (TR6) g/kg soil at the Middle site and from 0.0 to 0.0003604 g/kg soil at the East site. NO_3^- content declined rapidly (within 1-2 weeks) at both sites, reaching the lowest values within 1-2 weeks. NO_3^- the content was either non-existent or extremely low in all treatments between weeks 2 and 3 (Middle) and weeks 2 and 6 (Fringe). The conclusion of the pre-season was marked by an increase in NO_3^- content (week 5-10 for the Middle site and week 7-10 for the Fringe site). The addition of urea at week 6 resulted in a rapid and transient increase in NO_3^- at the start of the booting stage at both sites.

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Review: The role of local belief and wisdom of the Bajo community in marine conservation efforts

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Abstract. *Maulidyna A, Hartawan BS, Agustin HN, Irfan AN, Septiasari A, Utina R, Setyawan AD. 2021. Review: The role of local belief and wisdom of the Bajo Community in marine conservation efforts. Intl J Bonorowo Wetlands 11: 48-63.* The Bajo tribe are originally sea nomads, living in eastern Indonesia, South Philippines, and North Borneo. Their maritime culture and *sama* language identify them. They have similarities with the Orang Laut tribe in western Indonesia and the Moken tribe in the Mergui Archipelago in terms of exploring the seas. Today, most Bajo ethnic groups no longer wander on houseboats and live in a particular place; although they still preserve maritime culture, they have similar social and cultural features, including shared shipbuilding and fishing, traditions, beliefs, and myths. The Bajo tribe living from marine natural resources closely relates to the marine and coastal environment. It raises the values of environmental concern in maintaining the sea and coast. This study aims to determine the environmental conservation of the Bajo tribe based on their beliefs. The Bajo tribe is one of the tribal communities that manage, maintain, and utilize marine biological resources based on cultural norms and values institutionalized and attached to the Bajo community. They are maintained through social control based on their belief system. This belief brings the Bajo people to fear breaking the taboo or *pamali* that has existed since their ancestors orally and from generation to generation. The Bajo people have the wisdom to protect the marine environment, namely corals, mangroves, and marine resources. They have a deep concern for preserving coral reefs as a buffer for the underwater ecosystem. They are very aware of the need to protect the sources that are the basis of their livelihood fulfillment.

Keywords: Bajo, conservation, life, marine, trust

INTRODUCTION

As a maritime country, Indonesia is the “main sea,” but three main seas make up Indonesia as a sea system, namely the Java Sea, Flores Sea, and Banda Sea (Surowo 2012). The majority of Indonesia’s territory consists of water areas (± 70%), causing many Indonesians to live in coastal areas and depend on the sea for their livelihoods and form a maritime culture (Yuga 2011). In Indonesia, several ethnic groups still apply marine cultural patterns in every aspect of their lives. One of the ethnic groups very well known to support maritime culture is the Bajo (Bajau, Badjaw, Sama, Same). Bajo is an archipelago that lives in the sea (Baharudin 2011). The formation and development of culture significantly influence the national identity; unity plays a role in its construction. The community has a vital role in forming a culture to continue to survive in the times, both directly and indirectly, by utilizing its abilities (Susanto 2010).

The Bajo or Bajau are the names of outsiders, while the Bajo themselves call themselves “*samma*” (Susilowati 2020). The name “Bajo’’ itself has a negative meaning, namely pirates. The Bajo tribe always feels exploited and suspected by other tribes around them, so with this assumption, they always move from one place to another (Rusba et al., 2018). The Bajo tribe in certain areas has become a minority community because the Bajo ethnic group split up (Syefriyeni and Rosie 2020). Before settling as they are now, the Bajo tribe built a water settlement using wood and palm leaves. This building serves as a temporary dwelling, storage of equipment, and catches. Then it developed, and the Bajo tribe settled in an area and built more permanent buildings (Rahim et al. 2018). This shifting tendency occurred for hundreds of years, but the Bajo people began to choose to settle in coastal areas over time. According to the story that developed from anthropological circles, pirates in ancient times were believed to have come from the Same Tribe as the Bajo Tribe. The meaning is the pirate tribe. Surprisingly, the name of the Bajo Tribe is more famous and has spread throughout the archipelago. Thus, any marine tribe in the archipelago is often equated with the Bajo tribe (Daeng 2010). There have been many Bajo tribes who have spread along the coast and made permanent homes as residences. Several settlements of the Bajo tribe that have settled with a sizable population are found along the coast of the Wakatobi Islands, Southeast Sulawesi (Ali 2014).

The Bajo tribe built their houses on the sea because they often wandered by boat long ago. Their population was spread across many Indonesian seas (Dai 2020). The Bajo tribe, as a community that cannot be separated from the sea, has a unique tradition. The Bajo tribe is very loyal and proud of their culture (Andri and Anwar 2019). The cultural wealth of the Bajo tribe varies in various places where the Bajo tribe is located, according to their territorial and genealogical factors (Halim 2012). The Bajo tribe has a solid attachment to nature, especially the sea, which has been around since the time of their ancestors. The sea is a source of livelihood and life for the Bajo people (Halim et al. 2020). The dependence of the Bajo tribe on the sea makes them have confidence in the spirits guarding the ecosystem around them. The Bajo community's attachment to the sea makes them greatly respect the sea. Many rituals and traditions of the Bajo people are dedicated to the ruler of the sea to get a good life and be kept away from all kinds of dangers (Chou 2020). Some Bajo community groups also believe that everything on earth has a guardian spirit; if disturbed or damaged, it will cause disaster. Based on the beliefs and traditions of the Bajo tribe, the author is interested in examining more deeply the environmental conservation values contained in the traditional teachings and beliefs of the Bajo tribe, especially regarding the conservation of marine ecosystems. Therefore, the goal to be achieved by conducting this study is to determine the environmental conservation of the Bajo tribe based on their beliefs.

SEA NOMADS OF SOUTHEAST ASIA

Based on cultural, geographical, and linguistic differences, there are three significant groups of sea nomads in Southeast Asia. The first are the Moken and Moklen Tribes of the Mergui Archipelago in Burma and the islands of Southwest Thailand. The second is Orang Laut or Orang Selat (Celates); they live in the Southern part of Johor, Singapore, Riau-Lingga Archipelago, and the eastern coast of Sumatra. And finally, the Sama-Bajau Tribe or Bajo Tribe occupies islands in the Philippines, Borneo, Sulawesi, Maluku, and Lesser Sunda Islands (Sather 1995; Marsanto 2013; Chou 2016) (Figure 1).

Based on the history and culture of the Bajo Tribe and the Orang Laut, there are similarities but no linguistic relationship. They live a nomadic life, live on boats, and move from one place to another. The similarity from the animist aspect is to give offerings in the form of rice and coconut to the spirits of the sea (Nurrohim 2020). The Bajo people prefer fishing on coral reefs, submerged coral terraces, associated sandy beaches, and tidal shallows and avoid turbid waters. They rarely use the mangrove shores except to collect firewood. While the Orang Laut prefers places in brackish mud plains and mangrove swamps. According to the environmental conditions, they have developed adaptations for foraging that are very special. However, they cannot meet their own needs. Orang Laut gets other needs, such as food, boats, etc., through trade with riverine Malays. The Moken tribe is very different from the two tribes above. In addition to collecting marine products, the Moken Tribe utilizes the resources around the island, namely collecting honey, fruit, tubers, hunting wild boars, and planting activities on the beach. They return during the harvest season (Sather 1995).

In the 10th to 17th centuries, the sea and rivers were the primary means of transportation, so ports generally became the center of the development of civilization. So, it is not surprising that many maritime communities were formed in the region, one of which was the Orang Laut. Orang Laut had a significant contribution to the era of the Srivijaya Kingdom (7th to the 12th century AD), the first unified kingdom to dominate much of Southeast Asia. Most of the war soldiers of the Srivijaya Kingdom were Orang Laut. Srivijaya wants to strengthen land and sea areas and control ports. The Orang Laut and Srivijaya are in a bond of mutualism. The Orang Laut can survive in Srivijaya's territory, and Srivijaya is vital in the ocean, with the Orang Laut protecting their territory. This is evidenced by the Telaga Batu Inscription on the Sabukingking Village, South Sumatra (Marsanto 2013; Nurrohim 2020).

BAJO COMMUNITY

The Bajo, the world's largest remaining sea nomad group, are scattered across hundreds of recently settled communities in Island Southeast Asia, along the coasts of Eastern Indonesia, Malaysian Borneo, and Southern Philippines; across 1300 km from east to west and 2000 km from north to south. With a significant role in historical trading, the Bajo lived until recently as nomads, spending their entire lives on houseboats while moving long distances to fish and trade (Kusuma et al., 2017). Along the routes they traveled, the Bajo settled and intermarried with local land-based groups, leading to 'maritime creolization' (Nagatsu 2013), a process whereby Bajo communities retained their culture, but assimilated - and frequently married into - local groups. They still have similar social and cultural features, including shipbuilding and fishing culture, beliefs, traditions, and myths (Stacey 2007; Nuraini 2008; Nagatsu 2013). They maintained contact by sharing goods, trading, fishing, and marriage (Kusuma et al., 2017). Their languages belong to a single subfamily, the Sama-Bajau subgroup on the West Malayo-Polynesian branch of the Austronesian language family (Noorduyn 1991; Blust 2007).

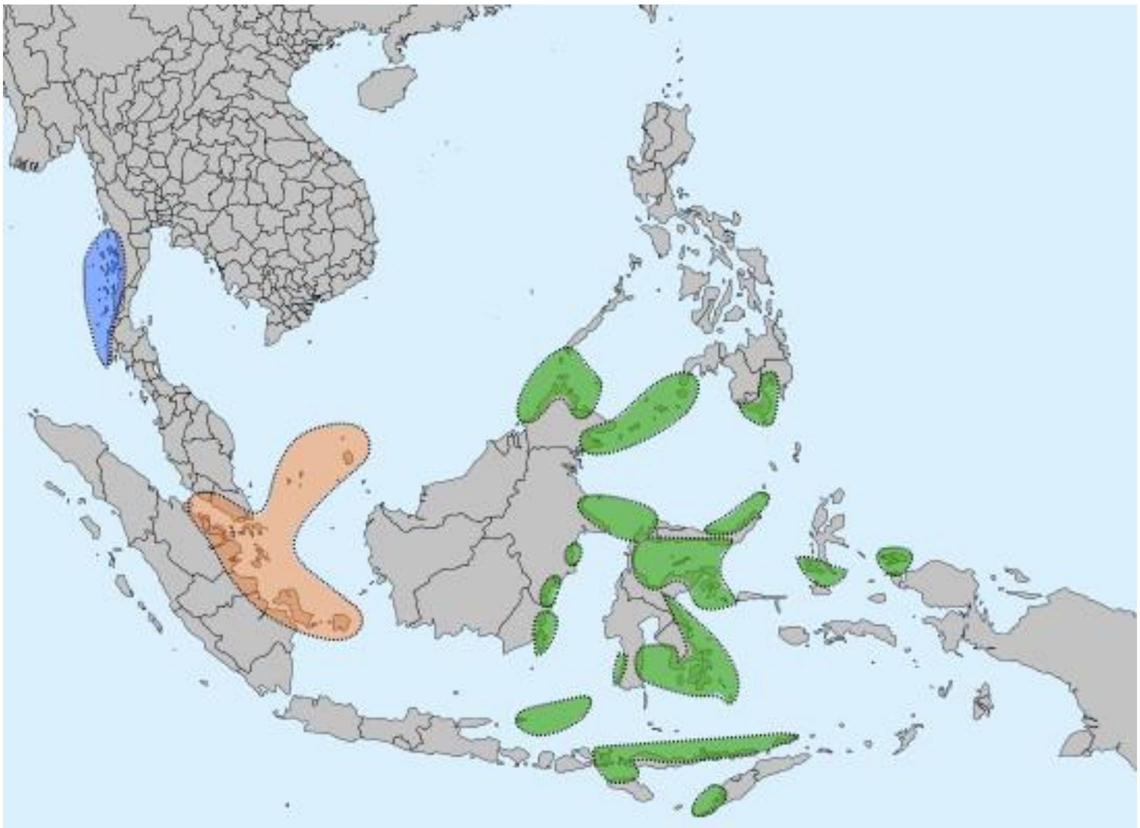

Figure 1. Southeast Asian regions are inhabited by peoples usually known as sea nomads. ☐ Moken, Orang Laut, Sama-Bajau (Clarkson and Sopher 1968)

The origins of the Bajo have remained unclear despite several hypotheses from oral tradition, culture, and language. The linguistic and genetic evidence are in broad agreement regarding the timing of the Bajo dispersal along the east coast of Borneo but point to entirely different locations for its origin: Southern Sulawesi for the gene pool and Southeast Borneo for the languages. Bajo likely shares a common connection with Southern Sulawesi, but crucially, each Bajo community also exhibits unique genetic contributions from the neighboring populations (Kusuma et al., 2017).

Some have stayed on the mainland, and some are on the coast and even in the middle of the sea. The people who live in the middle of the sea are truly unique. They are called the Bajo tribe, who are known as tough sailors. In the past, people only knew the Makassar tribe, the Bugis tribe, or the Mandar tribe as kings in the sea. Even though the Bajo people were once said to be part of the Sriwijaya Royal Navy thus, his toughness and skills to navigate the ocean are clearly indisputable (Tahara 2013). The Bajo tribe is famous for its prowess in exploring the sea. Ilardo et al. (2018) state that the Bajo tribe can dive to a depth of 70 meters below sea level with just one breath. Based on the results of his research, the spleen of divers and non-divers of the Bajo tribe has a size difference that is not too significant. Meanwhile, the spleen of Bajo divers is more significant than that of the Saluan tribe. The differentiating factors between these two tribes are diversity, gender, age, height, and weight. Therefore, it is concluded that the study results are not only due to the plastic response of the spleen during diving activities, but it is suspected that genetic factors can explain the difference in spleen size between the Bajo and Saluan tribes. With ancient boats without modern directional equipment to guide their journey, they only rely on the position of the stars. The Bajo people lived on their boats or were often called nomads in ancient times. However, many Bajo people nowadays build houses above the shallow sea.

The Bajo tribe is widely spread in marine and coastal areas in Southeast Sulawesi, especially the Wakatobi region. Some of the Bajo tribes in the Southeast Sulawesi region include the Bajo Sampela Tribe, the Bajo Mantigola Tribe, the Bajo Loha Tribe, etc. Not only in Indonesia, but the Bajo tribe has also spread across the seas of Malaysia, the Philippines, and Thailand. In Indonesia, they are scattered in East Kalimantan, South Kalimantan, South Sulawesi, Southeast Sulawesi, West Nusa Tenggara, East Nusa Tenggara, and other parts of eastern Indonesia. History says that this tribe originated from the Sulu Islands in the Southern Philippines who lived in the open seas, bringing them to this beloved country, the Indonesian homeland (Utina 2014). The Sama Bajo is the Bajo Tribe who lives in Eastern Indonesia and semi-nomadic life. In addition to Eastern Indonesia, Sama Bajo is also spread in the Southern Philippines and East Malaysia. Like the Bajo Tribe in general, the Sama Bajo have various basic skills, namely hunting, sailing, navigation, diving, fishing, and maritime warfare (Nolde 2014). In addition, the Bajo Tribe is also found on some of the smallest islands in the Sapeken Islands (East Java) and the East Nusa Tenggara Islands. The Bajo tribe in Sapeken Islands is thought to have originated from South Sulawesi then began to settle in the Sapeken Islands in the 17th century (Rahayu 2019). In general, the Bajo tribe is Muslim and upholds the culture of their ancestors. The Bajo people believe in refusing to ask for kerosene, salt, water, or anything after sunset and also believe in the ritual of ransoming the soul and throwing chicken offerings into the sea. Another uniqueness of the Bajo tribe is that they have a particular culture when they go to sea, see the weather, and educate their children to become tough sailors (Utina 2014).

The Bajo people believe in the existence of spirits in the sea as guardians of the sea, so they often prepare offerings to be carried out in the middle of the sea as offerings for the spirit of the sea guardians (Nurhaliza and Suciati 2019). The Bajo people work as fishermen and are friendly with the underwater world, and their survival also depends on the fishing results they get every day. The Bajo tribe is known as accomplished sailors who live and die on the ocean. Even initially, their entire life was spent in a boat that consistently sailed the seas (Suyuti 2011). The boats used are called *leppa* or *soppe* (Baskara and Astuti 2011). Although life on leppa looks difficult, this is not a problem for the Bajo community (Azhari et al., 2020). They start from small children to adults going to the sea every day. *Bapongka (babangi)* is an activity at sea for several weeks and even months using a large boat measuring approximately 4×2 m^2 called *leppa* or *soppe*. This activity often involves families, such as wives and children, and some even give birth on a boat. When boys are 5 years old, children begin to accompany their parents (fathers) going to sea. Meanwhile, girls are accustomed to following their mothers to find clean water, wood for cooking materials, etc. According to the research conducted by Artanto (2017), it is explained that the culture believed by the Bajo tribe includes various rules resulting from their experiences and spirituality with their lives that depend entirely on nature (Isabelle 2012). The Bajo tribe has a rugged, decisive, and open character as a coastal community. Because their entire life is facing the sea, the characteristics of their social, cultural, and economic life are greatly influenced by their view of the natural forces that surround daily life (Tjahjono 2013).

THE SOCIAL AND ECONOMIC LIFE OF BAJO COMMUNITY

The economic condition of the Bajo tribe tends to be still low. This is because the Bajo people only depend on their income from working as fishermen. The socio-economic conditions of fishers' families are greatly influenced by fishing season, fishing season, uncertain natural conditions, limited capital, limited technology, and low levels of education (Moldjo et al., 2019). The fishing gear commonly used by fishers of the Bajo tribe is usually a simple tool with the capacity to catch small fish. For example, in the Kinabuhutan Village, North Sulawesi, Bajo fishers only use simple fishing gear such as fishing rods, nets, charts, or even soma giop. The choice of fishing gear for fishers is adjusted to the type of fish to be caught. The operation of this fishing gear is limited to the area around coastal waters. In addition, fishers' activities also depend on the season and climate, so fishers cannot go to the sea every time to catch fish. Especially in the season when the waves tend to be high and big, Bajo fishers will find it difficult to go to sea, resulting in limited catches, even if no catch is obtained. The Bajo people who live in the sea will exchange the fish they catch with staple foods such as sago, rice, and corn to meet their needs. They infrequently buy it with money from selling the fish (Hassan and Peters 2020).

Based on the map of the distribution of Bajo community settlements in Figure 2, it is known that the Bajo tribe population has spread throughout almost all regions of Indonesia. However, most people of the Bajo tribe can be found on the island of Sulawesi. According to Suryanegara et al. (2015), there are three settlement patterns of the Bajo tribe in Wakatobi District, namely the pattern of settlements in the open seas separated from the mainland, settlement patterns that jut into the open sea but are still connected to the mainland (coastal areas), and integrated settlement patterns with the coast. According to Gobang et al. (2017), the distinctive features of the settlement architecture of the Bajo tribe are the symmetrical, orthogonal forms of the plan (horizontal), and sections (vertical), and the Bajo Tribe architecture for *bundaang buliang* and *rumak-diaruma* are considered as space. The majority in the composition of the overall residential building. Apart from the territory of Indonesia, the Bajo tribe population is also scattered in countries in the Southeast Asian region. According to the 2000 population census results, the people of the Bajo tribe in Southeast Asia are around 1,077,020 people, which are spread in the Philippines as many as 570,857 people, 347,193 people in Malaysia, and about 158,970 people in Indonesia (Nagatsu 2017).

In terms of living at sea, the Bajo Wakatobi tribe has a strategy that has been mutually agreed upon with the Buton tribe on land so that in the future, it will not cause harm to both parties. The process of settling the Bajo community in Mola Village, Wakatobi, Southeast Sulawesi is regulated by *Sara Mandati* (Mandati Adat Institution) as the representative of the land people. It is based on the governance of land ownership and development at sea. Management of land tenure and development at sea. Establishing a settlement must go through several stages until the issuance of permits and recommendations for development at sea, including the appointment of locations for construction of houses and facilities and infrastructure and imposing sanctions if violations are found. In addition, people who have been recognized and approved to build at sea will receive a certificate of land at sea and ownership for buildings at sea (Eryano et al. 2020).

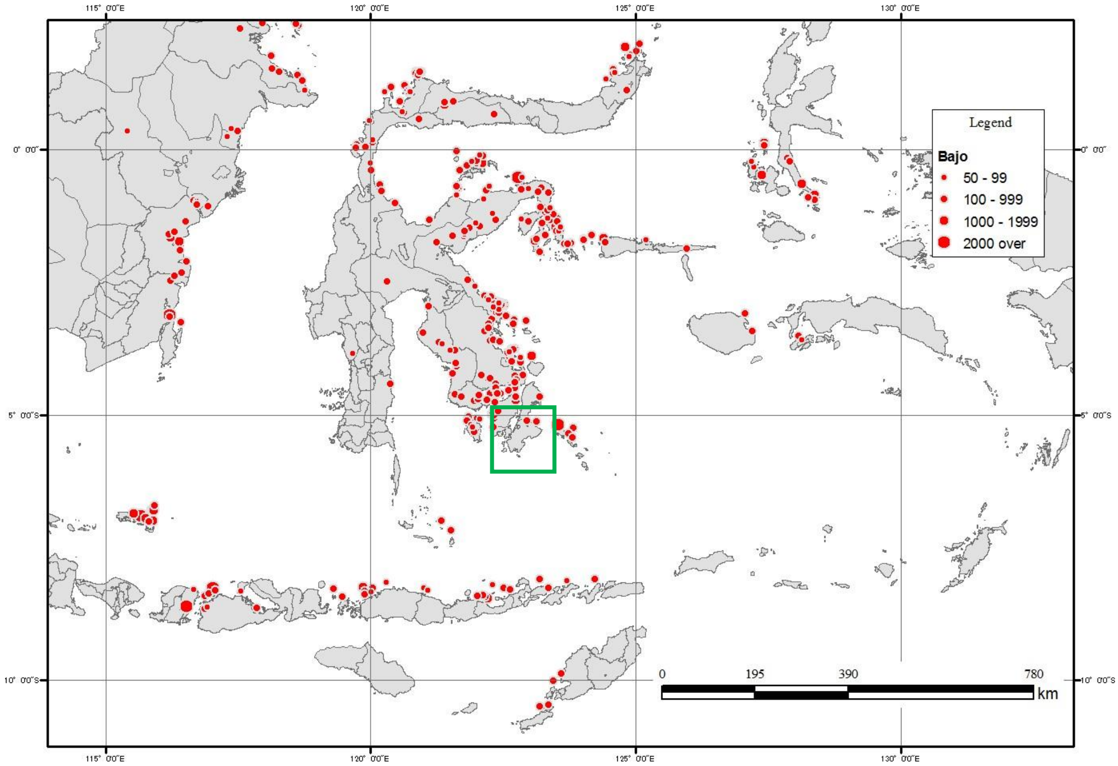

Figure 2. Distribution map of Bajo Tribe settlements in Indonesia and Wakatobi District, Southeast Sulawesi (inbox) in 2000 (Nagatsu 2013)

In terms of social interaction with Bajo's fellow people and the surrounding community can be seen from community activities such as mutual cooperation activities, weddings, celebrations, etc. It can be said that the Bajo people, in general, have a strong sense of kinship with the surrounding community, both fellow Bajo people and non-Bajo people (Kobi and Hendra 2020). For example, the Bajo people who live in the Ranooha Raya Village area have the same characteristics in building social networks, both based on kinship and friendship, and have strong social network ties, both among themselves and others (Jasman et al. 2018).

The level of education of the Bajo tribe varies depending on where they live. Generally, the Bajo people who still apply the nomadic settlement pattern have a low level of education. Meanwhile, the Bajo people who have settled on the mainland and are familiar with information and technology have a higher level of education. The Bajau Maratua tribe is one of the Bajo people who have settled and lived in the mainland of Jenebora, Penajam Paser Utara District. The Bajau Maratua tribe is familiar with writing and reading, so it is not surprising that many of the children of the Bajau Maratua Tribe have succeeded in weaving education to a higher level. The Bajau Maratua is part of the Bajau Tribe touched by modernization because the lives of those who have faith, weave education, live on land, and, most importantly, have socialized like the general public (Nisah et al. 2020). Despite having most people with low education, the Bajo tribe perceives gender equality. This is evidenced through equal opportunities for Bajo men and women in making decisions. Men and women in the family share responsibility in making decisions regarding matters within the household, whereas men are more dominant in making decisions related to education. In contrast, women are dominant in economic, social, and religious terms (Halim et al. 2020).

In the health sector, awareness of the Bajo community regarding maintaining immunity and the importance of having a clean and healthy lifestyle is still lacking. Most of the Bajo tribe's knowledge about health still relies on traditional medicine, which is passed down from generation to generation from their ancestors. According to the Bajo people, health or illness can occur due to the influence of elements of experience that happened in the past and from cultural factors. The Bajo tribe also believes that the ability to treat various diseases is a hereditary legacy that the Bajo community has recognized until now. They already know about the existence of health services that are much better than traditional medicine, but for the Bajo people, this is an alternative last resort (Syahrani 2020). According to research conducted by Pinto et al. (2020), the most common health problem but less aware of by the Bajo community is the problem of hearing loss. In contrast, as many as 47 divers, respondents from the Bajo community in Bone District, South Sulawesi,27 or around 49, 15% suffer from hearing loss. Even though they are sea people with excellent diving skills, Bajo divers may also have health problems if they dive too deep in the ocean for a long time. Meanwhile, based on Hassan and Peters (2020), the disease that most often affects the children of the Bajo Laut tribe is skin infections, while the most severe health problems in adult communities are malaria, typhus, and tuberculosis. Some daily activities of Bajo can be seen in Figure 3.

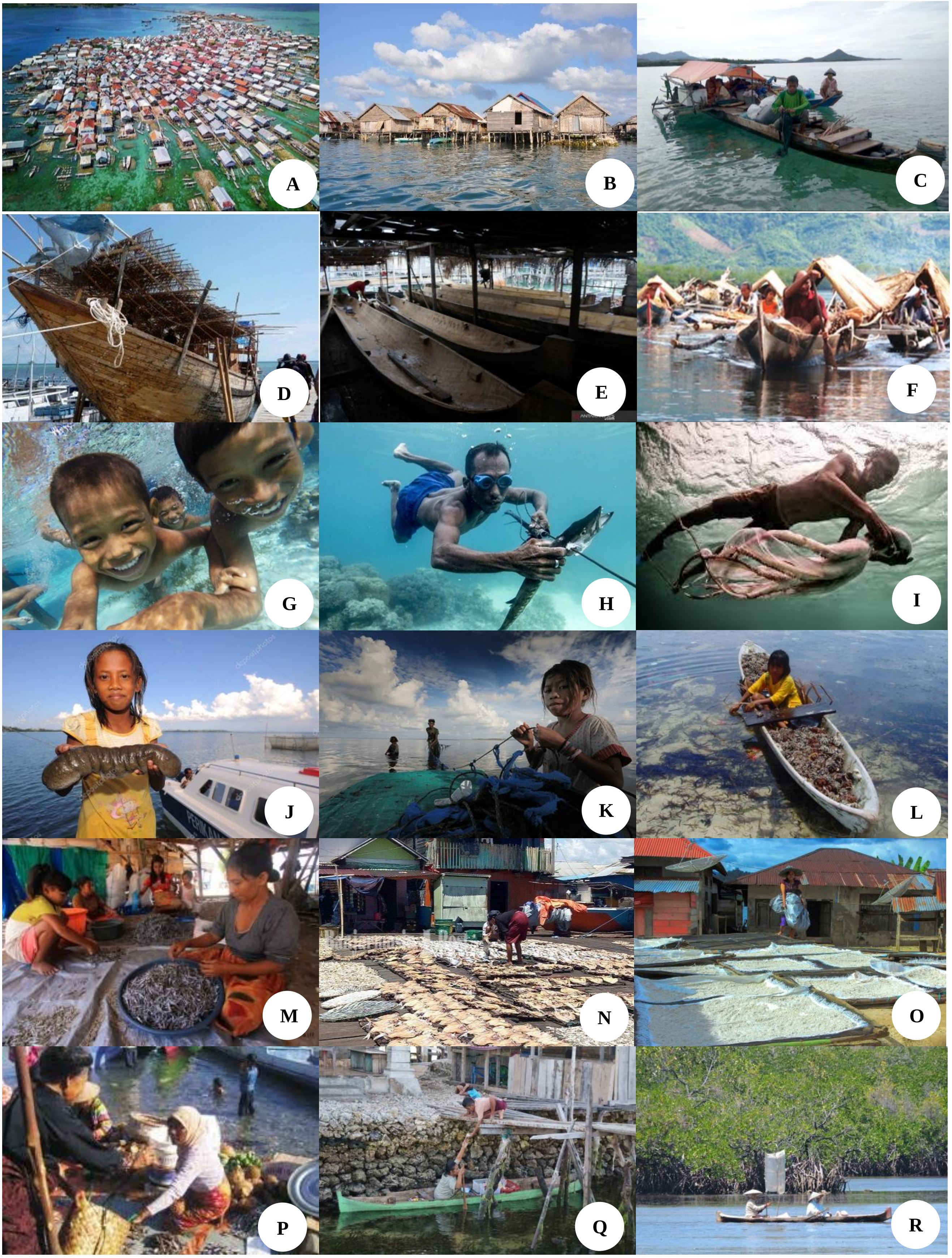
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Figure 3. Bajo people nature and activities. A. Bajo tipical floating village in Bungin Island, West Nusa Tenggara. B. Bajo housing in Wakatobi, Southeast Sulawesi. C. Bajo boat house in Togean, Central Sulawesi. D. Bajo ship-building in Takabonerate, South Sulawesi. E. Making canoes in Torosiaje, Gorontalo. F. Migration of Bajo tribe from Sabah to Derawan, East Kalimantan. F. Bajo boys: play and work in Takabonerate, South Sulawesi. G-H. Bajo fishing activities: fish and octopus in Wakatobi, Southeast Sulawesi, I. Bajo girl with trepang in Semporna, Sabah. K. Catching fish with nets in Takabonerate, South Sulawesi. L-M. Cleaning and selecting seafood in Takabonerate, South Sulawesi. N-O. K. Drying of marine product in Rampa Village, South Kalimantan (N) and Bajo Sangkuang, North Maluku (O). P-Q. Selling and buying marine products and others in Wakatobi (P), Bajo Bahari, Buton, Southeast Sulawesi (Q). R. Collecting marine products by anoeing in Torosiaje, Gorontalo, S. Collecting water in Leppe Village, Southeast Sulawesi, T. Young Bajo study of Indonesian Archipelago in Wakatobi, Southeast Sulawesi. U. Bajo children play white sand in Kera Island, East Nusa Tenggara. V. Bajo women with *burak* sunscreen in Sulu Islands. W. Bajo martial arts in Sapeken Island, East Java. X. Afternoon prayer in Wakatobi, Southeast Sulawesi. Y. Lepa-lepa festival in Semporna, Sabah. Z. Bajo women traditional dress in Cebu. AA. Bajo dancing in Sapekan Island, East Java

BAJO TRIBE LOCAL WISDOMS

A community's wisdom and local knowledge are obtained through a long process. Its existence is the result of adaptation through a social learning process to the conditions and dynamics of its environment, both the natural environment and the social environment (Fajarini 2014). Thus, local wisdom and knowledge have been tested and always experience contextualization, in line with developments and changes. Consequently, local wisdom and knowledge are not static but constantly develop cumulatively, in line with the development of the community. Local wisdom is the idea of a local community with good values, given life, values, norms, and customs, usually symbolizing myths and rituals (Hasrawaty et al., 2017). The functions of local wisdom are as follows: first, as a marker of the identity of a community, second, as an adhesive element (cohesive aspect) across citizens, across religions, and beliefs. Third, local wisdom gives a community color together. Fourth, changing the mindset and reciprocal relationship between individuals and groups by placing them on their common ground/ culture. Fifth, encouraging the development of togetherness, appreciation, and a joint mechanism to ward off various possibilities that reduce, even destroy, communal solidarity, which is believed to originate and grow on shared awareness, from an integrated community (Takiddin 2014).

Local wisdom of the Bajo tribe is characterized by traditions and culture of the sea in supporting Conservation Area Management related to the sea. The function of the sea as a place of life illustrates that the values, customs, or norms contained in it are an effort for the Bajo Tribe to protect an area (Prameswari et al., 2019). The Bajo tribe is known for its extraordinary marine life skills, utilizing all the natural potentials available around it to survive, carry out all activities, and fulfill the necessities of life dependent on marine products. The life activities they do are predominantly carried out on seawater. The Bajo tribe also has traditions and culture. One form of culture in physical form is the aspect of the house as a container for the embodiment of traditions that can be seen apart from their behavior (Amri 2014). The Bajo people usually anchor on one beach when building a new community. Over time they stockpiled the beach with stones and built stilts (Tahara 2011). In the environment around the Bajo community settlements, the mangrove ecosystem, seagrass beds, and coral reefs are still well preserved. This condition is not visible in other coastal community settlements because the Bajo community has an emotional closeness to natural resources, creating actual behavior considering ecology. The Bajo community has local wisdom in the form of traditions, rules, or hereditary taboos (*pamali*) that are practiced, maintained and obeyed (La Ode Ali Basri et al. 2017).

The mirror of the harmony of the Bajo tribe appears as they maintain the welfare of nature, especially the sea, which is believed to be the source of life (Yamran 2011). The Bajo tribe takes marine products such as catching, fishing, fishing, octopus, squid using a cage-type weapon known as a polo. This trap is inserted into the seabed, and bait is installed. If the fish gets into the polo, it will be challenging to get out again. This tool is safe to use because it does not damage marine life. They also use machetes, spears, nets, arrow guns, and fishing rods (Shester and Micheli 2011). The Bajo tribe, in the tradition of disembarking a new ship, work together to push the newly made ship into the sea; this is a symbol of togetherness and expresses gratitude for the sea products they get after months of fishing. Returning home safely, they make porridge made from starch or green beans, and brown sugar is eaten together on the beach (Rustan et al., 2018). This tradition has existed since the ancestors of the Bajo tribe. The gratitude expressed through alms like that is what the Bajo people do to appreciate the seafood from the Creator.

According to the local community, overcoming the ecological crisis is not only a technical matter, but it is necessary to explore the intricacies of human spirituality, world view, awareness of nature, and ecological behavior (Hanan 2010). He said that ecologically intelligent humans position themselves as environmental controls reflected in attitudes and actual behavior when treating nature. “The universe is not only a source of exploitation but a common house that is continuously protected, cared for, arranged, not destroyed” (Sangadji 2011). The kinship and kinship system of the Bajo community is a feature that distinguishes it from other groups or tribes. Generally, their kinship is very strong so that an attitude of tolerance and mutual help is maintained. So that the impression of individuality is subtle. Simple, there is no sign of stability even though in fact they can and can realize it by living a little frugally and not being wasteful, paying attention to life patterns, maintaining and preserving what the main factors that support their lives are, and seeing the future they will walk on (Ali 2017).

The wisdom of the Bajo tribe is shown by protecting the marine environment. This was done because they realized that they needed the sea as a source of energy or life (Tjahjono 2013). Diseases commonly suffered by Bajo fishers are cramps in the limbs, barotrauma disease, and paralysis. The strategy of Bajo divers in preventing disease begins with “*paruru*” (ritual inside the house before going to sea), “*pakangbalapati*” (feeding sea guards), “*niba pinah*” (throwing peanuts into the sea to ask for protection from sea guards) (Arifin et al. 2020). There is an indirect relationship between people’s health and the environment in Bajo culture. That’s because *Mbo*, the sea soul considered by the community to be the guardian of the sea, always controls people’s health. If people make mistakes at sea, including destroying special places, *Mbo* will cause them to get sick or even die. Several elements of the environment, especially turtles, are essential for wearing in traditional ceremonies related to health. Apart from that, elements, such as Kima, are necessary for traditional beliefs. For example, kima’s interest is to ensure women’s health when giving birth.

Unfortunately, this wisdom has now begun to erode along with changing times and the influence of community culture that comes from outside the Bajo tribe with various types of fishing gear and more modern technology that has triggered competition between communities, damaged marine ecosystems, and threatened the preservation of coastal and marine natural resources (Martono 2014). The inclusion of modernization in the Bajo tribe clearly deals with cultural values lifestyle, and one side impacts the effectiveness and increase of fishers’ catch (Makmur 2011). Technology transfer can certainly increase fishers’ production and income. The fishing tradition of Bajo people, including in Nain (Island in Bunaken, North Sulawesi), has changed. Previously they caught fish as far as possible and settled in the target area *(palilibu, bapongka, babangi, lamma)*. Now Bajo Nain fishers have settled in their villages. The use of the marine fleet has changed a lot, no longer for only daily needs in obtaining fish catches; there has been a lot of cultural mixing (assimilation), for example, between Bajo-Bugis-Mandar in the style of utilizing coastal and marine biological resources (Bahtiar 2012). One of the impacts is that it is now difficult to get fish, especially during the dry season; you have to leave the island a long distance to get fish. Because of the existing changes, we can categorize them into negative and positive impacts. The positive impacts arising from these social changes are the emergence of educational awareness, the creation of new jobs, increased living standards, and the modernization of the fishery system. Meanwhile, the negative impacts that arise are the reduced existence of customs, reorientation of life views, and the emergence of consumptive lifestyles (Suryanegara et al., 2015).

BELIEFS OF THE BAJO TRIBE

The belief systems adopted by the Bajo tribe are very diverse; some adhere to the teachings of Islam, Christianity

Protestants, and some belief in animist and their mixtures. Animism believes that every object on earth has a soul that must be respected; the goal is to avoid disturbance from souls and evil spirits in everyday life (Ali 2017). Examples include belief in Bojanggo, the sea god in the water, and the belief that the spirit of the Bajo tribe is in a crocodile (Nurhaliza and Suciati 2019). The trust of the Bajo community grows and develops through ethical values of morality that come from religion and cultural value orientation, thus causing the growth of certain rationality in the Bajo community (Wianti et al., 2012). Although there is a lot of diversity regarding beliefs in the Bajo people, tolerance remains the main thing. It should be for every individual and community group to live up to ancestral values to create a peaceful life in existing diversity, prioritize tolerance but still adhere to customs, carry out what is required, and stay away from what is not allowed (Syefriyeni and Rosie 2020).

The element of belief is very important for human life, which functions as a human perspective in solving life's problems. The Bajo tribe itself has very strong animistic beliefs; as depicted in the film "*The Mirror Never Lies*" by Kamila Andini, the Bajo people still use the services of a shaman (*Sandro*) to solve a problem (Susiati 2018). *Sandro* (shaman) in the Bajo community is a term for people who master the occult, and only a few people are believed to have it and are not inherited from all their children. *Sandro* has an important task when implementing traditional ceremonies and sometimes leading the healing process for sick people (Alimran et al. 2020).

Even though in some historical literature, it is said that most of the Bajo people embraced Islam, over time, it did not rule out for them to believe in other beliefs (Nurrohim 2020). The Bajo tribe has a strong belief that the sea is life; they believe that their ancestors were descended from the God of the sea so that the Bajo tribe cannot escape from the sea (Marhadi 2012). The belief held by the Bajo community is indeed very strong because it is a legacy that has been passed down from generation to generation (Syahrani et al. 2020). However, some Bajo community groups have been influenced by globalization practices such as media and technology such as television, *mobile phones, and the* internet (Chaidirman et al. 2020). In addition, the influence of the existence of Islamic diversity, especially for people who have performed the Hajj or Umrah pilgrimage, has led to new assumptions and awareness that local knowledge, especially beliefs regarding sea gods and rituals at sea, are contrary to the values of Islamic teachings. These conflicting Bajo rituals are starting to be abandoned (Said et al. 2020).

The Bajo tribe believes in the existence of a Sea God already and is hereditary from their ancestors. In the general belief of the Bajo Tribe, they were performing rituals to the ancestors during preparation for fishing (*nyalamak di lao*), while at sea (*nobire palibudi lao*), and after fishing (*mole palibu di lao*) is an obligation. Violation of these rituals will impact the results obtained, cause disasters at sea, and even the families suffer from the disease (Eryano et al. 2020). In addition, this ritual is also a medium for cultural socialization in the civilization of the Bajo people. Therefore, every activity of the Bajo tribe is always carried out by rituals together and in groups. This ritual is a form of respect for the bombonga di lao (a sea king named petta sidampallie to get a lot of sustenance, calm, peace, and protection while at sea. Bajo people also believe that this ritual is a medium to unite their souls with the sea (Marhadi 2012). This tradition can also be found in Bajo fishers who live in Petoaha Village who believe that the boats they own can be likened to living things, so they believe that boats also have the same spirit as humans. Therefore, there is an expression that Bajo fishers actually maintain the boat and do not have a boat. Therefore, no wonder the Bajo people treat the boat as treating to humans. This belief was done long ago; Bajo people in the Village Petoaha usually held a ritual since the commencement of the manufacture of boats (Saleh 2018).

Religious ceremonies are an element of community life and ethnic groups globally, which describe human fascination with unseen things. Rituals are procedures in ceremonies carried out by a religious community, which are unique, sacred, and special to generate respect (Hamriani et al., 2019). Religious rituals connect humans with the supernatural they believe in (Taena 2011). Ritual is a local culture for the Bajo people, starting from the ritual of birth, entering adolescence, entering adulthood, the ritual of marriage, and the ritual of death. These rituals are carried out to turn Bajo children into useful humans and not become useless humans both in this world and hereafter (Dalnia et al. 2018). The Bajo tribe has various kinds of traditions that are believed or believed; for example, the tradition *duata* is one of the traditions carried out at sea by boat or ship. In addition, there is also a tradition *Madduaiang* which is not much different from the traditional *duata.* However, the tradition *Madduaiang* in its implementation, is not held over the sea; this tradition is only carried out on the beach (Hamriani et al., 2019). In addition, the Bajo tribe also has a series of religious rituals when a relative dies, from preparation for the funeral to completion. This is a unique and distinctive feature for the Bajo community and a form of respect for left relatives (Mokhtar 2020).

The rules in carrying out the activities of these Bajo traditions show that the Bajo community truly respects the territorial waters, especially the sea where they live (Herlina et al. 2020). This cannot be separated from the significant influence of the sea in supporting the lives of the Bajo people, also known as sea people. Based on the story of the Bajo tribe's ancestors, the Bajo people believe that the sea was created by the Creator for them (Pierre 2010). Therefore, they must preserve marine waters and utilize the natural resources in them (Prabowo 2017). In addition to playing an important role as the manager of coastal resources, the social entities owned by the Bajo tribe also have important political power for the dynamics of local politics in the areas where they live (Ola et al., 2018). This is because the large population of the Bajo Tribe (for example, in the largest Bajo village in Wakatobi, namely Mola) creates a great deal of political interest in them (Some community groups Bajo also believed that all kinds of diseases that arise between them come from spirits- the spirit of guarding these ecosystems The Bajo tribe believes that the destruction of the coastal ecosystem is a disaster for their community. This is based on the belief of the Bajo people that guardian spirits inhabit all resources on the coast and the sea. So that all forms of destruction and misuse of natural resources will bring badness to the Bajo community (Obie 2016). The older generation in the Bajo community still believes that certain coral clusters are the place for the souls of their ancestors to reside. Therefore, many parents forbid their family members to capture everything. Species of fish and another biota around the coral cluster, except j If a certain ritual is carried out first by preparing dishes for the ancestors (Artanto 2017).

The existence of the Bajo tribe spread across various regions in Indonesia, even to several neighboring countries, has led to differences in beliefs held between the Bajo Tribe in one region and another. These differences can occur due to various influencing factors such as natural conditions, availability of technology and information, education levels, and the diversity of surrounding communities that live side by side. The Bajo tribe, who lives in the sea, generally strongly believes in ancestors and sea gods. The Bajo Laut people rarely interact with mainland people, who have typically embraced religion and are touched by modernization. They still hold the beliefs passed down from their ancestors, namely animism and totemism. Meanwhile, in some Bajo ethnic groups who have lived on the mainland, the belief in sea gods and their ancestral traditions is not as strong as the Sea Bajo Tribe. For example, the mainland Bajo people in Saur Saibus Village Sapeken District almost all of them embrace Islam. Even so, the use of mantras as a request to God in the activities of the Bajo community is still very strong. The difference in belief between the Bajo tribe in one area and another is actually not that big. The Bajo tribe still believes in the supernatural that guards the sea even though they have lived on land and are touched by modernization. The strongest difference is in implementing ancestral traditions and rituals to the sea god. Some Bajo community groups are no longer practiced because they violate religious teachings.

Some literature says that most Bajo community groups indicate their belief in Islam (Moldjo et al. 2019). However, they still believe in their ancestors, namely in the sea's ruler; these two things are inseparable, interconnected, and symbiotic with mutualism. No literature specifically explains what religion the Bajo tribe followed before the arrival of Islam (Rahmat and Usman 2016). Bajo people know Islam from the influence of land people around them due to the relationship between Bajo people and land people (Candra 2019). In several Bajo community groups, Protestant Christianity has also touched their lives through the teachings conveyed by priests and religious leaders, although they are still overshadowed by strong animistic beliefs (Yulia 2016). The Bajo people who live in Petoaha Village are all Muslim and have religious activities that are still very thick in filling the daily lives of residents in the area. Some of the Bajo Tribe's religious activities include routine recitation, religious holidays, and other religious activities. However, as explained earlier, some of these religious activities are still influenced by Bajo beliefs and culture (Saleh 2018).

The Bajo tribe has also been scattered in several other coastal islands, such as Sapeken Island, East Java. Almost all the Bajo people on the island of Sapeken adhere to Islamic beliefs. Regarding religion, in the Bajo tribe that occupies this area, animist beliefs on the Bajo Sapeken tribe are less visible due to the strong influence of the Koran teachers (Rahayu 2019). In addition, the Bajo tribe who live in Kabalutan Village, Central Sulawesi, also most people embrace Islam. However, in the Bajo tribe, religious values are still influenced by several ancestral beliefs, such as the Bajo tribe's wedding customs in Kabalutan Village which generally does not conflict with the teachings of Islamic law (Juniarsi 2019). Bajo people (Orang Laut) of Johor, Malaysia, mostly embraced the Islamic faith. They can generally understand the beliefs, although only limited to basic religious knowledge (Uniawati 2011). The Bajo people maintain their beliefs amid globalization by considering new assumptions regarding their beliefs by continuing to carry out functional relationships. Namely, the relationship between horizontal social processes (relationships with fellow communities) still has a good or no impact. In several villages, the Bajo community formed an environmentally conscious group (KSL) by the beliefs of the Bajo community so that later directions were given from the head of their community institution (Utina 2012).

BAJO COMMUNITY IN ENVIRONMENTAL CONSERVATION

Bajo tribe is a tribe that lives on boats and lives in shifts according to the potential fish resources that can be caught. Like the Bajo tribe in Southeast Sulawesi, a tribe with its characteristics in managing the marine environment, the Bajo people inhabit almost all the islands and coastlines in Southeast Sulawesi (Hernila and Surdin 2016). The Bajo people, as sea nomads, define the sea as a space for a living, a place to live, and a place to live for their ancestors. The Bajo tribe highly respects the sea and appreciates it because it is their source of livelihood (Umar 2019). The Bajo people are thick with cultural values and habits in interacting with the natural marine environment in managing marine resources to sustain. In contrast, The Bajo people always involve local knowledge that comes from their beliefs and beliefs while maintaining the natural marine environment (Said et al. 2020). Like the women of the Bajo tribe who are environmentalists, they will continue and always protect marine life, which is their source of energy. The view held by the Bajo people states that the natural sea is not only intended for humans, but other creatures live from the sea, and so that everything runs harmoniously, is balanced. There is no conflict of interest; it is mutually preserving and respecting the sea environment (Marhadi 2012). Various ethnic communities in Indonesia have long used nature for multiple activities. The influence of tribes with multiple experiences, perspectives, and perceptions of nature affects and produces multiple forms of life and the character of the community landscape (Aziz et al., 2018). The ecological intelligence possessed by the Bajo Torosiaje people can be seen in various aspects of life, such as the tradition of fishing for *mamia kadialo*, settlement management, community behavior in obtaining catches, as well as the knowledge that the community has about the natural phenomena of the sea and coast (Utina 2012; Mustamin 2020).

In many traditional communities with local wisdom practices (indigenous knowledge) that are still preserved in people's daily lives, the existence of these landscapes is very stable. It can continuously provide support for the people who live in these landscapes. The landscape that results from the community's activities and perceptions, influenced by local culture, is referred to as a cultural landscape (Kaunang et al., 2012). The culture of the Bajo tribe, which firmly believes in the existence of spirits in the sea as guardians of the sea, makes them often prepare offerings that are brought in the middle of the sea as offerings to the spirits of their ancestors who guard the sea (Nurhaliza and Suciati 2019). Maintaining marine wealth is a characteristic of the Bajo tribe based on local wisdom and culture to adapt to the ferocity of the ocean (Satriani et al., 2018).

The existence of marine natural resources and has the extraordinary marine potential can further encourage the spirit of the Bajo people with the characteristics of the Bajo tribe in protecting marine wealth and as a source of their livelihoods (Obie 2020; Syefriyeni and Rosie 2020). The coastal Bajo people who live from marine natural resources have a close relationship with the marine and coastal environment. It raises the values of environmental concern in maintaining the sea and coast (Tamu et al., 2017). Coastal areas, seas, and small islands play an important role in human life. The existence of the coastal regions, seas, and small isles has provided several supporting services for human life for more than a millennium that should be maintained (Romadhon 2014). The Bajo community, in obtaining marine product resources, is also very adaptive to the environment by conserving marine resources; one example is maintaining coral reefs as a place for fish to live. The Bajo community has a pretty good conservation awareness (Cohen and Simon 2013).

Conservation is an effort to manage changes towards preserving values and cultural heritage that are better, more harmonious, and sustainable (Rachman 2012). Meanwhile, marine conservation is an effort to prevent damage to marine ecosystems and pay attention to the benefits obtained by maintaining and preserving the components in the marine ecosystem. Marine conservation carried out by the Bajo community is very diverse to preserve the sea. Until now, the Bajo tribe still maintains a culture related to marine preservation because the sea is everything for them, so it must be preserved and preserved (Akram 2018). The Bajo tribe is one of the tribal communities that manage, maintain, and utilize marine biological resources based on cultural norms and values institutionalized and attached to the Bajo community. They are maintained through social control based on their belief system (Moldjo et al., 2019). Examples of such applications are the prohibition of fishing in large fish (Anugrah and Fatimah 2018). According to Lamane et al. (2020), the Bajo community in maintaining the sea and coast conserves mangrove forests by preserving and utilizing mangrove forests based on indicator provisions such as mangrove trees that cannot be cut down continuously, can be used as tourist attractions, mangrove forest areas cannot be converted into settlements, must not throw garbage in the sea, participate in a mangrove tree nursery, warn if you see someone cutting mangrove trees, participate in mutual cooperation in mangrove forest rehabilitation, and in maintaining mangrove forests must involve the Bajo community.

The Bajo tribe has wisdom about the environment due to a process of adaptation to environmental changes that have occurred from generation to generation (Francois 2015). A process that lasted decades, even hundreds of years, finally formed a problem-solving mechanism. The dependence of the Bajo community on coastal and marine resources has made the community develop a wise management mechanism (Kurniasari et al., 2017). The Bajo tribe has wisdom in protecting and utilizing coastal and marine areas sustainably (Umar 2019). The Bajo people have the wisdom to protect the marine environment, namely corals, mangroves, and marine resources. The marine resource management system associated with coral reefs by the Bajo people, especially in the past, is based on the Menteng Panglima Institution, which is characterized by a solid and neat socio-economic-political life order, patterns of marine resource utilization that reflect the relationship between human and environmental conditions, conditions equitable socio-economic welfare of the population, and the preservation of environmental conditions and the balance of coral reef marine resources (Lampe 2012). The Bajo Tribe has a deep concern for conserving coral reefs as a buffer for the underwater ecosystem. They are very aware of the need to preserve the sources that are the basis of their livelihood fulfillment (Susilowati 2017).

The Bajo community, with local wisdom in managing marine resources, has a regulation in terms of fishing, one of which is that they always choose fish that are ripe for consumption and do not want to catch fish that are still small, so that fish resources are maintained for sustainability (Suryanegara et al. 2015). In addition, there is also an example that includes the local wisdom of the Bajo community, which has become a habitual culture, including not catching fish for 12 months, where the timing of the catch can have an impact on the availability of marine life so that it remains sustainable (Wiralis et al. 2017). The Bajo people believe that when they are at sea and find sea cucumbers that are standing upright (not sloping), they should not be caught because, in the belief of the Bajo people, sea cucumbers that are in a standing condition can bring reinforcements if they are caught, and that is a characteristic of the reproductive process. Its means that the Bajo community prohibits the capture of breeding sea cucumbers to preserve their survival (Heryanti 2017). With the belief in the Lord of the sea and the spirit of the ancestral guardians of the sea, the character or personality of the Bajo tribe grows, which maintains fish sustainability as an effort to maintain the balance of the marine ecosystem (Kharisma 2019).

The life of the Bajo tribe, which is very close to the sea, makes fishers and the sea seen as a culture, a source of earning a living, or as a means of preserving the marine and coastal environment (Hamzah 2012). According to Dai (2020), there are also consequences for the Bajo people who take advantage of coastal and marine areas as tourist areas, namely increasing public awareness in maintaining and preserving the ecosystem of coastal natural resources and marine waters. According to Ikhsan (2020), based on oral heredity from ancestors, there are rules or restrictions in the form of things that cannot be done. Including not littering or wasting into the sea, such as wastewater washing rice or sea cucumbers, wood charcoal used cooking, coffee grounds, chili juice, ginger juice, orange peel, orange juice, kitchen ash, or charcoal, and cigarette butts or ash. The traditions or local wisdom that have been previously mentioned are taboo for the Bajo people, who have an excellent goal, namely to preserve the sea because they live and live in the sea (Damisi et al., 2014). In addition, in maintaining marine space as a place for ancestors and its contents as a source of life that is in harmony and harmony with the universe, the Bajo people build the architecture of Bajo tribal settlements that are primarily oriented towards the sea to maintain marine and coastal sustainability (Syam et al. 2017). The Bajo tribe has a maritime cultural ceremony, called the Sangal Tribe Bajo ceremony, a tradition to release turtles when their population decreases and release tuna to repel logs and preserve the sea and marine wealth (Final and Ponco (2012) in Aziz 2016).

The Bajo people, in maintaining the environment around their residential areas, do so by maintaining the quality and quantity of the clean water system in the Bajo village (Than et al. 2018). Also, the efforts of the Bajo community to be able to maintain and preserve the marine and coastal ecosystems of the Bajo tribe with its various socio-cultural uniqueness cannot be separated from the participation of the government in the district, which helps and provides regulation and social control to maintain the existence of the tribe. Bajo, because some of them have experienced many social shifts and changes resulting from acculturation and assimilation, especially on livelihood issues (Mukramin 2018). The Bajo tribe maintains its marine and coastal ecosystems because they permanently live side-by-side and are peaceful with nature. This can be why the Bajo people feel they have a natural environment, so they protect and preserve their ecosystem (Obie et al., 2014).

The large number of tourists who visit the Bajo Tribe can affect the Bajo Tribe's trust in environmental conservation. The development of tourism in the Bajo tribe area can change socio-cultural, economic, and ecological conditions. Lasso and Dahles (2020) revealed that the impact of tourism development in the economic sector is that local communities have begun to switch professions; who initially worked as fishermen and then turned into the tour boat business. This will threaten the sustainability of local people's livelihoods. In addition, tour boat providers have several challenges, namely intense competition, short holiday seasons, and dependence on tour operators. These changes led to a response or response from the Bajo community. This is probably due to the lack of knowledge and understanding of domestic tourists about responsible tourism and the importance of conservation that is not good enough. The increasing number of tourists who come can also decrease the environment's carrying capacity, such as damage to coral reefs, natural disasters, and a large number of piles of garbage in several locations. And possibly due to the influence of tourists who come to transmit modernization to the Bajo Tribe, causing a change in Bajo Tribe beliefs in environmental preservation.

THE IMPACT OF MODERNIZATION ON THE LOCAL WISDOM OF THE BAJO TRIBE

Modernization is a process of changing traditional society to more modern society. This process of change affects various aspects of life. These aspects include the agricultural, social, economic, and ecological sectors. As time goes by, modernization will affect the lives of the wider community. An example is the existence of local wisdom in an area. Modernization can jeopardize the existence of local wisdom to remain, be reduced, and even disappear from certain communities (Sari 2020). And this is happening to the local wisdom of the Bajo Tribe.

Modernization has affected the life of the Bajo Tribe in several areas. The local wisdom of the Bajo Tribe on Sapeken Island, Sumenep, East Java, begins to fade with time. The Bajo tribe is known as the sea tribe because they utilize marine biological resources and work as fishermen daily. Technological improvements affect changes in the Bajo Tribe's fishing methods, namely the number of fleets, trips, and the area and fish catches. In addition, the orientation of the cultural values of the Bajo Tribe has shifted, which was initially integrated with nature to exploit nature. Bajo fishers under 50 years old are starting to leave the local wisdom they believe in, and only those over 50 years old are still preserving the local wisdom of residents (Fadhila 2017). This condition is not much different from the Bajo Tribe who live in Karimunjawa. Globalization affects their social life (Suliyati 2017).

In the past, the Bajo tribe generally lived as nomadic; now, most of them have settled on the mainland. One of them lives in the Wakatobi Islands. They decided in one place because the Bajo people are starting to find it challenging to meet their daily needs due to reduced natural resources, government programs, and the cultural influence of mainland people. This social shift causes both positive and negative impacts. The positive impact is increasing the standard of living of citizens, the emergence of education awareness, the creation of employment opportunities, an increase in income and standard of living, and an increase in fishing gear technology. At the same time, the negative impacts are the reorientation of the relationship between humans and nature, the waning of local beliefs and customs, and the emergence of a consumptive lifestyle (Suryanegara et al. 2015).

Meanwhile, the Bajo tribe in Latawe Village, West Muna District, Southeast Sulawesi, has changed work patterns, social structures, and fishers' welfare. The reason is that government and private programs have begun to be mobilized. The program is counseling coastal communities, providing capital, and improving fishing facilities. Improvements in fisheries technology in boats and fishing gear have led to increased catches (Hamzah et al., 2019). In Wakatobi District, Southeast Sulawesi Province, there are two sub-ethnic Bajo Tribes, namely Mola and Mantigola. The two Bajo Tribe communities have differences in dealing with the times, especially in the rural economy. The Mola community is more affected than the Mantigola community. The Mola community shows the characteristics of local capitalism, while the Mantigola community still maintains ancestral customs, namely the traditional lifestyle (Wianti 2011).

CONCLUDING REMARKS

Based on the results obtained through literature studies, it can be concluded that the Bajo people believe that the sea is the source of their livelihoods and a place for the existence of sea gods and the location of ancestral dwelling. The Bajo tribe is one of the tribal communities that manage, maintain, and utilize marine biological resources based on cultural norms and values institutionalized and attached to the Bajo community. They are maintained through social control based on their belief system. This belief brings the Bajo people to fear breaking the *taboo* or *pamali* that has existed since their ancestors orally and from generation to generation. So, based on this belief, the Bajo people make various conservation efforts to maintain, maintain and protect the preservation of marine waters, coastal ecosystems, mangrove forests, and marine resources such as fish, seaweed, coral reefs, and others.

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