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Social-ecological systems and their connectivity in the East Coast District area, Mimika Regency Central Papua Province, Indonesia

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Abstract. Social-Ecological System (SES) is a system that connects the human system with natural systems where humans, as an inseparable part of nature, have functional dependencies and changes. This research was conducted on the East Coast District of Mimika Regency, Central Papua Province, Indonesia. Mimika Regency is in the southern part of Papua Island, Indonesia, characterized by swamp and mangrove forest ecosystems. Mimika Regency has a mangrove ecosystem type which is influenced by tides and large rivers that empty into the sea which carry tailings disposal. The purpose of this study was to study SESs using the Drivers-Pressure-Impact-State-Responses (DPSIR) approach. The DPSIR conceptual model is one of the frameworks showing the causal relationship between environmental systems and humans Based on analysis, it is knowed that tailings disposal causes pressure on the coastal and marine resources as well as social communities in the eastern coastal area of Mimika. Significant changed can be seen in the declining quality of forest, swamp, river, mangrove, and marine ecosystems, changes in fishing ground areas, silting of rivers and estuaries, and disruption of accessibility, which impacts the social vulnerability of the community. We identified the connectivity of the SES network formed in the East Coast District area of Mimika, which was dominant and related to livelihoods, and community perceptions of government institutions and PT. Freeport Indonesia.

Keywords: coastal, DPSIR, Mimika Regency, PT. Freeport Indonesia, tailings disposal, SES.

1. Introduction

The socio-ecological system (SES) is a system that connects humans and natural systems, where humans must be seen as part of and inseparable from nature (Berkes & Folke, 1998; Costanza, 1999; Berkes et al., 2000; Costanza et al., 2000; Berkes et al., 2003; Glaser & Glaeser, 2010), or in other words, an ecological system that is closely related and influenced by one or more social systems (Anderies et al., 2004), which are mutually related and dynamic (Petrosillo et al., 2015). Anderies et al. (2004) and Petrosillo et al. (2015) identified SES as functional interdependence between social and ecological change. SES is essential in management because it has emergent properties as a complex adaptive system (Levin et al., 2013; Virapongse & Alessa, 2016; Kanwar, 2018) and resilience or the ability of the system to continue

to function when intrinsic or extrinsic disturbances occur (Folke et al., 2016).

According to Rockström et al. (2009), the interaction and dynamics of social and ecological systems, both natural and anthropogenic, have become a significant challenge in managing natural areas and resources. The interactions and dynamics of SES become more complex when human intervention occurs. They provide not only the uncertainty of the system but also concepts, such as feedback cycles, tipping points, and regime shifts, that trigger fears of unintended consequences of management actions (Jackson et al., 2009; Dearing et al., 2015). Therefore, understanding the dynamic relationship between social, environmental, and climate phenomena is now considered the key to making appropriate management decisions (Sidlea et al., 2013; Gillson & Marchant, 2014) so that an integrated study of the combined SES is seen as something dominant in the ecosystem management framework (Liu et al., 2007). Then Ostrom (2009) emphasized that the complexity of the dynamics of humans and nature is best conceptualized with the SES framework.

Like other areas, the eastern coastal area of Mimika Regency has increasingly complex SES interactions and dynamics when development occurs in upland and around coastal areas, especially with the presence of PT. Freeport Indonesia has been the world's largest gold mining exploration company since 1973. One of the impacts of this exploration is the disposal of mining waste (tailings) flowing into the Aijkwa river, known as the Modified Ajkwa Deposit Area (ModADA) system, which passes through the settlements of the Comoros tribe in the coastal area. They are the indigenous tribes who inhabit the eastern coastal area of Mimika Regency. Studying this is interesting, considering that there have been massive changes to the environment and society since the operation of PT. Freeport Indonesia. Understanding the SES and its connectivity, as well as its issues and problems, is the main asset in designing a better management approach for developing coastal areas and sustainable communities on the Eastern Coast of Mimika Regency. Therefore, policymakers must accurately define the actual state of issues and problems in making development policies in the area. The aim of this research is to determine the impact of mining activities, especially from PT Freeport Indonesia tailings waste. This is important to do considering the real environmental conditions in the Eastern Coast District of Mimika Regency, Central Papua Province.

2. Material and method

2.1. Research time and location

This research was conducted in November 2019 in the East Coast District District area of the Mimika Regency, Central Papua Province, Indonesia (Fig. 1), namely the villages of Ayuka, Tipuka, Nayaro, Ohotya, Panamo, Omavita, Koprapoka, Nawaripi, and Amamapare. Mimika Regency is currently included in Papua Province, which was previously included in Papua Province based on Decree Number 15 of 2022 concerning the Establishment of Central Papua Province.

2.2. Sources, types, and collection of data

The data used is primary and secondary data. The primary data was obtained through a direct field survey through observation and interviews with 90 respondents--ten respondents in each selected village. The respondents were selected by purposive sampling with the criteria of having the ability to understand the problem being studied, to express opinions and ideas well, and the willingness to become respondents. Questions asked respondents, namely: what is the main problem currently being faced, what is the trigger, what impact does the trigger have on the environment and what impact do you feel, and what do you do to respond to this problem. The secondary data was obtained through literature studies from various journals, research reports, and other sources of scientific data relevant to the study. The data collected is based on existing understanding and conditions (Muhadjir, 2011), is than discussed descriptively and triangulated .

2.3. Data analysis

– SES with DPSIR (Drivers–Pressures–States–Impacts–Responses)

The DPSIR (Drivers–Pressures–States–Impacts– Responses) approach was used to determine the interrelationships of the factors causing pressure on the ecosystem so that it can be used to assess the intensity of human resource use and activities in coastal areas. The DPSIR conceptual model is a system-thinking frameworks that assumes cause-and-effect relationships between environmental systems and humans and has been used to analyze and assess social and ecological problems of the system (Petrosillo et al., 2015; Bradley & Yee, 2015).

The DPSIR approach was developed by the European Environment Agency (EEA, 1999) based on the Pressure-State-Response (PSR) framework previously developed by the Organization for Economic Co-operation and

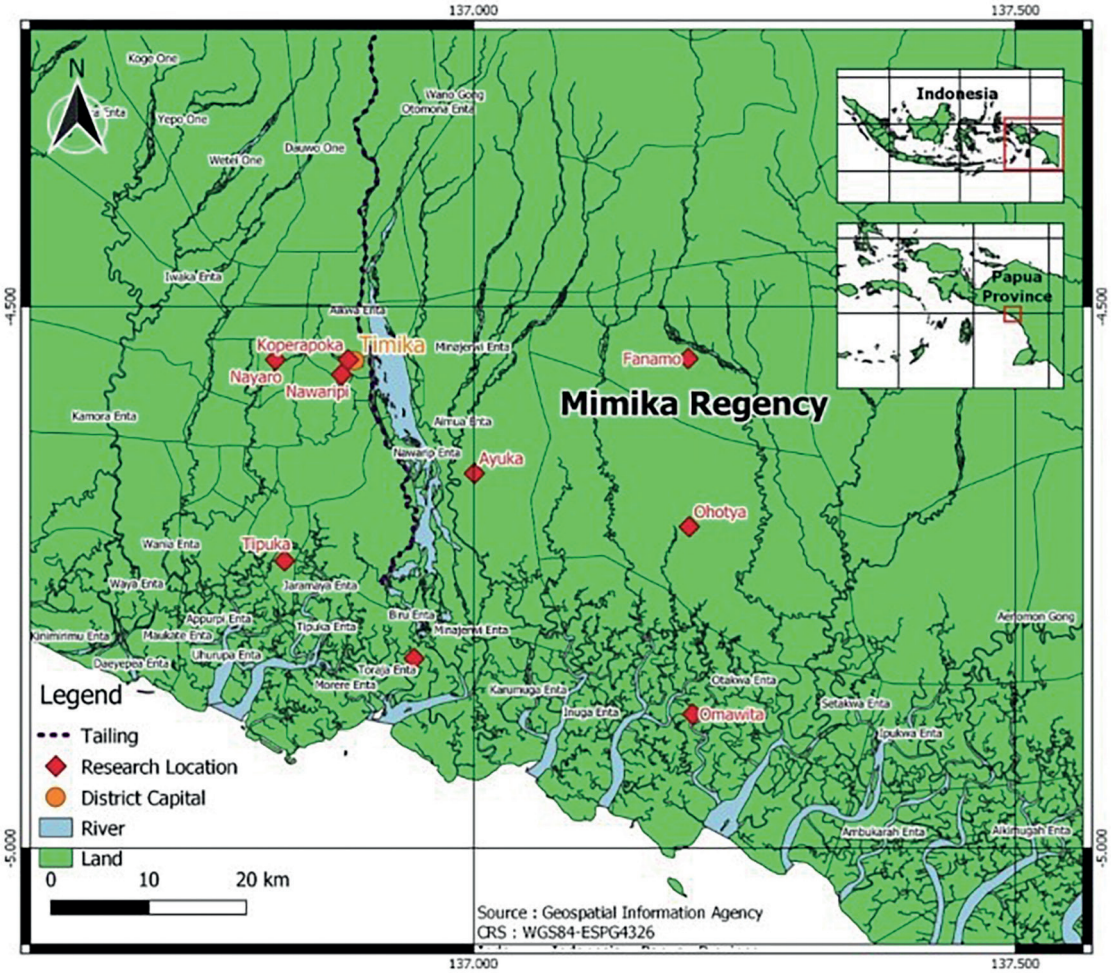

Figure 1. Research Location of East Coast District, Mimika Regency, Papua, Indonesia

Development (OECD) in 1993 (Rekolainen et al., 2003). DPSIR is generally used in ecology, environment, and management of socio-economic activities because this approach can analyze complex causalities between environmental and socio-economic systems. Within the DPSIR framework, socio-economic development is the driver (D) that creates pressures (P) on the environment. In response to these pressures, environmental conditions (S) change and impact (I) on human health, ecosystems, and others. Meanwhile, Response (R) is feedback for D, S, and I in the form of adaptation and prevention policies (Piragnolo et al., 2014). The framework of the analytical method with the DPSIR approach can be seen in Figure 2. The SES network entity and factual conditions in the East Coast District region of Mimika Regency are based on the author's justification, namely low, medium, high and very high.

3. Results

3.1. Overview of the Kamoros

The Kamoro tribe is an indigenous tribe inhabiting coastal areas in Mimika Regency. Kamoro is a name that still gets a lot of opposition from the public regarding its origin. In Pouwer's (2010) article, the Kamoro are better known as Mimikan. Communities in the coastal area of Mimika prefer to use the word "Mumuika" which later in Indonesian absorption became Mimika. In Solaiman (2018), Father Petrus Drabbe MSC first introduced the name Kamoro, where the word "Kamoro" means "living person," as opposed to "spirit" (dead person). He gave the name because there is no native language used to name this tribal group. People outside refer to them as "we nata," which means "real human." The spread of the tribe, which is famous for its expertise in catching fish, crabs, and other aquatic biotas as well as hunting, starts from Etna Bay to the east around the Minajerwi river, the Otakwa river on the eastern coast of Timika.

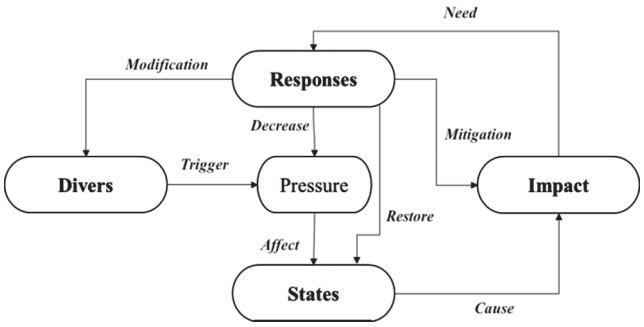

Figure 2. DPSIR concept

3.2. Overview of the Territory and Aquatic Environment

The eastern part of Mimika Regency is a swampy lowland area, and there are several small and large rivers with a stretch of mangrove forest. One of the largest rivers is the Ajkwa river which is directly connected to the tailings disposal channel by PT. Freeport Indonesia. The tailings waste that flowed through the Ajkwa river to the eastern region of Mimika Regency had a tremendous impact, where millions of tons of tailings flowed into the modified Ajkwa Deposition Area (ModADA). Tailings are natural water and rock residues on the fine soil surface after the concentrate is separated from the seeds at the processing plant (PT. Freeport Indonesia, 2020, https://ptfi.co.id/id/riverine-tailings-management).

4. Discussion

4.1. SES with DPSIR

Comoros generally make a living as a fisherman, forest animal hunters, fish catchers, and sago collectors. In the division of labor, men are tasked with building boats to find fish and hunting in the forest, such as wild boars, cuscus, cassowaries, monitor lizards, snakes, and birds. Meanwhile, women process sago as their daily food. For the Kamoro, women usually look for food for their families in the middle of the forest by tapping sago, catching crabs, and looking for tambelo, a type of mollusk that lives in dead/rotten mangrove trunks (Mulyadi, 2010; Jayaputra, 2012; Tebay & Manuputty, 2017); men (husband, son-in-law, and son) are more involved in driving and guarding boats and hunting forest animals and birds. Generally, the Kamoros live in wooden houses and move around (Mulyadi, 2010; Jayaputra, 2012), but some have lived in semi-permanent houses built by PT. Freeport Indonesia. The Kamoro tribe relies on sago forest products, rivers and seas as their source of livelihood, so it is synonymous with the term 3S (Sungai/river, Sampan/canoe, Sagu/sago).

In managing natural resources on the coast and the sea, the people who live around the tailings-affected area, especially in the villages where the study is located, have a strong network system with nature, as can be seen from the knowledge and local institutions owned and applied from generation to generation, known as the Taparu system. Taparu, which means land or refers to land, is a family or clan-based natural resource management system (Kemong, 2014). Taparu (Sempan: se) means residential land or environment (Pouwer, 2010). Land forests, sago forests, swamps, rivers, estuaries, mangroves, and marine areas are essential in life for the Kamoro people. On this basis, its various resources will be managed and maintained by enforcing customary norms.

Natural resources in the coastal area, especially in the tailings-affected area in the eastern part of Mimika Regency, are complex ecosystems. This socio-ecological system consists of land forests, swamps, rivers, estuaries, mangroves, and marine waters, which consist of physical interactions (water flows) and biology (biota interactions). For the Kamoro people living in coastal areas, this system has increased their resilience in the face of pressure from both inside and outside. It is proven that they are using fisheries resources sustainably, documented in the practice of local wisdom (Tebay & Manuputty, 2017).

The social system in the village area affected by Tailings is quite complex. Various resource uses have existed and influenced each other, both the influence of the social system on the ecology and vice versa. Several types of livelihoods in the area are affected by tailings, such as hunting or trapping (wild boar, cuscus, cassowary, mambruk, parrot), gardening (coconut, areca nut, and vegetables), fishing (catching fish, shrimp, crabs) and clams and molluscs) and sago sticks. Land use in the tailings-affected area is limited to villages or settlements and the construction of educational, health, worship, and government facilities. The distribution of area utilization and resources in the social system of the Kamoro tribal community is based on Taparu, which also refers to the customary rights system, where forest areas, sago forests, swamps, rivers, estuaries, mangroves, and the sea and even small islands are areas of use based on family.

As human and biophysical subsystems are intrinsically connected and highly dependent on natural resources, the Comoros people who inhabit the village are the first to feel the impact of tailings waste. Environmental changes caused by tailings waste have eroded and changed the resilience system of the socio-ecological system, which has implications for community social changes as feedback from natural changes. Based on DPSIR analysis, the driving factor was tailings waste which causes various changes to the

environment and people's lives on the coast of East Coast District Mimika Regency (Fig. 3).

In the WALHI Report (2006), the accumulated piles of mining waste rock and tailings have reached 840,000 tons. The tailings deposit has created a new problem that is difficult to reforest because it contains low oxygen and lacks vital nutrients for growth, making it difficult to return to its original condition. Total Suspended Solids (TSS) in the lower Ajkwa River (around the estuary) is very high and far above the acceptable quality standard. Water quality in mangrove waters in Muara Ajkwa also 10 times exceeds the legal limit for TSS in marine environments (80 mg/L), with an average TSS of 900 mg/L (WALHI Report, 2006). TSS from tailings directly harms fish gills and eggs, predatory organisms, organisms that require sunlight (photosynthetic), and organisms that filter their food (filter feeding). The highest potential risk was experienced by benthic invertebrates that live in sediment deposits (Parametrix, 2002a). In addition, the tailings waste contains heavy metals, especially copper, which can inhibit the work of fish gills and other aquatic biotas (Ballard, 2001; WALHI Report, 2006). In the same report (WALHI, 2006), soluble copper in the range of concentrations found in the lower Ajkwa River reaches chronic toxicity levels for most (30% to 75%) freshwater organisms. The actual toxicity tests were conducted by the Commonwealth Science and Industrial Research Organization (CSIRO) and analysts at PT. Freeport Indonesia in WALHI (2006) show that water and tailings deposits are toxic to shrimp larvae (*Caridina* sp), adult river shrimp (*Macrobrachium rosenbergii*), minnow fish larvae (*Cyprinodon variegatus* and *Pimephales promelas*), river algae (*Chlorella*), embryos and larvae. Rainbowfish (*Melanotaenia spledida*), and the invertebrates *Gammarus* and *Nassarius* sp. Not only was copper found in the tailings content, but also other dangerous metals such as arsenic, manganese, lead, silver, and zinc, whose concentrations in biota and waters were very worrying.

Environmental impacts on people's health and livelihoods have become a persistent problem in PT. Freeport Indonesia and widely documented in national and international media, including deforestation and pollution where tailings are dumped directly into the Ajkwa river and then into the Arafura Sea. Mine tailings deposition directly into the Ajkwa river caused flooding, destroying most of the lowland forest, threatening Timika City, and submerging most of the mangrove area. The water supply comes from the watershed adjacent to the operations of PT. Freeport Indonesia, and there has been an increase in copper levels in marine fauna (Ballard, 2001). This pollution has an impact on the human security of the community around the mine. Greenomics Indonesia's calculations show that the cost to restore the damaged environment is IDR 67 trillion.

In Figure 3, it can be seen that the driving force factor in the eastern coastal area of Mimika Regency is tailings

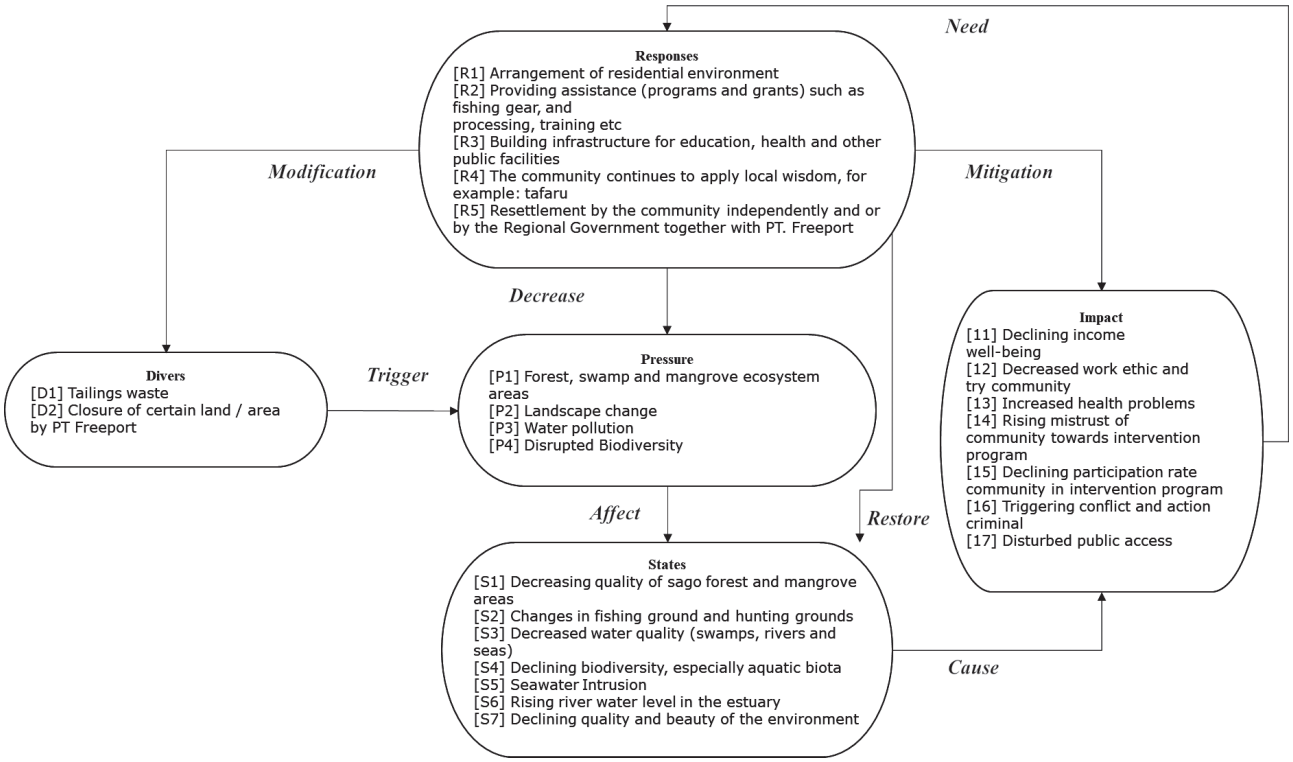

Figure 3. Analysis of DPSIR on the East Coast District, Mimika Regency

waste which is channeled using the ModADA system. As part of the ModADA system, several areas are closed to the public, especially to communities around the area, both as transportation routes and as hunting and fishing locations. The closure of the area is not only for public safety reasons but also for the area as an operational area. The two driving forces have triggered pressure on areas including forests, swamps, and mangroves, causing turbidity and sediment deposition around the estuary. WALHI Report (2006) stated that the tailings waste channeled using the ModADa system also contained heavy metals such as copper, arsenic, manganese, silver, and zinc, which might have caused exposure to fish and other biotas. It is stated that copper levels in the body of non-mobile biotas, such as mollusks, have reached 100 times the standard limit. Meanwhile, the concentration of arsenic contained in tailings is still relatively low, namely below 10^{-4}, which means it has no potential to cause cancer (Parametrix, 2002b)

The conditions include changes in fishing grounds and hunting grounds, silting of rivers, river flow, and decreased water quality in swamps, rivers, and at sea. The changes occur in heavy metal pollution, seawater intrusion, loss of clean water sources, decreased land area of sago and mangroves, rising river water levels in estuaries, declining quality, and beauty of the environment increase community apathy.

Meanwhile, the impact is caused by decreasing people's income, lowering work ethic or community business, improving public health problems, and increasing public distrust of PT. Freeport Indonesia, the Regional Government, and other institutions ultimately lead to low community participation in various intervention programs and trigger conflicts and criminal acts. Amin (2015) calculates the social costs of waste disposal reaching USD 29,645,506.51 per year, which calculates the impact of damage to natural resources in productive areas in the form of mangrove forests, tropical rain forests, and the Ajkwa river economically, which threatens the survival of freshwater organisms. These people live daily, consuming water and using rivers as transportation routes as a source of livelihood, and food.

4.2. Socio-ecological system and connectivity

Sedimentation and tailings deposits are dumped and channeled through the Ajkwa river, swamps, and seas. These have caused a multiplier effect on the SES of the surrounding communities, especially those on the eastern coast. The impacts on the human system include causing impaired community food vulnerability and security, health problems, and conflict. In terms of food security, the community is very vulnerable because sago as a food ingredient has undergone much degradation. It is even worse over time that people have abandoned sago as a staple food and have begun to switch to rice and instant food, only supplied from outside (from the city). Such conditions become very vulnerable for the community because the supply of rice and instant noodles is highly dependent on weather conditions. Public access and transportation practically stop during the rainy and wave seasons at sea. It is not surprising that many incidents of malnutrition occur, but related data are not well available.

Public health is also one of the serious issues and problems in this region, where maternal and child mortality rates are comparatively high. However, data recording is readily available due to various obstacles from existing health workers and facilities. Nevertheless, the diseases usually found include malaria, typhoid, and skin diseases. Conflicts between communities are risky even though they rarely appear on the surface, so they can become an iceberg phenomenon—the conflicts between communities and PT. Freeport Indonesia is no longer a secret. Many small and large cases often arise but can still be suppressed with various approaches and strategies. Usually, conflicts between communities occur because of the struggle over the fishing area related to the recognition of ulayat rights. In addition, conflicts also often occur at the community level related to distributing direct assistance from PT. Freeport Indonesia as well as from the Regional Government. These conditions are often found in the community, causing public apathy towards various programs in that PT intervenes. Freeport Indonesia as well as by the Regional Government.

Communities on the East Coast District of Mimika Regency, with all their social and cultural conditions, can change the shape of the ecological system and vice versa. The ecosystem dynamics in the coastal area can change the social and cultural conditions of the local community. This pattern of SES connectivity in Mimika Regency is proven by the impact of mining activity waste on community activities, for people who make a living as forest animal hunters, gatherers of food from sago, fishermen, and other activities. The network model formed from SES connectivity in the eastern coastal area of Mimika Regency is a complex system. The interaction between the components of the ecological and social systems can be illustrated by the social-ecological networks that occur. The SES network from the results of the study illustrated that in the social system, there is a relationship between the damage to forest resources, swamps, mangroves, rivers, and estuaries as well as the sea with the level of welfare, level of health, and conflicts that occur. In the ecological system, there is a relationship between turbidity sedimentation, deposition, and changes in river flow which are interrelated with each other and causes a decrease in the quality and area of forests, swamps, rivers, river estuaries, and the sea, which in turn disrupts the flow of biota migration, hunting areas, fishing areas, and sago forest

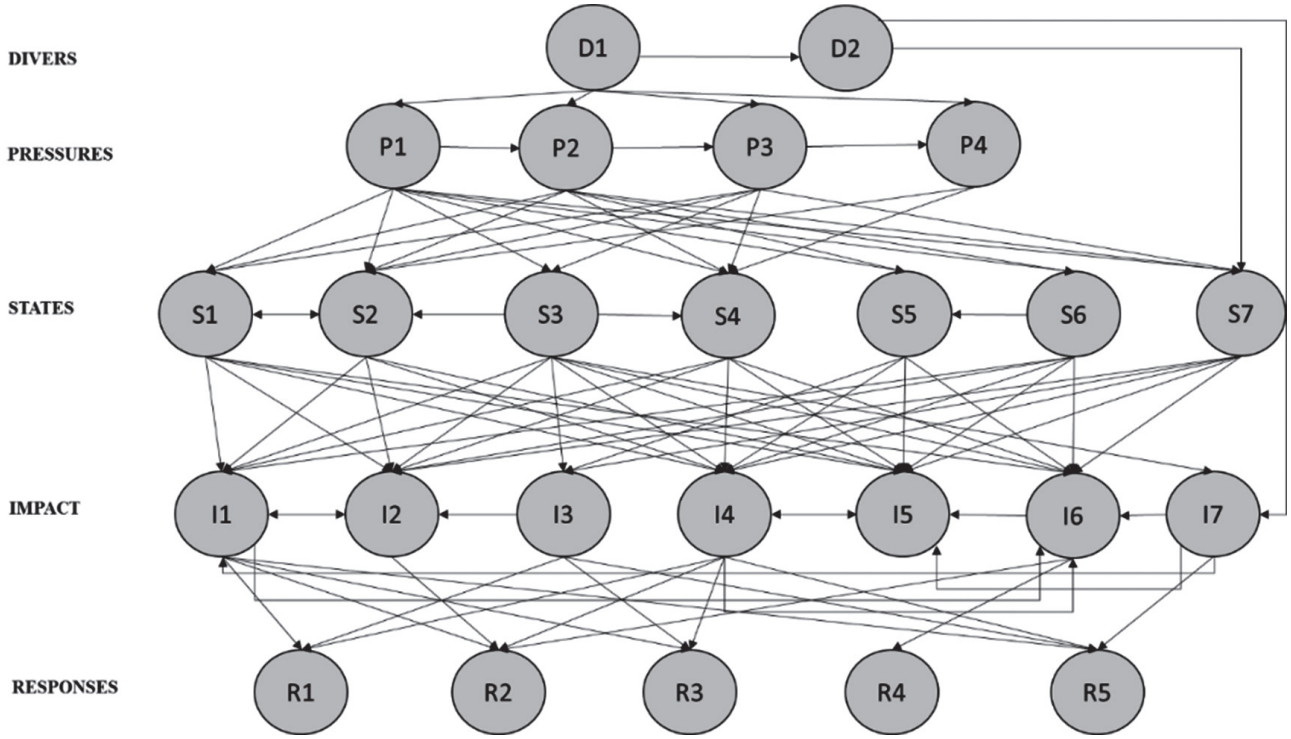

Figure 4. The complex system and impact network of Tailings in the East Coast District area of Mimika Regency

land. In simple terms, the complexity and network of SES in the Tailings-affected area of the coastal area of Mimika Regency are presented in Figure 4. below.

The entities from the SES network at the research site can be seen in Table 1.

SES relationship patterns usually form different dependency and related relationships. According to Anderies et al. (2004), the pattern of connectivity that occurs in coastal areas not only has a positive impact on each other but also harms the community and its coastal and marine resources. This SES analysis is carried out descriptively by presenting qualitative data in graphs or tables. Analysis of the SES connectivity network in the eastern coastal area of Mimika Regency was carried out by referring to the connectivity pattern according to Anderies et al. (2004), while the connectivity analysis was carried out graphically and discussed descriptively and triangulated.

The results of the social-ecological system analysis show that environmental damage due to tailing waste disposal is increasing and unavoidable and the impact can only be minimized. In such conditions, communities need to adapt to reduce their vulnerability. Ironically, the programs developed by the regional government and PT Freeport, especially for the Kamoro tribe community, tend to pamper the community with aid programs that make the community very dependent on assistance from the regional government and PT Freeport Indonesia.

5. Conclusion and recommendation

Tailings waste using the ModADA system, which flows through the Ajkwa river, and the closure of certain areas around the Aijkwa river causes a systematic impact on SES conditions in the East Coast District, Mimika Regency. These conditions have caused pressure on the function and degradation of the surrounding ecosystem. The increase in sediment and turbidity into swamps, rivers, and seas causes people to lose hunting areas, fishing areas, sago forest areas, seawater intrusion, loss of clean water, and disturb the natural beauty around them. As a result, people experience decreased income, health problems, and community anxiety and apathy that can trigger conflict and crime in the community.

The SES connectivity system has systematically caused a chain of problems that causes various problems that, if not appropriately managed, will lead to increasingly serious problems. The most dominant connectivity system on the East Coast District Mimika Regency is related to livelihood networks, health, and community perceptions of related parties with existing conditions. Seeing the real conditions, the Regional Government and PT. Freeport Indonesia needs to repair the damaged environment and develop programs that can make the community more independent to be able to adapt to environmental changes that occur.

Table 1. SES net entities and factual conditions in the eastern coastal area of Mimika Regency

Component	Condition
Ecological Aspect	
1. The area of land forest, sago forest, and mangrove areas keep reducing due to river runoff that carries sediment and tailings waste from mining activities with the ModADA system that occurs in all eastern coastal villages.	Very high
2. Increased turbidity in rivers, swamps, estuaries, and the sea is due to sediment and tailings waste into the waters of all eastern coastal villages.	Very high
3. Sedimentation causes turbidity, decreases water quality and death of biota, and causes changes in spawning ground, nursery ground, and fishing ground areas.	High
4. Rise in river water levels due to sedimentation and tailings deposition, especially in the estuary, which has an impact on villages such as those found in Ohotya and Otakwa villages	Medium
5. Seawater intrusion is due to the destruction of the mangrove ecosystem as a buffer and the availability of water as a source of clean water in Ohotya and Otakwa Villages.	Medium
Social Aspect	
1. The ethos of trying and working is low (judging by the number of days at sea or in the garden). All people generally have a low work ethic. This condition is also caused by the socio-cultural needs of the people who are still traditional.	Very high
2. The constraints of markets and the marketing of products are due to accessibility factors. Limited market access is an obstacle experienced by almost all coastal villages in the east, except for the villages of Koperapoka and Nawaripi, which are relatively accessible by land transportation. In addition, the two villages enjoy bus transportation facilities provided by PT. Freeport. Meanwhile, people can reach some villages, such as Ohotya, Omawita, and Fanamo villages only by speed boat via river and sea.	Very high
3. The mastery of technology, especially the processing of fishery products, is very low. It is rarely occupied if there is only in the form of salted fish processing. Fishermen in the eastern coastal area, as in general, indigenous fishermen in Papua, are still classified as subsistence fishermen. The scale of the business is still subsistence. Especially for fishing activities, the community still uses simple fishing gear such as canoes, fishing rods, nets, and gates to catch crabs.	High
4. The dependence of fishing on natural conditions, such as during the rainy season, fishing activities are practically stopped due to flooding, while at sea at the same time, there is a wave season, so fishing activities are abandoned. In a season like this, people switch to gardening activities.	High
5. Agriculture or plantations are difficult to develop because they are generally swampy, so there is no agricultural business, especially for long-term crops, except for coconut, areca, and vegetable gardens.	Medium
6. The scale of the business is still subsistence. Especially for fishing activities, the community still uses simple fishing gear such as canoes, fishing rods, nets, and gates to catch crabs.	Very high
7. Lack of guidance, counseling, and assistance supports businesses so that the community does not have the understanding and views related to business development that can improve their standard of living.	High
8. Alternative livelihoods are still low, although opportunities are very high. This condition is also caused by the lack of counseling and the lack of supporting facilities and infrastructure.	
9. People's dependence on staple foods from outside, especially rice, is because people's consumption patterns have changed from sago to rice and instant food. Meanwhile, people have not developed sago as a staple food source. Although in some kampongs, PT. In cooperation with the State University of Papua, Manokwari, Freeport introduced local sago species from outside the region, a type of sago from Sentani Jayapura.	High
10. The level of public education is low. This condition is caused by the lack of existing educational facilities and infrastructure. Even in some villages, only elementary school education is available. Worse yet, the school is still limited in teaching staff (teachers). There are even some schools that are only served by 2-3 teachers.	Medium
11. The level of public health is low. This condition is caused by the limited personnel and existing health facilities. The health facilities generally found in every village are the Integrated Service Centers that only serve health problems such as malaria, coughs, and skin diseases and help pregnant women give birth. Meanwhile, serious illnesses must be referred to outside the village or the Mimika Regency capital in Timika.	Medium
12. Community conflicts with the government regarding development assistance programs in villages are indicated in almost all existing villages. Conflicts between communities regarding island ownership occurred in Ohotya village.	Medium
13. Low community participation in intervention programs carried out by PT. Freeport as well as by the Regional Government. This condition is more or less caused by the lack of socialization and involvement in development planning, as well as the lack of coordination between the local government and PT. Freeport includes programs in the fields of education, health, fisheries, etc.	High
14. The Taparu system has begun to degrade, so it needs to be revitalized, especially in strengthening customary rights. The degradation of the Taparu system is one of the causes of ownership conflicts, both conflicts over fishing grounds and ownership of ulayat rights.	Medium

Source: Processed from Interviews and FGDs

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Authors' Contributions

The contributions of each author are as follows, Paulangan and Arsyad and Lukitoo collected the data, Barapadang and Tangkelayuk helped draft the manuscript, and Hisyam helped in designing the images and maps. The authors drafted the main conceptual ideas, discussed the results, and contributed to the final manuscript.

Conflict of Interest

The authors declared no competing interests.

References

Amin S.A.A.M., 2015, Analisis Social Costs Pada Pembuangan Limbah Tailing PT Freeport Indonesia di Sungai Ajkwa. Jurnal Ilmiah Universitas Bakrie 3(1).

Anderies J.M., Janssen M.A., Ostrom E., 2004, A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society 9(1), 18. [online] URL: http://www.ecologyandsociety.org/vol9/iss1/art18

Ballard C.H., 2001, WWF, Retrieved April 11, 2017, from Freeport mine: http://wwf.panda.org/what_we_do/where_we_work/new_guinea_forests/proble ms_forests_new_guinea/mining_new_guinea/papua_freeport_mine/

Berkes F. & Folke C., 1998, Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge Univ. Press. Cambridge

Berkes F., Folke C. & Colding J., 2000, Linking social and ecological systems for resilience and sustainability. Beijer Discussion Paper Series 52: 18–27. https://doi.org/10.5751/es00202-040205.

Berkes F., Folke C., Colding J. (eds.), 2003, Linking social and ecological systems: management practices and social mechanisms for buiding resilience. Cambridge University Press. UK.

Bradley P. & Yee S., 2015. Using the DPSIR Framework to Develop a Conceptual Model: Technical Support Document. US Environmental Protection Agency, Office of Research and Development, Atlantic Ecology Division, Narragansett, RI. EPA/600/R-15/154.

Costanza R., 1999, The ecological economics and social importance of the oceans. Ecological Economics 31(2): 199–213.https://doi.org/10.1016/s0921-8009(99)00079-8

Costanza R., Low B.S., Ostrom E. & Wilson J., 2000, Institutions Ecosystems and Sustainability. Lewis Publisher. Washington (USA). https:// doi.org/10.1016/ s09218009(02)00132 -5.

Dearing J.A., Acma B., Bub S., Chambers F.M., Chen X., Cooper J., Crook D., Dong X.H., Dotterweich M., Edwards M.E., Foster T.H., Gaillard M.J., Galop D., Gell P., Gil A., Jeffers E., Jones R.T., Krishnamurthy A., Langdon P.G., Marchant R., Mazier F., McLean C.E., Nunes L.H., Raman S., Suryaprakash I., Umer M., Yang X.D., Wang R. & Zhang K., 2015, Social-ecological systems in the Anthropocene: the need for integrating social and biophysical records at regional scales. The Anthropocene Review, p. 1–27. Doi: 10.1177/2053019615579128

European Environment Agency [EEA], 1999, Environment in the European Union at the turn of the century. Environmental assessment report No. 2. Luxembourg, European Environment Agency, Office for Official Publications of the European Union. https://www.eea.europa.eu/publications/92-9157-202-0-sum

Folke C., Biggs R., Norström A.V., Reyers B. & Rockström J., 2016, Social-ecological resilience and biosphere-based sustainability science. Ecol Soc 21(3), 41. http://dx.doi.org/10.5751/ES-08748-210341

Gillson L. & Marchant R., 2014, From myopia to clarity: Sharpening the focus of ecosystem management through the lens of palaeoecology. Trends in Ecology and Evolution 29: 317–325. Doi:10.1016/j.tree.2014.03.010

Glaser M., Glaeser B., 2010, Global change and coastal threats: The Indonesian case. An attempt in multilevel social ecological research. Human Ecology Review 17(2):135-147.

Jackson S.T., Betancourt J.L., Booth R.K. & Gray S.T., 2009, Ecology and the ratchet of events: Climate variability, niche dimensions, and species distributions. Proceedings of the National Academy of Sciences US 106 (supplement_2): 19685–19692. https://doi.org/10.1073/pnas.0901644106

Jayaputra A., 2012, Mimika Community Dinamics of Social Resilience in Perspective. Informasi 17(3): 165–176.

Kanwar P., 2018, Ecological risk in the anthopocene: an evaluation of theory, values, and social construct. Encyclopedia of the Anthropocene 4: 367–372. https://doi.org/10.1016/ b978-0-12-809665-9.10487-2

Kemong B., 2014, Sistem mata pencaharian hidup nelayan tradisional sukubangsa Kamoro di desa Tipuka Kecamatan Mapurujaya Kabupaten Mimika Propinsi Papua. Holistik 8(14): 1–19.

Levin S., Xepapadeas T., Crépin AS., Norberg J., De Zeeuw A., Folke C., Hughes T., Arrow K., Barrett S. & Daily G., 2013, Social-ecological systems as complex adaptive systems: Modeling and policy implications. Environ Dev Econ 18: 111–132. Doi:10.1017/S1355770X12000460

Liu J., Dietz T., Carpenter S.R, Alberti M., Folke C, Moran E., Pell A.L., Deadman P., Kratz T., Lubchenco J., Ostrom E., Ouyang Z., Provencher W., Redman C.L., Schneider S.H. & Taylor W.W., 2007, Complexity of coupled human and natural systems. Science 317: 1513–1516.

Muhadjir N., 2011, Metode Penelitian. Yogyakarta. Rake Sarasin.

Mulyadi M., 2010, Pengaruh Program Pemberdayaan Masyarakat terhadap Penanggulangan Kemiskinan di Kabupaten Mimika Provinsi Papua (Studi pada Suku Kamoro di Kabupaten Mimika), Jurnal Kajian 15(1): 29–58. Doi: 10.22212/kajian.v15i1.378

Ostrom E., 2009, A general framework for analyzing sustainability of social-ecological systems. Science 325(80): 419–422. https://doi.org/10.1126/ science.1172 133

Parametrix, 2002a, Aquatic Ecologikal Risk Assessment. Prepared to PT. Freeport. Final Report 1, P 33.

Parametrix, 2002b, Human Health Risk Assessesment. Prepared to PT. Freeport. Final Report. 2, 34. https://www.fcx.com/sites/fcx/files/documents/sustainability/audits/HHRA.pdf

Petrosillo I., Aretano R. & Zurlini G., 2015, Socioecological Systems, Reference Module in Earth Systems and Environmental Sciences. Elsevier 2015. 22-July-15. Doi: 10.1016/B978-0-12-409548-9.09518-X

Piragnolo M., Pirotti F., Guarnieri A., Vettore A. & Salogni G., 2014, Geo-spatial support for assessment of anthropic impact on biodiversity. ISPRS Int J Geo Inf *3*(2): 599–618. https://doi.org/10.3390/ijgi3020599

Pouwer J., 2010, Gender, Ritual and Social Formation in West Papua: A Configurational Analysis Comparing Asmat and Kamoro. Leiden: KITVL Press.

PT. Freeport Indonesia, 2020, https://ptfi.co.id/id/riverine-tailings-management

Rockström J., Steffen W., Noone K., Persson A., Chapin FS., Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber HJ., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H, Sörlin S., Snyder PK., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P. & Foley J.A., 2009, A safe operating space for humanity. Nature 461: 472–475.

Rekolainen S., Kamari J. & Hiltunen M., 2003, A conceptual framework for identifying the need and role of models in the implementation of the Water Framework Directive, Intl. J. River Basin Management 1(4): 347–352.

Sidlea R.C., Benson W.H., Carriger J.F. & Kamai T., 2013, Broader perspective on ecosystem sustainability: Consequences for decision making. Proceedings of the National Academy of Sciences US. 110: 9201–9208. Doi:10.1073/pnas.1302328110

Solaiman A., 2018, Perempuan dalam Masyarakat Papua: Suku Kamoro dan Muyu. Jurnal Inada 1(2): 125–155. DOI: https://doi.org/10.33541/ji.v1i2.906

Tebay S. & Manuputty A., 2017, Kearifan Lokal Suku Kamoro dalam Pemanfaatan Sumberdaya Perikanan di Distrik Mimika Timur Jauh Papua. Prosiding Simposium Nasional Ikan dan Perikanan, p. 989–998. http://iktiologi-indonesia.org/wp-content/uploads/2019/04/Selvi-Tebay-989-998-resize.pdf

Virapongse A. & Alessa L., 2016, A social – ecological systems approach for environmental management. Journal of Environmental Management. 178, 8391. https://doi.org/10.1016/j.jenvman. 2016.02.028

Wahana Lingkungan Hidup Indonesia [WALHI], 2006, Dampak Lingkungan Hidup Operasi Pertambangan Tembaga dan Emas Freeport-Rio Tinto di Papua. Jakarta. P.119. https://newberkeley.files.wordpress.com/2017/03/dampak-lingkungan-hidup-operasi-pertambangan-tembaga-dan-emas-freeport-rio-tinto-di-papua.pdf