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Identification of Water Pollution Sources and Their Impact on the Sagea River Waters in the Central Halmahera Mining Area

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A B S T R A C T

The Sagea River in North Weda District, Central Halmahera Regency, has an important role as a source of clean water, fisheries, irrigation, and support for people's lives. However, traditional gold mining activities (gold trays) have the potential to cause pollution that has an impact on water quality and human health. This study aims to identify the source of pollution in the Sagea River due to the activities of local miners. The method used is a quantitative-qualitative research with a field survey based on a model receptor. Sampling refers to SNI 6989.59:2008, was carried out in two seasons at three points (upstream, middle, downstream), and analyzed descriptively and using ANOVA. The results of the PCA analysis show two main components of pollutants, namely the domestic waste of miners as the dominant source of biological pollution and tailings mixtures and human activities. This study concludes that the Sagea River experiences significant biological pollution, especially in areas of gold tray and downstream activity, and confirms the effectiveness of PCA and CMB in identifying sources of pollutants.

INTRODUCTION

Sagea Village is one of the villages located right on the banks of the Sagea River, North Weda District, Central Halmahera Regency, North Maluku Province, with a population of 1,317 people (Results of interviews with the government of North Weda District, 2025). The Sagea River is the main river that has long been needed by the local community for their living needs (Lestari et al., 2020), such as drinking, washing, cooking and as a source of clean water, fishery habitats, transportation routes, agricultural irrigation, and karst-based ecotourism that supports the lives of local communities (Brahmantyo & Bandono, 2018). River pollution not only impacts water quality, but also on human health (WHO, 2017). Therefore, a comprehensive study is needed to identify the source of pollutants due to mining activities in the Sagea River watershed.

The Sagea River is one of the important rivers in Central Halmahera Regency, North Maluku. However, in recent years, the intensity of nickel mining activities and small-scale gold mining activities (gold trays) by communities around watersheds (watersheds) has increased rapidly (Widiyanto et al., 2020). Residents of Sagea Village and its surroundings have experienced a clean water crisis since the Sagea River was polluted by mining activities in 2023, so they no longer consume river water for fear of getting sick (DLH Central Halmahera, 2023).

This activity has the potential to cause degradation of water quality (Adriyani et al., 2017), through an increase in suspended solids (TSS), turbidity, heavy metals (Hg, As, Fe, Mn), and changes in river morphology (Yuliastuti et al., 2021). Based on the results of interviews with the North Weda sub-district government, the activities of several mining companies operating in the upper part of the Sagea River in August 2023 caused the Sagea river to change color to blur (Cloudy), so that the residents of Sagea Village experienced a clean water crisis since the river was polluted. According to the Central Halmahera Environment Agency (DLH, 2023), it was said that the Sagea river in Central Halmahera was polluted through a change in color to a cloudy brown, so that at that time the community experienced a clean water crisis.

Water pollution in the Sagea River not only has an impact on the quality of aquatic ecosystems (WHO, 2017), but also on the health of people who use the river as a source of drinking water and fish consumption (Widiyanto et al., 2020). Identification of pollution sources is very important to be carried out so that the relative contribution of each activity, both mining, agriculture (Alloway, 2013) and settlements, to the burden of pollutants in river waters (Lestari & Trihadiningrum, 2019).

Pollution of the Sagea River occurs not only due to large-scale mining activities but also small-scale mining activities such as local mining activities (gold trays) carried out by the community and natural factors such as heavy rains and karst rock formations. According to PT IWIP (2023), the results of laboratory investigations show that water quality still meets environmental quality standards, and water turbidity is more caused by natural factors such as heavy rain and karst rock formations, not by mining activities. In addition, deforestation occurs in the upstream area of the Sagea River watershed, which is suspected to be the cause of turbid river flows and ecosystem damage.

Mining activities, both large and small-scale, have the potential to increase the burden of pollutants in the form of heavy metals (Hg, As, Fe, Mn), suspended solids (TSS), and turbidity, as well as change the morphology of rivers. On the other hand, agricultural, residential, and tourism activities also contribute to pollution through domestic waste and pesticides. This condition has implications for water quality, public health, and the sustainability of aquatic ecosystems.

By looking at the breadth of this study, this study is limited to identifying the sources of pollution and community activities in the Sagea river. Therefore, the purpose of this study is to identify the source of pollutants that affect the water quality of the Sagea River and analyze community activities that result in pollution in the Sagea river, Central Halmahera. It is hoped that this research can provide scientific information about the condition of water quality of the Sagea River, the main source of pollutants, and its impact on biota and the surrounding community, and the results of the research can be the basis for the formulation of sustainable water resource management strategies and pollution control in the Central Halmahera mining area.

THEORETICAL REVIEW

Environmental pollution is the entry of living things, substances, energy or other components into water so that it exceeds the environmental quality standards that have been set (Law of the Republic of Indonesia No. 32 of 2009).

H1: Sources of Pollutants: There are sources of pollution from mining activities that contribute to the decline in water quality of the Sagea River. If mining activities produce tailings, runoff, or sediment towards the river, then the value of water quality parameters such as TSS, heavy metals (Fe, Mn, Hg), or turbidity will increase compared to the quality standards. This hypothesis was tested by mapping the source points of pollutants and measuring water quality at several river points.

H2: Pollutant Impact: Water pollution due to mining activities has a significant impact on the condition of river ecosystems, as shown by changes in water quality parameters that exceed quality standards and potential disturbances to aquatic biota. If the water measurement results show that the pH is decreasing, the DO is decreasing, or heavy metals are increasing, it will affect aquatic life such as fish that are more sensitive to changes in water quality.

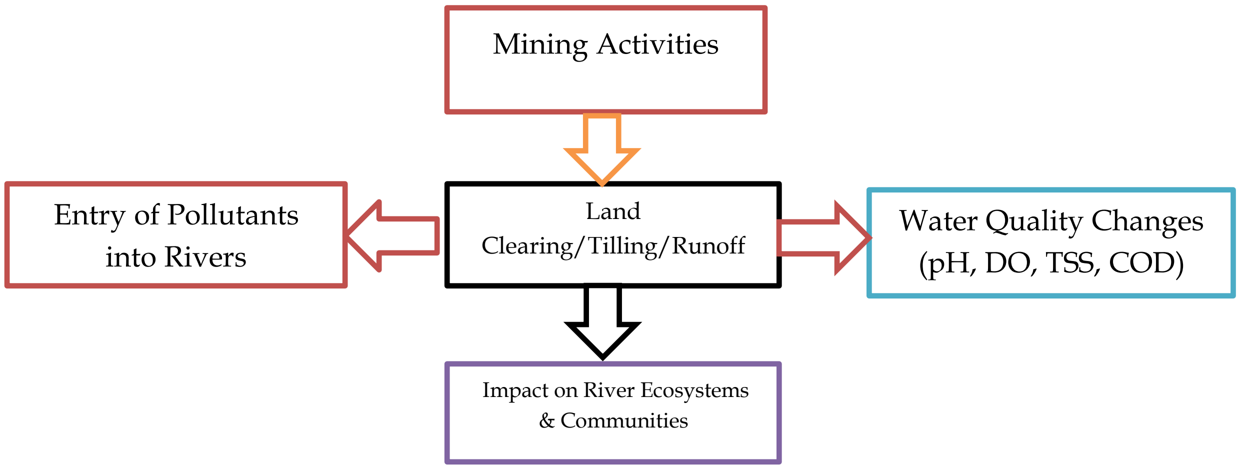

Figure 1. Conceptual Framework

METHODOLOGY

This research was carried out along the Sagea Watershed, North Weda District, Central Halmahera Regency, North Maluku which was carried out from January to July 2025. The selection of the location is based on the importance of the Sagea River as a source of clean water, biota habitat, and high community activity around the watershed. Data collection was carried out in two seasons, namely the dry season (to see the condition of water quality at the minimum discharge, with concentrations of pollutants tending to be more concentrated), and the rainy season (to see the influence of surface runoff and the distribution of pollutants due to increased water discharge). This two-season approach is important in order to obtain a picture of the temporal (seasonal) variability of pollution.

The Data Collection Method is carried out through water quality measurement with three indicators, namely physical parameters, namely temperature, turbidity, and TSS. Chemical parameters are pH, DO, BOD, COD, heavy metals (Hg, As, Fe, Mn) and biological parameters are with plankton indicators, microorganism indicators.

The second data collection method is observation of community activities conducted through interviews with the North Weda sub-district government and the head of Sagea Village, and direct observation of mining, agriculture, and settlement activities. The secondary data used is water quality data from DLH Central Halmahera. The research data was analyzed using:

1. Descriptive statistics to determine the status of water quality based on the quality standards of Government Regulation No. 22 of 2021.
2. PCA (Principal Component Analysis) is used to identify the dominant factors contributing to pollutants.
3. Spatial-Hydrological Analysis (GIS): mapping the location of pollutant sources and their distribution along river flows.

RESEARCH RESULTS

Sources of Sagea River Water Pollution

The results of descriptive statistical analysis of pollutant sources and water quality status by referring to water quality standards PP No. 22 of 2021.

Variable data (color, taste, substrate, topography, organisms, and sources of pollutants) were analyzed qualitatively to determine the status of water quality at three location points, namely Upstream, Middle, and Downstream. The results of descriptive statistical analysis can be presented in Table 1 below.

Table 1. Results of descriptive statistical analysis of pollutant sources

Main Components (PCs)	High Loading Variable	Interpretation of Dominant Factors	River Location	Water Quality Status (PP No. 22/2021)
PC1 (Water Quality & Human Activity)	Water color, water taste, mining activities, waste, agriculture	Showing degradation of water quality due to human activities (gold trays, sewage disposal, domestic)	Middle & Downstream	Does not meet Class II quality standards (water for recreation, fisheries, irrigation). High TSS, heavy metal potential.
PC2 (Physical Condition of the River)	Substrate (mud, sand), river topography	Geomorphological characteristics influence sedimentation & distribution of pollutants	Upstream (mud, 3–6 m) & Downstream (sand, 2–3 m)	Classes II–III. The upstream is still clear (quite good), the downstream is affected by sediment and solid waste.
PC3 (Ecology Biotics)	Organisms (fish, bamboo, trees, cultivated plants)	Response of aquatic ecosystems to pollution pressures	All locations, most affected Central & Downstream	Decline in biodiversity. Upstream is still functioning well (Class II), Middle-Downstream shows ecological pressure (towards Class III).

Based on Table 1, it can be stated that the interpretation based on Government Regulation No. 22 of 2021 is that at the upstream point the water quality status is relatively good, Class II → can still be used for fisheries, water recreation, and irrigation. However, indications of mud and tourist activities need to be controlled. At the Middle Point, the water is cloudy due to local mining activities and waste without treatment. It does not meet Class II quality standards, tends to enter Classes III-IV (more for agriculture or water transportation), and at the Downstream/Estuarine point, it is affected by domestic waste, garbage, and community activities. Class III status, because the water quality is no longer suitable for consumption or recreation, only for agriculture or limited industrial purposes. This suggests that the dominant pollutant factors come from human activities (PC1), especially manual gold mining and domestic waste disposal.

Results of the Identification of Dominant Factors of Pollutant Contributors

Identification of Dominant Factors Pollutant contributors were analyzed using PCA (Principal Component Analysis) and the results are presented in Table 2 below.

Table 2. PCA Interpretation Table Identification of Pollutants in the Sagea River

Main Components	Variable with High Loading	Interpretation of Dominant Factors	Location of Affected Rivers
PC1 (Water Quality & Human Activity)	Water color (clear/cloudy), pollution causative factors (mining activities, waste, plantations), taste of water (fresh/brackish)	Describe the degradation of water quality due to human activities (manual gold mining, sewage disposal, agriculture, domestic activities)	Middle (cloudy due to mining) and Downstream (slightly cloudy due to domestic waste & garbage)
PC2 (Physical Condition of the River)	Type of substrate (muddy, sandy, sandy), topography/river slope	Represent the geomorphological characteristics of the river that affect the sedimentation & distribution of pollutants	Upstream (muddy, topography 3–6 m) and Downstream (sandy, topography 2–3 m)
PC3 (Ecology Biotics)	Types of organisms (fish, bamboo, trees, cultivated plants)	Reflecting the response of aquatic ecosystems to pollution pressures (diversity is still maintained upstream, declining in the middle & downstream)	All locations, but the impact is most visible in the Middle & Downstream

PC1 is the dominant factor as the main pollutant sourced from human activities (mining, waste, domestic activities). PC2 is a natural factor (substrate & topography) that affects the distribution of sediments and heavy metals. PC3 is describing the ecological impact on organisms living in the Sagea River watershed.

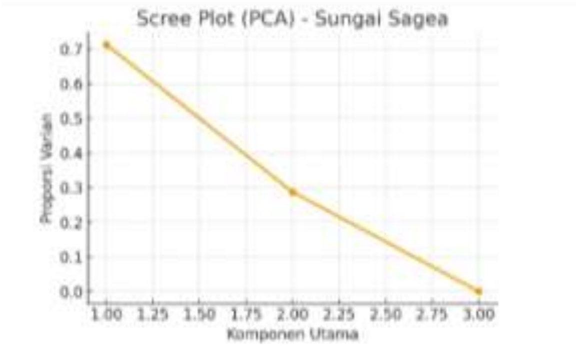

Figure 2a.

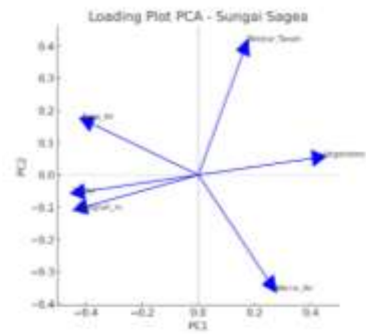

Figure 2b

Figure 2. PCA graph of Sagea River dataResults of Mapping the Location of Pollutant Sources and Their Distribution Along the Sagea River Flow using (GIS) Spatial-Hydrological)

Mapping the Location of Pollutant Sources and Their Distribution Along the River Flow

Mapping of Pollutant Source Locations and Distribution Along Rivers using PCA and the results can be seen in the following Figure.

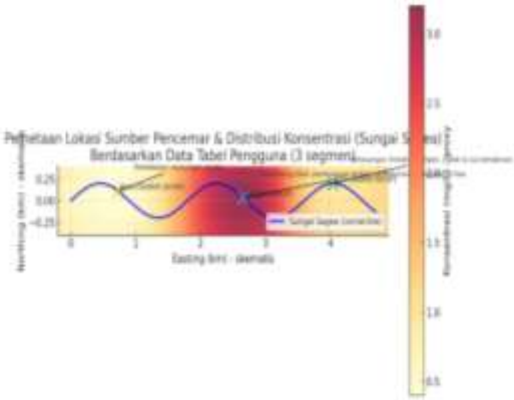

Figure 3a.

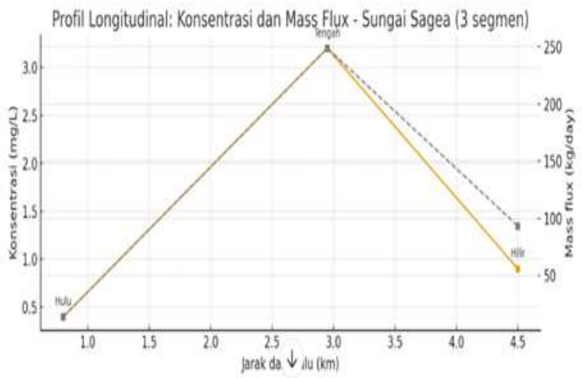

Figure 3b

Figure 3. Mapping the location of pollutant sources and their distribution based on three points (Upstream, Central, Downstream).

PC1 explains the dominance of polluting factors due to human activities, especially traditional gold mining, household waste, and agriculture. The most affected locations are in the middle point where the water is cloudy due to mining and at the downstream point where the water color is slightly cloudy due to domestic waste and garbage.

DISCUSSION

Spatially, water quality has decreased from Upstream → Central → Downstream. Based on Government Regulation No. 22 of 2021 Upstream: Class II (quite good), Middle: Class III-IV (heavily polluted) and Downstream: Class III (moderately polluted). Community activities in the upper reaches of the Sagea

River in the form of plantation activities indicated by the use of chemical fertilizers and pesticides cause an increase in nutrients (nitrates, phosphates) to the river body, triggering eutrophication. Furthermore, tourism activities in the form of ecotourism in Boki Maruru Cave, in the form of bathing, recreation, increasing the potential for solid waste (plastic waste, organic) and detergents. This has an impact in the form of organic and sediment loads. According to Effendi (2003), agricultural waste such as fertilizers and pesticides can pollute waters through surface flows (run-off), while unmanaged tourism activities add to the burden of domestic pollutants.

Activities carried out by the community at the Middle Point of the Sagea River, namely traditional gold mining activities (manual trays) so as to increase suspended sediment (TSS) and water turbidity, as well as the potential to release heavy metals (Hg, As) into the river. In addition, the community also disposes of domestic waste without treatment in the form of washing water, detergents, organic waste, and plastic directly into the river. Furthermore, fishing activities that mostly use unenvironmentally friendly methods (chemicals or stun guns). Some of these activities have an impact on the Sagea river watershed and the surrounding environment, namely murky water, increased heavy metal content and organic load, and decreased aquatic biota diversity. According to Sitorus et al., (2020), small-scale gold mining (ASGM) activities in Indonesia often cause an increase in TSS and heavy metal pollution, while untreated household waste is the main source of organic pollution in rivers (Ministry of Environment and Forestry, 2021).

Community activities at the Downstream/Estuary point of the Sagea River, the community makes the downstream area a center for the disposal of waste and community waste in the form of solid waste (plastic, organic) and domestic liquids that accumulate downstream. Domestic activities such as toilets and vehicle washing can increase the burden of organic pollutants such as BOD, COD, coliform) and oil/oil. Transportation and activities around long bridges contribute to inorganic pollution such as metals, plastics, and hydrocarbons, which directly cause impacts in the form of brackish and slightly cloudy water, causing the quality of aquatic habitats to decrease, and increasing the risk of disease for the community. According to Barus (2004), domestic activities in the form of toilets and waste disposal are the main contributors to biological pollution in waters, while transportation and urban activities increase hydrocarbon and heavy metal contamination (Widiyanto & Hartono, 2019).

Based on main component 1 (PC1 – Water Quality & Human Activities), it explains the dominance of pollutants due to human activities, especially traditional gold mining, household waste, and agriculture. The most affected locations: central (cloudy due to mining) and downstream (slightly cloudy due to domestic waste & garbage). According to Sitorus et al. (2020), small-scale gold mining (ASGM) activities significantly increase turbidity and heavy metal loads, while the Ministry of Environment and Forestry (2021) reported that domestic waste is the main contributor to river pollution in Indonesia.

Main Component 2 (PC2 – Physical Condition of the River). PC2 describes the geomorphological conditions of rivers, which play an important role in the distribution of pollutants. Upstream (muddy, topography 3–6 m) is more prone to erosion, while downstream (sandy, topography 2–3 m) is the location of accumulated pollutants. Effendi (2003) stated that the substrate and morphology of rivers greatly affect the capacity and transportation of pollutants in waters.

Key Component 3 (PC3 – Biotic Ecology), reflects the response of aquatic ecosystems to pollution stress. The upstream still shows high biodiversity of biota, but in the middle and downstream there is a decrease in the number and types of organisms due to increased polluting pressure. Barus (2004) emphasized that the diversity of aquatic biota can be used as a biological indicator of pollution, while Widiyanto & Hartono (2019) stated that the degradation of water quality is directly proportional to the decline in biodiversity.

According to Sitorus et al. (2020), small-scale gold mining activities (ASGM) significantly increase turbidity and heavy metal loads, while the Ministry of Environment and Forestry (2021) reported that domestic waste is a major contributor to river pollution in Indonesia.

PC2 is the physical condition of the river, which describes the geomorphological conditions of the river, which plays an important role in the distribution of pollutants. Upstream (muddy, topography 3–6 m) is more prone to erosion, while downstream (sandy, topography 2–3 m) is the location of accumulated pollutants. Effendi (2003) stated that the substrate and morphology of rivers greatly affect the capacity and transportation of pollutants in waters.

PC3 reflects the response of aquatic ecosystems to pollution stress. The upstream still shows high biodiversity of biota, but in the middle and downstream there is a decrease in the number and types of organisms due to increased polluting pressure. Barus (2004) emphasized that the diversity of aquatic biota can be used as a biological indicator of pollution, while Widiyanto & Hartono (2019) stated that the degradation of water quality is directly proportional to the decline in biodiversity. Thus, the dominant factor of pollutants (PC1) is human activities such as mining, domestic waste, and agriculture. The supporting factor (PC2) is the physical condition of the river in the form of substrate and topography. and ecological factors (PC3) are the response of biota that decline at the midpoint and downstream.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, it can be concluded that pollution in the Sagea river is influenced by community activities along the river flow. In the upstream, the main source of pollutants comes from plantation and tourism activities; in the middle, dominant of manual gold mining and untreated waste; Meanwhile, downstream, pollutants come from the disposal of domestic waste and garbage. PCA analysis shows that the dominant factors of pollutants are human activities that reduce water quality, the physical condition of rivers, and biotic ecological pressures. These findings confirm the importance of integrated management to maintain water quality and the sustainability of river ecosystems.

ADVANCED RESEARCH

Previous research has identified that mining activities in the Central Halmahera region, especially around the Sagea River, have led to a decline in water quality. However, previous research has only been limited to describing the source of pollutants and the direct impact on water quality. Further analysis has not been carried out on the extent to which these pollutants have an impact on aquatic ecosystems and the biota that live in them, especially fish, shrimp, and aquatic organisms that play an important role in the food chain. Therefore, it is recommended to conduct further research on Ecological Risk Analysis and Bioaccumulation of Heavy Metals in the Biota of the Sagea River Waters in the Central Halmahera Mining Area.

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