Yayu Indriati Arifin

ideas PUBLISHING

Geotourism,

A Solution to Environmental Pollution of the Artisanal Gold Mining

(Case Study of Tulabolo Village, Gorontalo)

Yayu Indriati Arifin
Geowisata, Solusi Pencemaran Lingkungan Pertambangan Emas Rakyat

Geotourism,
A Solution to Environmental Pollution of the Artisanal Gold Mining
(Case Study of Tulabolo Village, Gorontalo)

Yayu Indriati Arifin

Geotourism,
A Solution to Environmental Pollution of the Artisanal Gold Mining
(Case Study of Tulabolo Village, Gorontalo)

ideas
PUBLISHING

IP.010.03.2022

Geotourism, A solution to Environmental Pollution of the Artisanal Gold Mining (Case Study of Tulabolo Village, Gorontalo)

Yayu Indriati Arifin

First edition published in March 2022
by **Ideas Publishing**
Address : Jl. Ir. Joesoef Dalie No. 110 Kota Gorontalo
Email infoideaspublishing@gmail.com
Member of IKAPI No. 001/GORONTALO/14

P-ISBN: 978-623-234-239-2

Editor	: Mohamad Jahja Intan Noviantari Manyoe
Layout	: Siti Khumaira Dengo
Cover Designer	: Ilham Djafar

Table of Content

Preface

Gratitudes towards the presence of Allah Swt., were given by the author. With His Permission and power, the author can complete this book with the title ***Geotourism: A Solution to Environmental Pollution of the Artisanal Gold Mining (Case Study of Tulabolo Village Gorontalo)***. From the writing of this book, it is expected that readers will get insight into the dangers of mercury. More specifically on the problem of mercury pollution in Gorontalo Province. Jewelry in the form of gold is a special need that cannot be separated from everyday life. The high demand for gold materials makes gold mining a fairly profitable business. Doing mining legally needs to be done by meeting the procedural standards, in contrast to illegal gold mining whose procedures often ignore safety, health, and the surrounding environment. While ignoring standard procedures, illegal gold mining in Gorontalo Province continues to emerge.

In the writing of this book, the author has sought to provide factual data drawn from previous research and the results of data retrieval directly in the field. Nevertheless, this book still has some shortcomings that the author himself is not aware of. Therefore, the author is always willing to accept criticism and advice from all parties that can be used as a reference in the development of this book. Thank you to all the parties involved in writing this book from the beginning until finally it can be arranged. May God bless us all.

Gorontalo, March 2022
Writer

Acknowledgement

This research was supported by The Research Institute for Humanity and Nature (RIHN: a constituent member of NIHU), Project No. 14200102.

Chapter 1
Introduction

A. Mercury Problem in Gold Mining

Since ancient times, gold has been precious as an accessory used by humans [1]. Therefore, the activities of gold mining both legal and illegally continue rapidly in accordance with human population growth.

The following discusses the mercury problem in local gold mining in Gorontalo.

1. Impact of Mercury in Gold Mining on the Society and Environment

Legal gold mining is conducted in accordance with correct standard procedures. In contrast, illegal gold mining often ignores the procedures of safety, health and the impact to the surrounding environment [2]. One of them happened in the small-scale gold mining owned by local people.

One example of the consequences of neglecting aspects of safety, health and the surrounding environment is the Minamata tragedy in Japan in 1960 [3]. This tragedy was caused by the poison of methylmercury ($HgCH_3$) from fish that had been contaminated and consumed by people which resulted in 1.784 deaths [4]. This tragic event was the first incident that caused the world to realize the real dangers of mercury to human survival.

After the cease that occurred in Japan, the same case happened in Basra, Iraq. Basra cases caused 10.000 people lose their lives due to methylmercury [5]. Then followed again by the same case in Sweden and the USA [6].

To these days, there has not been found a method to cure victims of mercury poisoning. However, the process of prevention through environmental management and eliminating toxic mercury from the environment is being developed by experts.

One example of a case that occurred in Indonesia was the Buyak Bay incident which happened due to the massive use of mercury (Hg) in mining areas. Additionally, the easy access to buy mercury or they use the term "quick" has been seen as the major cause of the Buyat Bay incident.

Every investor or dealer who collects gold (gold ore) usually provides or sells mercury. According to Ismawati, mercury imports to Indonesia are closely related to gold prices (Figure 1.1) [7].

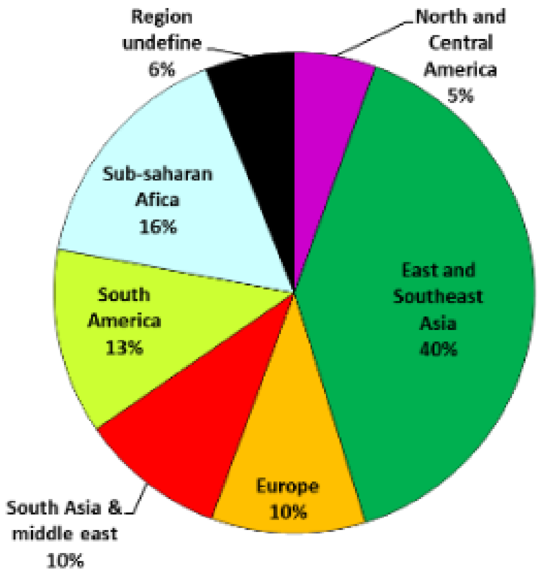

Figure 1.1 Graph of the Relationship between Mercury Imports and Gold Prices in Indonesia [8]

Local or small-scale gold mining is a complex problem and has been a problem on a global scale. According to UNEP data in 2013, nearly 40% of the region in the Eastern and Southeast Asian countries are the source of mercury pollution that comes from artisanal and small-scale gold mining. (Figure 1.2).

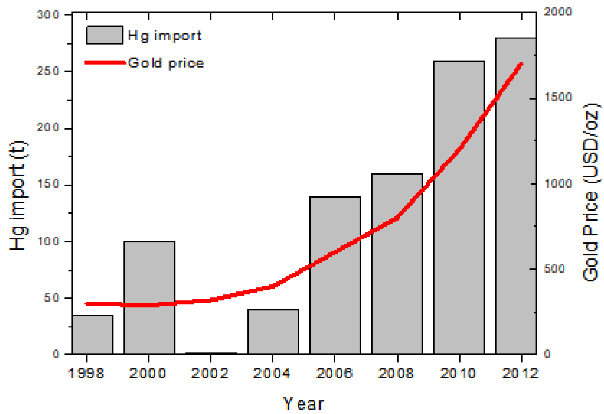

Figure 1.2 Mercury Emission in East and South Asian Countries are about 30 Percent fom Artisanal and Small-Scale Gold Mining

Local or small-scale gold mining is a complex problem and has been a problem on a global scale. The level of mercury pollution in the world that comes from small-scale gold mining is around 1.400 tons/year. Around 10—15 million miners (including 4—5 million women and children) which is about 12—15% produce gold every year [9].

Global mercury emissions increased by almost 20 percent in just five years (2000 to 2005). Mercury emission is a global problem because the pollution can spread without knowing the boundaries of countries or continents. The flow of mercury into the air can pass through the atmosphere before finally being precipitated back to the earth in the form of rainfall or gas.

In the world, the emission level of mercury pollution from small-scale gold mining is around 1400 tons/year. Around 10—15 million miners (including 4—5 million women and children) which is about 12—15% produce gold every year [10].

Mercury exposure has a negative effect on human health, namely the threat of toxic effects that cannot be prevented. One of the risks is the high impacts on the development of the fetus and child. Mercury pollution can also disrupt ecosystems and threaten wildlife.

2. Mercury in Gold Mining in Gorontalo

Indonesia is the second largest country that contributes to mercury pollution in the world after China [11]. Interestingly, the largest source of mercury pollutant in Indonesia comes from local gold mining compared to large gold mines which are usually owned by private companies.

Regions that already have problems with mercury in Sulawesi are Buyat and Talawan in North Sulawesi Province. The source of mercury pollution in this area comes from local community gold mining [12].

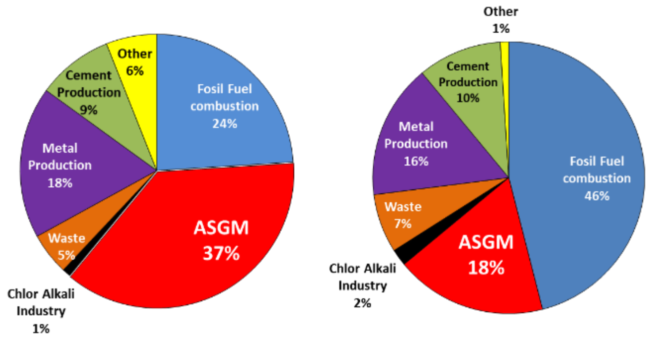

Figure 1.3 The Level of Mercury Pollution Emission

North Sulawesi is a province right next to Gorontalo Province. In the past, Gorontalo was part of North Sulawesi. Gorontalo then became a separate province from North Sulawesi in 2000. This was due to the regional expansion program.

Similar to North Sulawesi situation, in Gorontalo Province, there are many local gold mining. The people's gold mining is spread in the areas of Gorontalo Regency, North Gorontalo Regency, Bone Bolango Regency, Boalemo Regency and Pohuwato Regency.

a. Local Gold Mining in Buladu

One of the local's gold mining is located in Buladu District, North Gorontalo Regency. This mining has started operating during the Dutch colonial era around 1899. After the colonial periof eded or since 1970 to be exact, this mining was continued by the local people with adpted the model of Unlicensed Gold Mining (PETI). Based on data from the

BLH (environmental agency) of North Gorontalo Regency, in 2011, there were 500 miners in the area spreading in 4 tunnels and 40 vertical holes [13].

The local gold mining in Buladu uses mercury (Hg) of 1000 kg/month and the total gold production is around 8kg/month. The source of the data is from BLH North Gorontalo Regency.

Gold mining process is done in the traditional way, namely through the amalgamation process. This process allows mercury to be released into the environment at the washing and curing stages. The washing process causes waste that generally contains mercury to be dumped directly into water.

b. Local Gold Mining in Bone Bolango

The Bone River which is located in Gorontalo Province is the river with the biggest threat of mercury pollution. The report of Environmental Research and Development of Gorontalo Province in 2007 stated that the mercury (Hg) level in the Bone River was 0,022 mg/l (normally <0,002 mg/l). Research on mercury content in the estuary of the Bone River has exceeded the allowable threshold of 0,01489 mg/l (at low tide at the riverbed).

The main cause is the existence of traditional gold mining as a producer of mercury waste which is discharged into the Bone River. This mining activity existed even before Indonesia's independence, so it is feared that the chronic poisoning process in the community who uses the Bone River water source should be a serious concern. The problem is that the Bone River serves both domestic and major industrial needs as well as support aquatic life for all life in Gorontalo.

Pollution of the aquatic environment causes adverse health impacts for both humans and aquatic life. This is a good sign for sustainable development. Various pollutants such as lead, mercury, bacteria, protozoa, insecticides and inorganic materials can make water undrinkable [14].

Mercury available in water is taken up by microorganisms that undergo biomagnification, hence, it has a detrimental impact on aquatic life [15]. Each lead and mercury appears as the second and third hazardous substances according to the list of "The Top 20 Hazardous Substances" compiled by the Agency for Toxic Substances and Disease Registry (ATSDR) di Atlanta, Georgia [16].

c. **Mercury Problem in Tulabolo Village**

Tulabolo Village, located in Bone Bolango Regency, is a village bordering a national park, therefore, the local communities have been empowered through sustainable tourism-base activities by various parties, including the Gorontalo Provincial Tourism Office, Gorontalo Provincial Development Planning Agency, Bone Bolango Regency Government, the Office of Bogani Nani Wartabone National Park, study center of Universitas Negeri Gorontalo and international partners of SRIREP (Sustainable Regional Innovation for Reducing Environmental Pollution).

Other geological potentials in Tulabolo Village are abundant geothermal energy and small-scale gold mining. Gold mining in Tulabolo is divided into two, namely gold mining managed by the local community and gold mining managed by the company. Gold mining managed by the company legally and administratively was built as a contract area.

The contract system is used as a mining processing and utilization system or what is called a mineral agreement. The condition for the existence of a mining area is that the mineral content contained in the bowels of the earth has been identified. The purpose of this identification is for development, mining and utilization.

Local community's gold mining located in Nani Wartabone National Park, East Tulabolo Village, East Suwawa District, Bone Bolango Regency, is still using traditional tools as a method of harvesting gold which has a negative impact on local residents, especially in Suwawa Village and generally for the people of Gorontalo [17].

The access to the mining site is difficult because the location is far and the road to be traversed is extremely dangerous, therefore, miners who use motorbikes to the mining site prefer to walk. This is to anticipate if the circumstances such as landslides or muddy roads caused by heavy rain.

d. Mercury pollution on Nike, Gorontalo's Special Fish for Food

Nike is a fish that is consumed as food by the people of Gorontalo. Nike is classified in the Pisces class; sub-class Teleostei; Ordo Gobioidea; Famili Gobiidae; Genus Sadar; Spesies Awaousmelanocephalus Bleeker [18]. This fish has a transparent, colorless, and scaly body with a length of 2,5—3 cm and a depth of 3-5 mm.

The larvae float from upstream to river mouths and hatch in the sea to form juvenile groups. The fish caught at this juvenile stage in the last ten days of the lunar calendar are 99% juvenil Awaousmelanocephalus and the rest are juvenil Eleotrisfrusca [19].

Juvenile Nike fish migrate or return to their native rivers at the end of each fishing season before the new moon rises. In Gorontalo Province, Nike can be found in certain estuaries, which in the local language are called Milango. There are at least four estuaries: Milango Taludaa, Milango Hulondalo, Milango Paguyaman, and Milango Hulandalo which are the mouths of the Bone Bolango River in Gorontalo City. These estuaries have the largest stock.

Nike has been contaminated with mercury and has disrupted the aquatic ecosystem and can damage the Nike ecosystem itself. In addition, Nike which has been contaminated by mercury pollution can endanger the people who consume it [20].

Based on observations, the location of Nike's catching is heavily influenced on the level of mercury pollution. Samples that have high levels of mercury are samples taken near contaminated reefs far exceeding the maximum limit id mercury contamination in food permitted by the Indonesian National Standard (SNI 7387:2009) which is 0,5 ppm. The samples taken near the shoreline were all at low levels of contamination. The cause of the high mercury content in Nike near the reef is still unknown [21].

The mercury content in water samples taken on the seabed near the reed edge at the Nike fishing spot in Leato areas was 0,0017 mg/l, much higher than elsewhere at the same station exceeding the permitted water quality standard of only 0,001 mg/l as stipulated by the decree of the Minister of Environment (KEPMEN-LH No. 51, 2004). This seems to provide several reasons why the mercury content in samples taken near the reef edge is higher [22].

Heavy metals such as mercury tend to bind organic matter and settle on the seabed along with sediments, hence, the content of heavy metals in water on the seabed is higher than the content of heavy metals in surface water. Mercury enters fish through respiration, digestion or skin penetration. Mercury that enters the organism cannot be digested and dissolved in fat soluble, hence it can penetrate cell membranes and accumulate in cells in the organism's organs [23].

B. Literature Review

Geotourism as a Solution for Local People's Gold Mining in Gorontalo

Sustainable tourism is tourism that is developing well and continuously, including increasing the flow of accommodation capacity, community population, and the environment. The development of tourism and new investments in the tourism sector should not have a bad impact and be integrated with the environment. If maximized, it will give birth to a positive impact and minimize the negative impact.

The public sector takes several initiatives to regulate tourism growth for the better and places the issue of sustainable tourism as a priority because a good business or business can protect important resources or assets for tourism, not only now but in the future [24].

In the book on sustainable tourism, it is explained that tourism development must be based on sustainability criteria. This means that development can be supported ecologically in the long term as well as economically, ethically and socially fair to the community [24].

Geotourism is defined as a tourism activity that preserves or strengthens the geographical character of a place, its environment, beauty, heritage, and culture of its inhabitants, this concept was introduced by the American Travel Industry Association and the National Geographic which was gradually adopted by Hose [26]. Currently, there is a need to conduct intensive work on geodiversity, especially with reference to the following issues: laying the legal foundation for protection for geodiversity, such as geoparks and geosites. The use of geodiversity in geotourism can be based on environmental, economic and social characteristics. It is important to note that geosite damage is irreversible, therefore, it needs a maintenance process.

1. **Geotourism Potential Mapping**

   Mapping is one of the requirements for land use management, besides that mapping aims to provide information to the general public as long as it can be understood [27]. In general, mapping is done by mapping an area based on geographical conditions and layout of the house and so on. Geotourism potential mapping is conducted by mapping geological conditions, as well as tourist conditions and facilities in a geosite area. Mapping of geological conditions is done by mapping lithological conditions, geological structures and geomorphology in an area. Furthermore, mapping of tourism conditions and facilities is conducted by mapping and describing existing tourism conditions and facilities in the geosite location area. Mapping of tourist conditions and facilities in a geosite area aims to attract tourist to visit the geosite area [28].

2. Geotourism Potential in Gorontalo Province

The potential of tourism, especially Geotourism in Gorontalo Province, has been widely discussed by experts, and specifically, Idham et al., recently reviewed the potential for development towards Geoparks [29]. Additionally, the development of geotourism is considered necessary as one of the best solutions for alleviating poverty and environmental destruction through illegal extractive industries such as artisanal gold mining [30]. Geopark development efforts in Gorontalo Province have started marked by the research on the potential of Geosite in several regencies and cities. Furthermore, top-down efforts such as discussions with stakeholders conducted by the Provincial BAPPEDA and related agencies such as ESDM and Tourism continue to be conducted.

However, the approach of bottom-up efforts is greatly necessary considering that it is the local community who should be the driving force for this tourism activity. The active participation of the local community/Gorontalo Province in enjoying this geotourism is the main hope of tourist visits at this time, because the Covid-19 pandemic situation requires restrictions on tourist visits from other provinces and especially foreign countries.

3. Participation of Local Communities for Sustainable Tourism Development

The participation of local community who are not related to tourism activities is distinguished in a pyramid according to Kantsperger [31]. The pyramid is shown in the figure 1.4, where there are five levels of community participation from completely not participating to participating legitima-tely. By knowing the level of community involvement in the geosite, the government can make appropriate efforts to increase their level of participation.

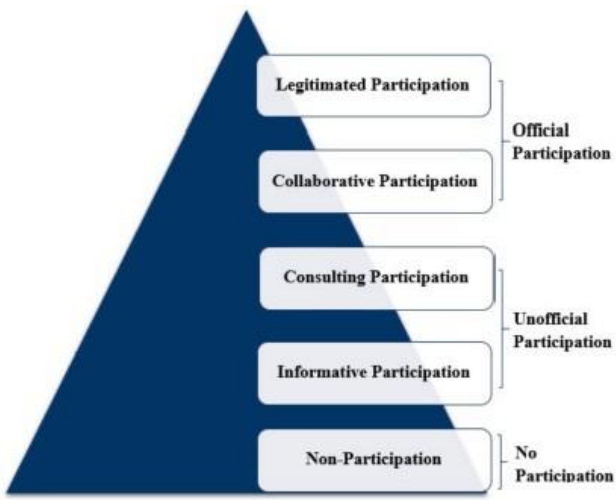

Figure 1.4 The Pyramid of Community Participation That is Not Related to Tourism Activity According to Kantsperger [31]

C. The Purpose of the Research

The study aims to identify health problems that occur in the community around the Bone River in case of mercury pollution and analyze health problems that occur in terms of biomedical and community characteristics around the Bone River, Gorontalo Province, and mapped spatially using a SIG-based mapping system [32].

The aims of this study are to examine mercury concentrations around mining sites and analyze mercury contamination in humans by measuring the mercury content in hair as well as conducting health checks on communities around the mine and in further research efforts are made to find solutions for communities around mining through Geotourism.

Therefore, this book describes in more detail about the gold mining process conducted and its effects on the mining environment and the surrounding community. At the same time, it actively searches for better solutions to the community and aims to provide alternative income expectations by utilizing the existing Geodiversity potential through Geotourism activities. It is hoped that through this activity, the community has alternative sources of other income, which in their activities minimize the risk of polluting the environment and endangering health, but still being able to get income to the needs of life.

D. Research Methodology Used

This research was conducted in the area around the Bone River located in the eastern part of Gorontalo, Indonesia. Artisanal's Small-scale Gold Mining (ASGM) activities is located in the upper reaches of the Bone River in the eastern of Gorontalo. This activity causes pollution of toxic metals to the environment and exposure to humans.

The exposure to the human body is proven by using bioanalysis by taking hair samples from miners and people living around the mining area. Hair samples in this study were taken from residents of three villages upstream to downstream along the Bone River which is one of the waste disposal sites from the mining area of Bone Bolango Regency, Gorontalo Province. The three villages are named Tulabolo, Poduoma, and Pangi.

The health effects of ASGM on miners and villagers were examined by collecting scalp hairs from communities living in the vicinity of the mining area. The strands of hair cut close to near the scalp were collected, put in a clear plastic bag, and labeled. The mercury content in hair was determined using proton-induced X-ray emission (PIXE) at Iwate Medical University, Japan, as reported in other articles [30,33,34]. This procedure is recognized as the standard method for hair analysis without as reported in previous studies [30,33–35].

In detail, the stages of sample preparation up to the stage of sample analysis can be explained as follows. First, the collected hair samples were immediately stored in zip-lock plastic bags and identified the names of the individuals. Seconds, sample preparation of human hair were washed with deionized water, a Sharp ultrasonic cleaner for five minutes to remove dust, bacteria, dirt, hair cosmetics, and other possible contaminants. After that, it was washed again with acetone (Wako Pure Chemical Industries, Ltd., Osaka, Japan) to remove adhering materials that did not purify the water. Next, the clean hair samples were dried in a ventilated oven at 40 celcius for 48 hours for analysis of particle-induced X-ray emission (PIXE) at the Cyclotron Research Center, Iwate Medical University, Japan. Analytical methods Particle-induced X-ray emission analysis (PIXE) was used to determine the concentration of toxic metals in human hair samples. For PICE analysis, eight pairs per person were plugged into the target holder, and irradiated with a proton beam of 2,9 MeV and energy from a cyclotron [23].

The widely accepted exposure limit values for mercury concentration in hair (μg/g) as suggested by the German Human Biological Monitoring Commission (HBM) as the following categories are adopted: concentrations (μg/g) below 1,0 are considered normal, 1,0−5,0 is considered an alert level, and above 5,0 is an indication of a serious risk of health effects.

Geodiversity potential analysis that will be used as geotourism using survey methods and field observations. This research included several stages, namely the preparation stage, field data collection, field data processing and report writing.

1. **Stages of Preparation and Preliminary Study**

   This preparation stage competes several requirements needed in the implementation of the final project and preliminary study. This stage deals with everything that needs to be prepared before leaving for the field, such as a permit letter addressed to the local government as a form of notification that research will be conducted in the area. Tools and materials are also borrowed at this stage, the tools borrowed are hammers, compasses and GPS.

   Preliminary study conducted in the form of literature study on matters related to research, namely literature studies from previous researchers. At this stage the interpretation of the topographic map is also conducted, which will then be used to obtain a general description of the geological and morphological conditions of the research area, hence, it can be used for trajectory planning and other field activities.

At this stage, a map is made in the form of a regional geological map that refers to the Tilamuta Sheet Regional Geological map with a scale of 1:250.000 by Bachri, et al. 1993. It is namely a mao of river flow patterns used for making tentative geological maps, maps of research locations, tentative geomorphological maps based on interpretation, the geomorphological units in the research area are volcanic hill units, denudational hill units and fluvial sediment units. Interpretation of tentative geological maps of rock units in the research area in the form of Volcanic Breccia units, Sandstone units and alluvial sediment units, these maps were modified from the Indonesian Earth Map with as scale of 1:25.000 Molombulahe Sheet 2216/33 published by the Geospatial Information Agency.

2. **Stage of Field Data Collection**

This stage is intended to obtain primary geological data to be analyzed and process the hypothesis in the previous stage. Data collection for the geological map of the research area begins at this stage. Field data collection includes the following:

a. Geomorphological observations, to determine the slope, valley shape, ridge shape, river genetic type, river stadia, controlling factors in the form of lithology and structure.

b. Outcrop observations, to determine the characteristics and types of lithology, distribution and thickness, depositional environment or formation and its relationship with other lithologies that can be observed in the field.
c. Geological structure observations, which include structural elements in the form of three-dimensional images that must be examined for type and measured for their position, whether they are considered as plane elements or line elements.
d. Rock sampling at each observation station which is then analyzed in the geology laboratory to determine the type of lithology, thickness and depositional environment.
e. Geodiversity observations, to determine places that have unique geological diversity and different from other areas as well as assessing the values of science, education, tourism and the risk of degradation in the research area.
f. Field sketches and documentation. The results of this are field data notes (outcrop descriptions, sketches, rock descriptions), rock samples, outcrop photos, track maps, geomorphological maps, temporary geological maps and assessment sheets of the

values of science, education, tourism and risk of degradation.

3. **Data Analysis and Processing Stage**

In this phase, data analysis and processing will be conducted in the laboratory. This data analysis and processing includes laboratory analysis and data processing studio. The analyzes conducted at this stage are the following:

a. Paleontological analysis, for age determination and depositional environment.
b. Petrographic analysis, to determine the composition of rocks and determine the type of lithology of the rock samples taken.
c. Sedimentological analysis, to determine the mechanism and environment of deposition.
d. Structural data analysis, to analyze the deformation that has occurred in the related area.
e. Analysis and determination of locations that have geodiversity potential, seen form the assessment of the values of science, education, tourism and the risk of degradation. At this stage, all the values of science, education, tourism and risk of degradation are summed and seen by the ranking of the research sites which consists of low, medium or high ratings.

At the end this phase, it is expected to produce as the following:

a. Map of geodiversity potential distribution in several Heosites of Gorontalo Province.
b. Written scientific reports regarding geological conditions and geological history as well as geological processes in the research area.

Chapter 2
Mining Pollution in Tulabolo

A. Impact of the Amalgamation Process on Human Health and the Environment

One of the processes to get gold in mining is the amalgamation process. The amalgamation process is a method used by mining in Indonesia in general, although this method is still fairly traditional.

The amalgamation technique is done by mixing rocks containing gold and mercury using a drum [36]. The following describes the stages of the amalgamation process in gold mining.

The initial processing is at the ore material processing site. Here are the following phases.

1. Mercury is mixed with gold ore that has been ground with water and cement.
2. The next process, material weighing 10—25 kg is mixed in a drum is rotated using energy from a generator.
3. After the process of mixing the ore and mercury is complete, the amalgam is separated from other materials through a squeezing process which usually used cloth.

The residual material mixed with water is flowed into the holding pond and some flows in the yard around the processing site.

Technically, the process of obtaining gold ore and processing it into gold has several stages, namely as follows.

Ore is dug manually from a nearby hill or mountain (2.1c) using a vertical hole in the ground (Figure d).

Traditional tools such as wide hoes, rods, and simple pulleys are used for extracting ore (Figure e).

1. The ore is manually crushed (Figure f), using a hammer or other percussion.
2. Some processing plants use homemade mechanical crushers.

The ore is then packed into sacks and manually transported to the processing plant (2.1g) [37].

a
A drum that is in place for processing ore material

b
The water in the Bilato River is brown due to mining activities

c

d

e

f

g

Figure 2.1 Gold mining of local community in Bilato, Boliyohuto District, Boalemo Regency, Gorontalo Province, Indonesia

B. Impact of the Amalgamation Method on Health and the Environment

The amalgamation method can cause mercury pollution which can pollute the environment during the washing process. This is because local people's gold mining is usually located in watersheds. The amalgamation process produces waste from washing. This waste contains mercury and is dumped into river bodies, causing the water to be contaminated with mercury poison. Mercury changes shape into a fine material that is mixed with other materials during grinding and during the amalgamation stage.

In the dregs washing process, elemental mercury flows into the river along with the rest of the material [37]. The water that flows into the river along with the oxidized mercury and elemental materials turns into organic compounds, methyl mercury or phenyl mercury. This process is called the bacterial decomposition process.

Mercury organic compounds are absorbed by microorganisms and then enter the food chain. This causes bioaccumulation and biomagnification events in the body of fish that consume these microorganism [38].

The contamination process will continue to the living things that eat the fish, both larger fish and humans. Through this process it is understood that mercury from gold mining has the potential to contaminate water, soil, sediment, biota, and has the potential to affect human health.

A wider impact can occur when mercury has polluted the environment. Mercury will spread quickly because of its very high mobility and can be concreted through the food chain. Humans as part of the food chain will not escape the impact of environmental pollution caused by mercury.

The effect of mercury pollution on human health is obtained because people consume food. Even meat from livestock that eat plants that have been contaminated with mercury is also very risky for contamination.

Chronic effects arising from exposure to mercury are more dangerous that effects that appear immediately upon exposure (acute) because they will disappear after exposure to toxins is removed [39].

Mercury-contaminated soil will contaminate plants that grow on it such as fruits, vegetables, and even meat from livestock that eat grass that grows on contaminated soil. This will harm humans who eat fruits, vegetables, and livestock meat that has been exposed to toxic mercury.

The amount risk that a person will suffer depends on how much and the type of element mercury is exposed to in the body. Patients will experience mild symptoms such as paresthesia (burning or prickling sensation) to severe symptoms such as dysarthria (*difficulty speaking caused by brain damage*), even death.

Other health effects caused by mercury can occur in infants. Babies born to mothers who eat food that has been contaminated with mercury will experience cerebral palsy or mental retardation.

Drinking water is one of the most important things for human health and the environment. This is due to the increasing need for water for people with an increasing population. The availability of potable, high-quality water can be demonstrated by healthy ecosystems, human contact, and local geology [40]. One of them can be shown from the existence of a clean river.

This is due to the form of mercury which has been mixed/split into fine grains which are difficult to separate in the milling process which is conducted simultaneously with the amalgamation process. In this washing stage, the mercury in the dregs is carried into the river [40].

Furthermore, in water, mercury can undergo oxidation and turn into organic compounds methyl mercury or phenyl mercury through a decomposition process by bacteria. Next, if this mercury organic compound is absorbed by micro-organisms and then continues to enter the food chain and there is bioaccumulation and biomagnification in the fish body.

Contamination can then occur in humans who consume fish that have been contaminated with mercury [40]. Through this process, it is understood that mercury from gold mining has the potential to contaminate water, soil, sediment, biota and has the potential to affect human health.

Chapter 3
Mercury Hazards for Safety, Health and the Environment

Local people's gold mining using mercury is a source of environmental pollution. Generally, gold mining uses mercury as amalgam with the uncontrolled discharge of its waste into rivers.

Before discussing the dangers of mercury, the following will also define the general information of mercury.

A. Dangers of Mercury from the Amalgamation Process

Mercury is one of five elements (bromine, cesium, fransium, and gallium) that are liquid at room temperature and occur naturally. Mercury is a type of heavy metal that is dangerous and can be toxic of even in small concentrations. Elemental mercury can be found in water, soil, and air in the form of elemental mercury (Hg^0), monovalent mercury (Hg^{1+}), dan bivalent (Hg^{2+}). Another characteristic of mercury is that it is not easily bonded expect with hydrogen and has three oxidant states [40]. The oxidation states include (Hg^0) which is elemental mercury, (Hg+) for example methylmercury

(CH_3Hg^+), (Hg^{2+}) and dimethylmercury ($(CH_3)_2Hg$) [41].

This element is often referred as mercury. Substances including heavy metals are very toxic. In low levels, mercury is generally toxic to plants and animals, including humans. Although exposure in relatively low levels can cause damage to the nervous system. This is very dangerous especially for pregnant women and children development. Mercury compounds can cause physical and metal defects in the of the fetus. If collected or accumulated in the human body and animals through cycle of the food chain, particularly, some types of fish and shellfish because their aquatic environment has been polluted with mercury compounds.

Mercury is an element that belongs to the transition metal group and is also a toxic element (see periodic table). The nature of this element is such as a liquid element at room temperature, and easily evaporates below 650°C. This character causes mercury to evaporate easily and causes pollution in the atmosphere.

This element has the characteristic of being easy to form alloys with other metals (amalgams). This character also causes mercury to be used by miners to extract gold from rock. After the amalgam process, then proceed with the separation of gold with mercury.

This metal comes from the earth's crust. The presence of mercury occurs naturally, so it cannot be removed. Physically, mercury is a pure metal that is silver in color, odorless, liquid, and shiny. Useful in industries such as industries that produce thermometers, neon lights, car lights, batteries, to the production of chlorine gas. In the manufacture of thermometers, the use of mercury can produce more precise measurements than using alcohol. This is because mercury is very sensitive to temperature changes even though it must be stained first.

In the developing countries, mercury is used in the small-scale gold mining industry. Although its use poses a risk to health, especially for women and children who live in areas around mining [39]. Mercury and mercury compounds have very high toxicity, because they are highly reactive and are biologically active molecules.

Mercury pollution has now become a global problem, not only in Indonesia but also in the world. Based on the data of year 2000 that was published in 2006, 10 countries that were ranked 10th in the world as the countries with the highest mercury emissions from anthropogenic sources (man-made) can be seen in the image below (Figure 3.1).

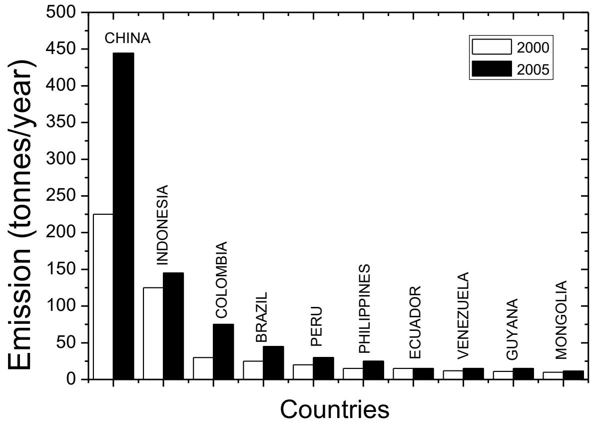

Figure 3.1 Histogram of Countries with the Largest Mercury Emissions from Small-Scale Gold Mining [42]

B. Mercury Pollution

Mercury pollution exists in three forms, namely metal elements, inorganic salts, and organic compounds. Each form has specific toxicity and bioavailability.

1. Metal Element
2. Inorganic Salt

   The threat of inorganic mercury is dangerous [43]. The threat is known to be more nephrotoxic than its organic form. This is due mainly to accumulation in the proximal tubular cells of the kidney. This is a serious threat to human health, in terms of food supply.
3. Organic compounds

   Mercury compounds bonded to one carbon compound will form organic mercury compounds, for example, methyl (organic) mercury.

Organic mercury compounds are considered more dangerous and can dissolve in the fat layer on the skin that covers the nerve core.

Methyl mercury is an organic mercury that has always been a serious concern in toxicology (the science of poisons). This is because methyl mercury can be absorbed directly through the digestion of fish, animals, and humans and will accumulate in the bodies of fish, animals and humans, following the pattern of the food chain [43].

Furthermore, mercury compounds can enter the body through breathing with an absorption rate of 80%. The vapor can penetrate the lung membranes and when absorbed into the body, mercury compounds will be bound to sulfhydryl proteins such as systems and glutamine. In the blood, 90% of methyl mercury is absorbed into red blood cells.

Organic mercury is known to accumulate in the food chain [43] and cross the blood brain after human consumption has caused various neurological effects in humans [44].

C. Process of Heavy Metal Forming

Heavy metals such as mercury occur naturally in the earth's crust. However, human activities such as industry, agrochemical applications, medical applications, mining, and burning fossil fuels cause high global emissions of toxic metals [44].

Natural phenomena such as weathering and volcanic eruptions also contribute to toxic metal pollution [44]. Toxic metals that are related to heavy metals and metalloids such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) are carcinogenic to humans.

Excessive levels of toxic metals are harmful to organisms that enter the food chain and damage human health [45,46]. In an epidemiological study, hair can be used to measure levels of toxic metals in the body as an established method in several cohort studies [47–49].

The concentration of mercury (Hg) in hair can be used as an indicator of total mercury in the human body. When toxic metal ions come into contact with the human body, they are absorbed and form complexes with carboxylic acids, amines, and protein thiols resulting in cell malfunction or death and consequently cause various diseases. In recent years, many scientists are concerned about the concentration of toxic metals and human health problems [50,51].

According to the Ministry of Forestry and Mining of Gorontalo Province in 2012, Gorontalo Province has PESK locations. Bone Bolango Regency is the district with the most PESK locations and also the number of miners.

According to Limbong and Agusa as cited in Arifin 2015, mercury (Hg) pollution can occur in hair, fish, and sediments associated with PESK activities. It is possible that other toxic metals will also be polluted from groundwater or surface water when the rock is formed [30]. The impact of PESK activities on the environment and human hair in Gorontalo has been reported in some researches [30,52].

D. Process of Geological Heavy Metal Forming

There are seven kinds of geological processes that form heavy metals.

1. **First Process**

   Heavy metal leaching is segregation process in magma. Larger density mineral grains settle through the molten magma (fluid) while crystallization is still taking place. One of them is chromite ($FeCr2O_4$), the main ore Cr with a density of 4,4 g cm-3.

2. **Second Process**
   The second process is tangent metamorphism. In this case, a very active chemical solution contain-ned in the magma changes the surrounding rock in exchange for the components present in the rock. For example, a limestone bed is replaced by an iron deposit consisting of the minerals hematite ($Fe2O_3$) and magnesite [$Fe(FeO_2)_2$], or deposits of Cu, Zn, or Pb.
3. **Third Process**
   The third process is the formation of a pegmatite body, which is an indentation of coarser grained material within a large, finer grained plutonic parent rock mass. Pegmatite bodies can spread into the surrounding rock in the form of veins. Heavy metals found in pegmatites are Ta (tantalum), Nb (Niobium), U (Uranium), Th (Thorium), and several other rare earth metals [53].
4. **Fourth Process**
   The fourth process takes place by involving a hydrothermal solution. Metal substances leave magma during the last stages of crystallization and are deposited in rock fractures to form mineral veins, or are emitted in very large rock masses. The hydrothermal solution moves upward towards the earth's surface. So shallow metal deposits are formed, which can even

appear as deposits from hot springs. Gold, silver and Hg are mostly found as shallow deposits.

5. **Fifth Process**

   The fifth process deals with the influence of the downward movement in the aeration zone and in the groundwater zone. Small deposits here and there in the aerated zone are dissolved in the meteoric water which percolates, collects and concentrates and finally settles on the groundwater zone to become a deposit, because it involves the enrichment of mineral deposits, this process is called a secondary process (Arsentina, 2008).

6. **Sixth Process**

   The sixth process which is a secondary process by the influence of meteoric water, but in contrast to the fifth process, forms a residual heap. Meteoric water that infiltrates and percolates, or moves sideways as runoff or seepage removes more substances that are more soluble than metals containing.

7. **Seventh Process**

   The seventh process is leaching by sedimentation through transportation by water flows and waves. Sedimentation can occur on land or at sea. First, rocks undergo weathering, next, weathered materials are transported by runoff into rivers. Then transported downstream and rock fragments containing heavy metals will settle first upstream than those that do not contain heavy metals because of higher specific gravity [54].

Chapter 4
Geological Characteristics of Gorontalo Region

A. Gorontalo Regional Physiography

The physiography of Gorontalo Province is divided based on morphological forms as well as rock types and geological structures. According to Bemmelen (2009) [55] physiographically the Gorontalo area is divided based on several physiographic zones as follows.

1. **Zone of Northern Mountain**

   The Northern Mountains Zone generally consists of Tertiary volcanic rock formations and plutonic rocks. This zone is characterized by steeply sloped mountains with several peaks, including Tentolomatinan Mountain (2207 m), Pentolo Mountain (2051 m), dan Boliohuto Mountain (2065 m).

2. **Zone of Limboto Depression**

   The second zone is a basin in the middle of Gorontalo Province, namely the Median Depression. This basin is formed by the Paguat River, Randangan River, Paguyaman River, Limboto Lake, Bone River, Ongkang Dumoga

River. This prolonged depression is known as the Limboto

3. **Zone of Southern Mountains**

   The Southern Mountain Zone generally consists of very old volcanic sedimentary rock formations in Gorontalo, namely Eosen – Oligosen (approximately 50 million to 30 million years ago) and Pliocene diorite, granodiorite and granite intrusions. This zone stretches from Bone Bolango, Bone Pantai, Tilamuta, and Pani Mountain.

4. **Zone of Wavy Hills**

   The undulating hilly zone is mainly found in the south and around Tolotio. This unit generally shows a rounded peak shape with a relatively gentle slope and a tower of less than 200 m. This zone is occupied by volcanic rocks and sedimentary rocks of Tertiary to Quaternary age.

5. **Zone of Coastal Plains**

   The last zone is a relatively limited zone on the Pohuwato Coastal Plain. The plains that stretch from Marisa in the East to Torosiaje and the border with the Central Sulawesi Province in the west, are coastal alluvial areas that were mostly swamp areas and tidal zones.

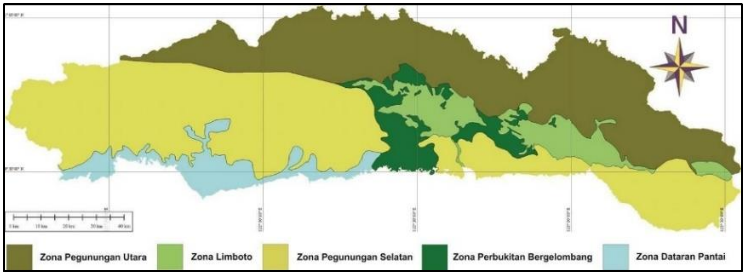

Figure 4.1 Physiography of Gorontalo Province [56]

B. Regional Geological Structure of Gorontalo

The island of Sulawesi and its surroundings, especially northern Sulawesi, is one of the most complex active margins in geological, structural, and tectonic time periods. This region is the center of the meeting of three convergent plates, due to the interaction of the three main crust (plates) in the Neogene period. This convergence gives rise to the development of all types of structures at all scales, including subduction and impact zones, faults, and thrusts.

These days, most of the Neogene structures and some pre-Neogene structures are still active or reactivated. The main structures include the North Sulawesi Trench (North Sulawesi Trench/Minahasa Trench), the Gorontalo Fault, the Sulu Thrust, and the Maluku marine double collision (*Molluca sea collition*).

1. **Zone of North Sulawesi Subduction**
   North Sulawesi Subduction (North Sulawesi Trench) is interpreted as a convergent subduction zone between the Sulawesi Sea and the North Arm of Sulawesi. The subduction zone of North Sulawesi belongs to a relatively old support system (dying subduction) whose rips develop eastward along the northern edge of Sulawesi.
2. **Gorontalo Fault Penun**
   In the northern part of Sulawesi Island, morphologically, four fault segments can be seen [57,58]. The central part of the north of Sulawesi Island is divided into three small blocks.

   The eastern part of the northern arm of Sulawesi Island is named the Manado Block, which is free from the influence of the North Sula Block. Therefore, geologically it is clear that the separation caused by the Gorontalo fault can be seen clearly.

   Based on lithotectonic conditions, Van Leeuwen (1994) [59] divided Sulawesi into three mandalas, namely as follows.
   a. West Mandala as a magmatic pathway which is part of the eastern end of the Sunda Shelf.
   b. The Central Mandala is in the form of metamorphic rock overlaid with bancuh rocks as part of the Australian block.

c. The Eastern Mandala is in the form of ophiolite which is a segment of imbricated oceanic crust and sedimentary rocks of Triassic–Miocene age.
d. West Mandala as a magmatic arc can be divided into two, namely the northern and western parts.

Sulawesi is located in the eastern part of Indonesia, which was formed as a result of the meeting of three large plates, namely the Eurasian Plate moving south-southeast, the Indo-Australian plate moving north, and the Pacific plate moving to west. This gave birth to a very complex and diverse geological condition of Sulawesi consisting of a complex of metamorphic, ophiolite, volcanic arcs, granitoids and sedimentary basins, [60].

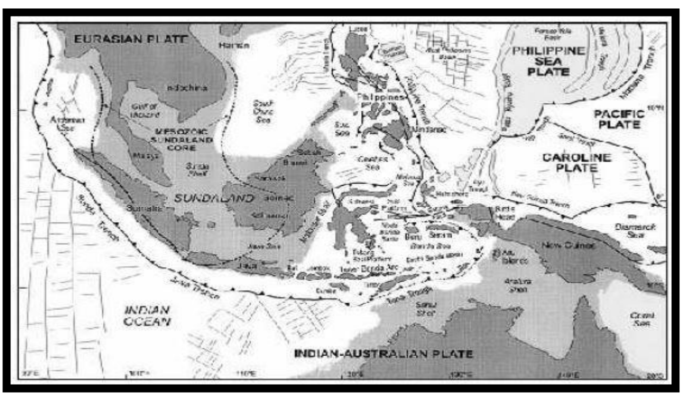

Figure 4.2 Three Large Plates that Create the Island of Sulawesi [57]

Sulawesi tectonic activity is thought to have occurred as a result of the East Sangihe subduction which subducted to the west and produced a quaternary volcanic strip with a depth of about 150 km. The subduction zone which is located to the north and east of the north arm has the potential to cause earthquakes and structural reactivity in the north arm, including the reactivity of the Gorontalo fault. This fault is a rightward fault which as indicated by the shape of the coastline around Gorontalo Bay which shows a rightward shift associated with subduction activity in the Sulawesi Sea [61].

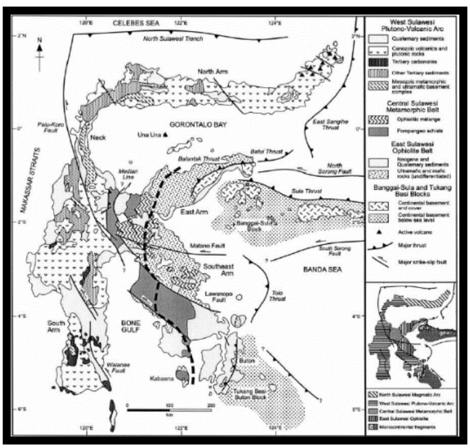

Figure 4.3 Map of Sulawesi Island Tectonic [57]

Referring to Apandi and Bachri (1997), [62] Gorontalo has a Gorontalo fault which is the largest horizontal fault with a rightward shifting direction. In the volcanic rock formations, especially Bilungala, there are several zones of fault uplift with an angle of 30°.

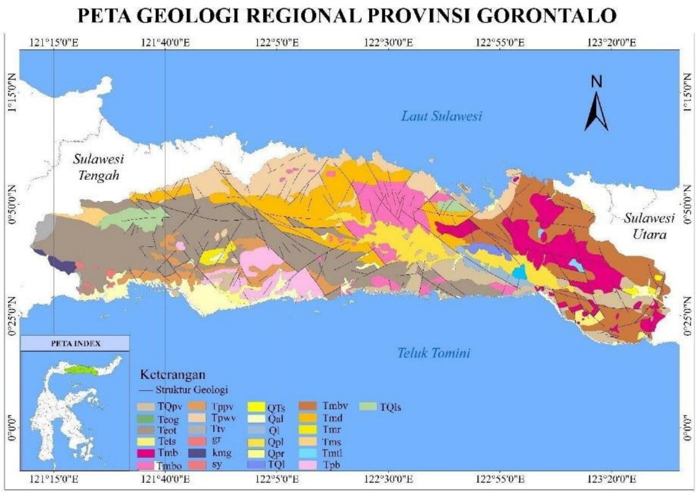

Figure 4.4 Regional Geology Map of Gorontalo Province (modified modification of Mobagu City Sheet Map, Tilamuta Sheet Map, and Tolitoli Sheet Map [63].

C. Gorontalo Regional Stratigraphy

The regional stratigraphy of Gorontalo Province based on the Kotamobagu Sheet Geological Map, Tilamuta Sheet Geological Map and Toli-toli Sheet Geological Map is divided into 25 units. The composition of the stratigraphy of Gorontalo Province from old to young is as follows.

1. Metamorphic Rock Complex (km)

The formation is spread out in the westernmost area of Gorontalo Province, which borders the Province of Central Sulawesi. This formation consists of metamorphic rocks that are estimated to have Mesozoic age [64].

2. **Metamorphic Rock Complex, Mainly Green Schist (kmg)**
   This formation is spread over the area around the border of Gorontalo Province and Central Sulawesi Province. This formation consists of metamorphic rock which is dominated by green schist. This formation is arranged in a radius with the km formation. The age of this formation is estimated to be the same as the formation km which is the Mesozoic [64].
3. **Gabbro (Teog)**
   This formation consists of gabbro, microgabbro, and diabase rocks. This formation is widely distributed in the northern area of Gorontalo Province. The age of this formation is estimated to be around Eocene to Oligocene [64].
4. **Tinombo Formation (Teot)**
   The Tinombo Formation consists of volcanic rock, sedimentary rock, and some weakly thermally treated rocks. The types of volcanic rocks in this formation are volcanic breccia, spilitan lava, basalt lava, and andesite lava.

   Sedimentary rocks consist of red limestone, gray limestone, wacke sandstone, siltstone and green sandstone. Some of these rocks undergo conversion at a low degree. This formation is not in harmony with the formation above it. Age withdrawals in the basalt rock indicate an age of

51,9 million years or the early Eocene. The thickness of this formation is estimated to reach thousands of meters. The Tinombo Formation is widely exposed which spreads from the Popayato area to the southern Tolotio area [65].

5. **Volcanic Facies Tinombo Formation (Tetv)**
   This formation consists of basalt lava, andesitic lava, interspersed with the smell of green sand, green siltstone, a little conglomerate, red and gray limestone. Pillow lava is well exposed in the S. Sogitia Kiki area, on the north coast. There are sedimentary structures in sandstone and siltstone, namely parallel layers, laminates, convolutes, parallel laminates, and ambiguous cross-laminations.

   Based on the association of lithology and sedimentary structure, it is estimated that this unit was deposited in a deep-sea environment. The age of this unit is estimated to be in the Eocene [63].

6. **Tinombo Formation of Sedimentary Facies (Tets)**
   This formation is a formation consisting of shale and sandstone with limestone and chert inserts. Shale rock has characteristics of gray and red, brittle, and some calcareous. Chert rock contains radiolarian fossils. The sandstone is greywake and quartz sandstone, gray and green in color,

dense, fine to medium grained, some containing pyrite.

The limestone inserts at S. Mayambak are red, solid, and well layered. This unit is intruded by granite, diorite, and trachyte. This unit has a close relationship with the Tinombo Formation of volcanic facies. The age of this formation according to Ratman (1976) [64] is Eocene to early Oligocene. Meanwhile, according to Sukamto (1973) [66] is the Late Cretaceous to Early Eocene.

The thickness of this formation is estimated to be more than 1000 meters, while the depositional environment is deep sea [67].

7. **Intrusive Rocks (sy)**

This formation consists of intrusive rocks. These rocks are scattered slightly in the border area of Gorontalo Province. The age of this rock is estimated to be Oligocene [64].

8. **Bone Diorit (Tmb)**

This formation consists of granodiorite, diorite, quartz diorite, adamelite. The units consist of medium to coarse-sized massive diorite with a hypidiomorphic to phaneroporphyritic texture with pyroxene and feldspar reaching sizes of 0.5 cm.

Diorite Bone which is fine grained has a mineral composition similar to andesite rock from the Bilungala volcanic rock. Based on this, Bone diorite is suspected to be the parent magma of the Bilunggala volcanic rock which is in the middle Miocene to early late Miocene [68,69].

9. **Rocks of the Bilungala Volcano (Tmbv)**

The rock of the Bilungala Volcano consists of volcanic breccia, tuff, and lava with an acidic to alkaline composition. These volcanic rocks are generally gray to dark gray in color. Its volcanic breccias are composed of andesite, dacite and basalt fragments. Tuff is generally Dacian and rather compact. Lava is andesitic to basalt, hypocrystalline to holocrystalline in texture, fine grained, and massive.

The rocks of the Bilunggala volcano are difficult to distinguish from the volcanic rocks of the Dolokapa formation due to the similarities in the composition of the rocks. It is estimated that this formation grows together with the Dolokapa formation and is intertwined. The age of this formation is estimated to be middle Miocene to early late Miocene [69].

10. **Dolokapa Formation (Tmd)**

The Dolokapa Formation is composed of sedimentary rocks with volcanic rocks interspersed. The sedimentary rock consists of wacke sandstone, siltstone, mudstone, and conglomerate.

The volcanic rocks consist of tuff, lapilli tuff, agglomerate, breccia, and lava with andesite to basalt arrangement. There are many different opinions in deciding the age of this formation. Marks (1995) [70] compares the age of this formation with the Tinombo formation which he considers to be Cretaceous to Eocene. However, Trail (1974) [68] mentions that the limestone fragments in this formation are from early Miocene age. Meanwhile, in the siltstone of this formation, fossils were found, including: Orbulina suturalis Broniman, Globigerinoides immaturus Le Roy, Globootalia menardii, Brazilina sp., and Anomalia sp. This fossil shows an age no older than the Middle Miocene. The depositional environment is the inner sublittoral [63].

11. **Randangan Formation (Tmr)**

The Randangan Formation consists of conglomerate, wacke sandstone, siltstone, and mudstone. The fossil content contained in this formation layer indicates the age of the Middle Miocene to Late Miocene. According to Trail (1974) [68], limestone chips within the conglomerate contain Middle Miocene to early Late Miocene fossils, with a shallow marine depositional environment. This formation overlaps with the Tinombo formation. While the relationship with the Dolokapa formation is unknown [69].

12. **Limestone Members of the Tapadaka Formation (Tmtl)**

    This formation consists of light gray limestone, solid, containing green volcanic rock fragments. This formation contains fossils including Lepidocyclina (Eulepidina) sp., L. Parva (Oppenoorth), L. sumatrensisi (Brady), L. Eppiodes (Jones & Chapman), Myogypsinoides sp., Spiroclypeus sp., Operculina sp., and ganggang gampingan. The age of this unit is estimated to be Early Miocene to Late Miocene.

13. **Boliohuto Diorit (Tmbo)**

    This unit consists of rock diorite to granodiorite containing 20% quartz with feldspar content, and biotite is quite prominent. Some places found xenolite base composition. The possibility of this unit breaking through the alkaline rock below the surface. These rocks break through the Dolokapa Formation. This unit is estimated to be of Middle Miocene to Late Miocene age [69].

14. **Pani Volcano Rocks (Tppv)**

    Pani Volcano rocks consist of dacite, andesite, tuff, and agglomerate. Andesite lava is the main constituent in this formation. Massive structure, gray in color, porphyritic texture, with phenocryst consisting of feldspar and quartz. The andesite lava is gray with a porphyro-aphanitic texture, and is massive. The tuff is light gray in color, with dacite and compact composition. Agglomerates are gray in color with andesite and basal components. These rocks overlap with the Randangan Formation. So, the age of the rocks of Pani Volcano is estimated to be Early Pliocene [69].

15. **Wobudu Breccia (Tpwv)**
    Wobudu breccia consists of volcanic breccia, agglomerates, tuff, lapilli tuff, andesite lava and basalt. Volcanic breccias are gray in color, composed of andesite and basalt rock fragments ranging in size from gravel to boulders. Tuff and lapilli tuff are yellow and yellow-brown in color, fine-grained to pebble-sized, slightly rounded, open-packed, stocky, generally soft and layered. While the lava is generally gray to dark gray in color, massive, porphyry-afhanitic textured and in andesite to basalt composition. The stratigraphic position is not aligned with the Dolokapa formation. Hence, the age of the Wobudu Breccia is estimated to be Early Pliocene [69].

16. **Bumbulan Granodiorit (Tpb)**
    This unit consists of granodiorite, granite, dacite, and quartz monzonite. Granodiorite is gray, massive, medium grained, contains biotite and pyroxene. Granite is light gray to gray with medium grain and contains little mafic minerals of the biotite type and is generally jointed.

Meanwhile, dacite is light gray in color with fine grained minerals such as quartz and feldspar. Quartz monzonite is gray, massive, medium grained, with the main constituents of quartz, plagioclase, and alkali feldspar. According to Sukamto (1973) this rock is Pliocene age [69].

17. **Lokodidi Formation (TQls)**

    The Lokodidi Formation consists of alternating conglomerate, sandstone, conglomerate sand-stone, tuddaceous sandstone, sandy tuff, claystone, and black shale. The conglomerate is brown in color, composed of limestone, andesite, and milky quartz chips ranging in size from gravel to cobblestone, rounded in shape, with a tuff bottom mass, poorly sorted and sealed. Sandstone is gray to reddish brown, fine to medium grained generally compact, is an insert between shale and conglomerate. The tuff and tuff sandstones are white to light gray in color, medium grained and somewhat compact. The flakes are black, generally less compact, and calcareous. This formation overlaps with the Wobudu Breccia which is of Early Pliocene age, so it is assumed that it is of Late Pliocene to Early Pliocene age [69].

18. **Pinogu Volcano Rock (TQpv)**

    This rock consists of alternating agglomerates, tuff, and lava. The gray agglomerates are composed of andesite fragments with sizes ranging from 2 to 6 cm, gray in color, angular, tuff bottom mass, poorly sorted, and somewhat compact. Tuff is light brown to brownish white, medium to coarse grained with andesite to dacite arrangement. Lava is dark gray, composed of andesite to basalt. This unit is thought to overlap the Wobudu Breccia, so its age is estimated to be Late Pliocene [69].

19. **Molasa Selebes (QTs)**

This formation consists of postorogenic deposits formed in small basins, consisting of conglomerates, breccias, and sandstone, which are generally weakly compressed. Conglomerates and breccias are composed of various component materials in the form of andesut, basalt, granite, granodiorite, limestone, sandstone and quartz. This unit shows a gentle slope of about 30^{o}. The thickness of this formation is estimated to be tens of meters. The age of this formation is Pliocene-Plistocene [69].

20. **Clastic Limestone (TQl)**

This formation consists of calcarenite, calcirudite, and coral limestone. Calcarenite and calcirudite are white, compact, and in some places show rather good bedding, containing fragments of fossilized algae and molluscs.

These rocks are usually associated with coral limestone which is white and solid. The age of this formation is estimated to be Late Pliocene to Early Pistocene. The distribution of this unit is in the west of Lake Limboto. The thickness of the formation varies from 100 meters to 200 meters [69].

21. **River Sediment (Qpr)**

    This formation consists of alternating sandstone, conglomerate sandstone, and conglomerate. This river sediment unit is still incompressible and forms coastal steps. The age of this formation is estimated to be Pleistocene to Holocene. The thickness of this unit is estimated to reach tens of meters. The distribution of this unit is around the Marisa area [69].

22. **Lake Sediment (Qpl)**

    This formation consists of claystone, sandstone, and gravel. This unit is still not compressed. The age of this unit is Pleistocene to Holocene. The distribution of this unit is around the Paguyaman Valley area and around Lake Limboto. Its thickness reaches 94 meters [69].

23. **Reef Limestone (Ql)**

    This formation consists of uplifted reef limestone and clastic limestone with the main component being coral and layered. This formation is scattered in the South coast area and near Panong in the North Coast area. The age of this formation is estimated to be Pleistocene to Holocene.

24. Alluvium (Qal)

This formation consists of sand, clay, silt, gravel and big gravel, in the form of coastal deposits, swamps, and rivers. The spread of this unit is mostly found in the western part of the southern coast, precisely at the estuary of S. Randangan and its surroundings. Its thickness reaches tens of meters. The age of this unit is Holocene.

Chapter 5
Analysis of the Potential and Risks of Local People's Gold Mining in Tulabolo Village, Gorontalo

A. History of Gold Mining in Gorontalo

Local people's gold mining activities using heavy metals such as mercury can be found in five regencies in Gorontalo Province. The mine site in northern Gorontalo district is one of the oldest and continuously active gold mines in Gorontalo Province. This mining activity can be found in several areas of North Gorontalo Regency, including in three sub-districts in Hulawa, Ilangata, and West Ilangata.

Mining activities in Hulawa sub-district are the oldest (late 19th century) in the province, while those in Ilangata and West Ilangata sub-districts only started ten years ago.

Mining activities use mercury element (Hg_0) to separate gold from rock or ore material [71]. Mining activities in the Sumalata and Anggrek sub-districts release mercury as waste that flows into rivers, resulting in pollution of the Hulawa and Ilangata watersheds.

Gorontalo Province is a regional food barn for several commodities such as rice, fish and beef. Therefore, the distribution of mercury in the North Gorontalo Regency, especially around gold mining, needs to be known.

Soil samples at selected points in the mining area were taken and measured using X-Ray Fluorescence (XRF), Particle Induced X-Ray Emission and Induced Coupler Plasma-Mass Spectroscopy (ICP-MS) equipment. Furthermore, the data will be presented in the form of a map. Meanwhile, the level of mercury contamination in humans will be obtained from hair samples and visible symptoms.

B. Local People's Gold Mining Practice

The level of activity changes rapidly from time to time depending on fluctuations in the gold market. Women and children are involved in the gold mining process. Female workers crush ore, treat sediment waste, and shift gold in rivers. The children help their mother in this activity and play around the mining site.

ASGM in North Gorontalo Regency is estimated to produce ca. 290 kg of gold and emits about 860 kg of mercury into the environment each year. The enormous impact of mercury emissions on the environment and human health needs to be assessed in order to reduce or avoid health problems and deaths.

C. Risks

Naturally, nature can affect health in various aspects. The composition of rocks and minerals contained in the air we breathe, the water we drink, and the food we eat for many people, the transfer of minerals and elements they contain is beneficial because they are a source of key nutrients (such as calcium, iron, magnesium, potassium, and about a dozen other elements) that are essential for a healthy life. However, local geological elements containing certain elements naturally dissolve in oxidation/ reduction conditions in groundwater.

In excess, these elements can cause significant health problems due to insufficient or excess amounts of these elements (such as arsenic, mercury, lead, fluorine, etc.), or gas combinations, such as methane gas, asbestos particles, too much quartz or pyrite-sized dust in the air, or certain natural organic compounds. The latter includes findings reported by the US Geological Survey that even groundwater passing through multiple layers of lignite can dissolve PAHs (Polycyclic Aromatic Hydrocarbons) in sufficient concentrations to cause serious health problems [72].

D. Geodiversity Identification of Tulabolo Village

1. Geographical Conditions

Gorontalo Province has 5 regencies and 1 city, including Gorontalo Regency, Bone Bolango Regency, Pohuwato Regency, Boalemo Regency, North Gorontalo Regency, and Gorontalo [73]. Bone Bolango Regency is one of the regencies in Gorontalo Province. Geographically, it has an area of 1.984,58 km2 or 16,24 percent of the total area of Gorontalo Province. Bone Bolango Regency is divided into 18 sub-districts, consisting of 166 sub-districts/villages. The sub-district with the largest area is East Suwawa District, while the sub-district with the smallest area is South Bulango District [74].

Based on its geographical location, Bone Bolango Regency is directly adjacent to Bolaang Mongondow Regency (North Sulawesi) and North Gorontalo Regency in the north. While in the east it is bordered by South Bolaang Mongondow Regency, in the south by Tomini Bay, and in the west by Gorontalo City [74].

2. Geological Conditions

Tulabolo village has quite complex and unique geological conditions. Based on research conducted by Pateda (2021) [75] the differences in river flow patterns at the research site are largely determined by differences in the topography of the structure and the type of bedrock. From the results of the analysis of topographic maps and river flow patterns, the research area only has one river flow pattern, namely rectangular [76].

Rectangular patterns generally develop in rocks whose resistance to erosion is nearly similar, but controlled by joints that have two directions at right angles to each other. Joints are generally less resistant to erosion so that they allow water to flow and develop through the joints to form a drainage pattern with straight channels following the joint system.

Rectangular flow patterns are found in areas where the region is broken. the rivers follow paths that are less resistant and are concentrated in soft rocky outcrops. The branches of the river form an obtuse angle with the main river. Thus, it can be concluded that the rectangular flow pattern is a river flow pattern controlled by geological structures, such as joint structures (fractures) and faults (faults). Rectangular rivers are characterized by waterways that follow the pattern of joint and fault structures.

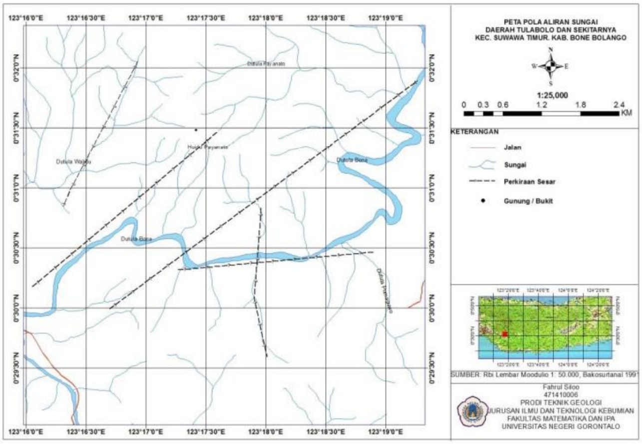

Figure 5.1 Map of River Flow Patterns in the Study Area

Based on the results of analysis and field observations, the research area stadia entered the easy stage, namely rivers whose river flow activity erodes in a vertical direction. The river flow that occupies the entire bottom floor of a valley and generally forms a valley profile like the letter V.

In general, the geomorphological unit of the study area is included in the northern mountainous zone which is controlled by lithology, structure, and erosion processes. Based on these factors, the landscape of the research area is divided into three landscapes, namely river plains, intrusive hills, and volcanic hills. The division of this landscape is based on the geomorphological division according to Brahmantyo and Bandono 2006.

Figure 5.2 The Stages of the Research Area Stadia are Shown in the Image Above

The stratigraphic unit in the study area uses an informal classification based on the lithological characteristics found at the study site and the results of laboratory observations. The stratigraphy of the study area is divided into five lithostratigraphic units which are sorted from old to young.

1. **Diorite**

   The diorite unit occupies approximately 30% of the research area. This unit can be found on the Walidu River. In the lower reaches of the Payanato River and on the banks of the Bone River, with fresh to weathered lithology conditions and sometimes altered minerals in the form of pyrite also found.

The lithological characteristics of this unit are faneric gray (intermediate), subhedral to anhedral, ekigranular, with forming minerals in the form of plg. Hbl, Biotite. This unit is a Tmb formation or better known as Bone diorite with a relative middle Miocene age of approximately 16 million years [77]. Based on the interpretation of the geological map, this unit is the bedrock of the lithology in the study area.

2. **Granodiorite**

   Granodiorite units occupy approximately 30% of the research area, units can be found on the Walidu River, on the lower reaches of the Payanato River and on the banks of the Bone River, with fresh to weathered lithological conditions and sometimes also found mineral alteration in the form of pyrite. Lithological characteristics in this unit are faneric gray (intermediate), subhedral to anhedral, equigranular, with forming minerals in the form of orthoclase, Qrz, plg. This unit is a member of the formation of diorite bone or better known as diorite bone with a relative middle Miocene age of approximately 16 million years [77].

3. **Lapilli Tuff Unit**

   Based on field observations, the lapilli tuff units are pyroclastic rocks or rocks formed due to volcanic eruptions, the units occupy nearly 30% of the study site and are spread out in the southern part of the study site. This unit is thought to have been deposited asynchronously on top of the diorite unit which is the bedrock. The lithological condition of this unit has undergone weathering due to exogenous forces acting on the research area. This unit is equivalent to the Pinogu volcano. The characteristics of this lithology are gray to yellowish in color, poor sorting, open packaging, poor porosity, poor permeability, sand grain size, round up.

4. **Volcanic Breccia Unit**

   From the results of field observations, the breccia unit at the research site is a volcanic breccia. This unit occupies 5% of the study area according to research [77]. This unit is early Pleistocene age, and also contains tuff lapilli. This unit can be found on the Maleo River. This unit is equivalent to the pyroclastic deposits of the Pinogu Volcano. This unit was deposited in conformable on top of the lapilli tuff unit. The lithological characteristics are gray, angular, open packing, poor sorting, poor porosity, poor permeability, and lapilli tuff cement (sand-sized tuff).

5. **Alluvial Unit**

   This unit is the easiest unit in the research area. This unit is estimated to be of holocene age and occupies 5% of the study site. This unit has special characteristics, namely terraces, floodplains, and there are also points bars with deposits in the form of intrusive rocks, in the form of andesite, granite, and diorite. This unit is located on the Bone River which leads from East to West and empties into Tomini Bay.

The geological structures found in the study area are joints, faults, and breccias. This is shown in the direct features of lithology and rivers controlled by faults. From the results of taking and measuring field data, several joints and faults were found in several places. The naming of these faults is also using classification [78,79].

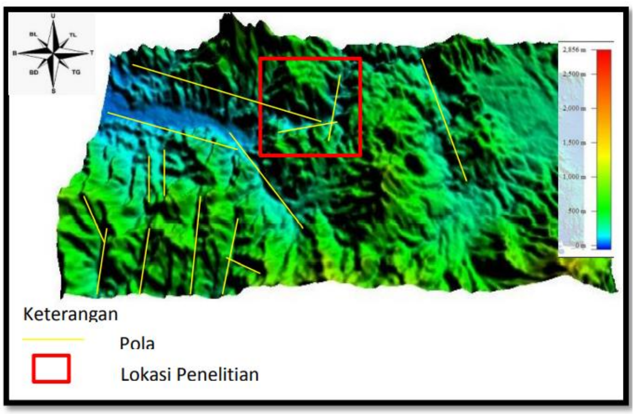

Figure 5.3 The Appearance of the Lineage Pattern of the Research Area Taken

From the results of the SRTM image analysis, the direction of the force obtained is to the northwest which follows the movement of the Gorontalo fault and a minor fault which is directed to the north, south and east west. This structure works in the Tulabolo area.

Based on field observations and structural data processing, it can be concluded that the general direction of brecciation in the Bone River is east–west, which can be seen in the picture above. Measurement of the direction of brecciation is to show the general direction of the fault movement. Brecciation occurs because it is influenced by two faults that are formed in the area.

Figure 5.4 Brecciation 4 that Occurs in Intrusive Rocks in the Form of Diorite

The purpose of this joint analysis is to interpret the direction of the tectonic forces acting in the research area, so that it is hoped that it can help interpret the fault structure and folds that exist in the research area. The relationship between joints, faults, and folds was suggested by Moody and Hill [78] in Sudarno et al. (2008) [80].

Figure 5.5 Joints found in St1 River Walidu Relative Image Direction

E. Geological Potential

Classification is divided into two. First, the classification based on its genesis. Second, descriptive classification. For example, based on the metal commodity or based on the rock it occupies (host rocks).

Actually, the descriptive classification based on the metal commodity is relatively easy to understand. But geologists do not use this classification. This is due to various reasons, including the distribution of many metal elements in various geological settings and this division may be considered unscientific.

Groupings that are often used by geologists are generally based on the form of deposits, wall rock, or structural control. For example, Bateman (1950) [81] in his book Economic Mineral Deposit in Hartosuwarno 2013 [82] classifies ores based on structural control, including ores formed on faults, on folds, on igneous rock contacts, dissemination, and so on. The problem is that there is also ore that forms in sheared folds or disseminates along igneous rock contacts. In connection with the emergence of tectonic theory, plates that can explain magmatism processes and the presence of ore deposits, genetic classification is increasingly being used [83].

Based on the above, the researcher found a quartz vein which is located in the east of the research location, precisely at Dutula Payanato. The upstream part associated with intrusive rocks is diorite [61].

Other geological potentials in Tulabolo Village are abundant geothermal energy and small-scale gold mining. Gold mining in Tulabolo is divided into two, namely gold mining managed by the community and gold mining managed by the company. The gold mining is managed by the company, legally and administratively, this mining area is built as a contract area.

The contract system is used as a mining processing and utilization system or what is called a mineral agreement. The condition for the existence of a mining area is that the mineral content contained in the bowels of the earth has been identified. The purpose of this identification is for development, mining, and utilization.

The local people's gold mining located in Nani Wartabone National Park, especially in Tulabolo Timur Village, East Suwawa District, Bone Bolango Regency, still use traditional tools in managing gold so that it has a negative impact on local residents, especially Suwawa Village and generally for the people of Gorontalo [84].

It is quite difficult to get to this mining site due to the remote location and the terrain or road to be traversed is very dangerous so the miners do not use motorbikes to go to the mining site, but prefer to walk. This is to overcome if something happens such as landslides or muddy roads caused by heavy rain.

F. Tourism Sector

Tulabolo Village has a conservation area, namely the Bogani Nani Wartabone National Park. This park is a tourist park suitable for visitors who like adventure in the outdoors. Bogani Nani Wartanobe National Park has various ecological uniqueness as a geographical transition area of Indomalayan area in the west and Papua-Australia in the east (Wallace Area).

The Wallace region is a meeting place for wildlife and plants typical of mainland Asia and Australia. This is what makes this area a unique and endemic biodiversity that only lives in the national park. It is estimated that more than a thousand species of flora and fauna have been identified living in this area.

The flora consists of 400 species of trees, 241 species of tall plants, 120 species of epiphytes, 100 species of mosses, and 90 types of medicinal plants. There are also 24 types of orchids, including the family orchideae (baby orchids). In this park you can also find endemic plant species and rare plants. For example, matayangan palm (Pholidocarpus ihur), ironwood (Intsia spp.), ebony (Diospyros celebica), yellow wood (Arcangelisia flava), and carrion flower (Amorphophallus companulatus).

Bogani Nani Wartabone National Park is a habitat for several types of animals, such as mammals (24 species), birds (125 species), reptiles (11 species), amphibians (2 species), butterflies (38 species), beetles (200 species), and fish (19 species). Most of the animals in the national park are unique/endemic to Sulawesi Island such as black monkey/yaki (Macaca nigra nigra), Dumoga bone monkey (M. nigrescens), tangkasi (Tarsius spectrum spectrum), Sulawesi civet (Macrogalidia musschenbroekii musschenbroekii), large anoa (Bubalus depressicornis), small anoa (B. quarlesi), babirusa (Babyrousa babirussa celebensis), and various types of birds.

Birds that become the national park's mascots are the maleo (Macrocephalon maleo), and the bone bat (Bonea bidens). These birds are endemic to this national park. Maleo bird body size is almost the same as chickens, but the eggs are 6 times the weight of chicken eggs. Maleo lay their eggs in the soil/sand to a depth of 30-40 cm and are usually located close to hot springs. With this geothermal heat the Maleo eggs hatch. Maleo chicks come out from the ground, run into the wild (one day old), peek at their mother who is digging a hole, are one of the animal attractions for tourists.

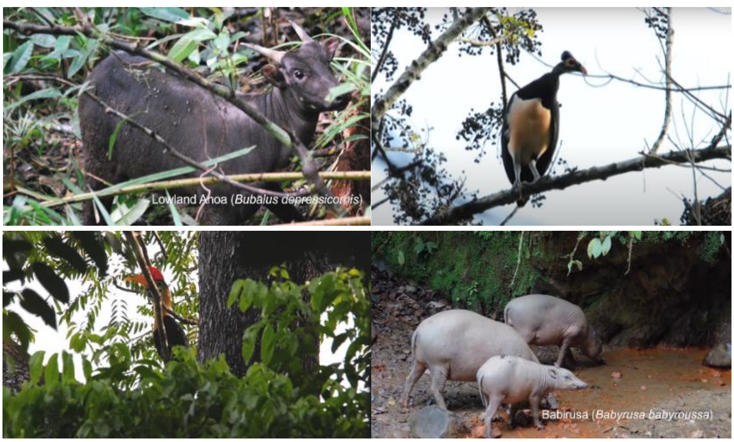

Figure 4 Pictures of Endemic Animals
in the Bogani Nani Wartabone National Park

Chapter 6
Conclusion

A. Conclusion

Concentrations of toxic metals (Hg, Pb and As) in the environment and hair of miners and the people of the Bone River area and surrounding areas are above the normal threshold according to the German Human Biomonitoring Commission. The use of Hg in the amalgamation process of gold mining is a source of toxins for the environment. This concentration of Hg in human hair is a consequence of small-scale gold mining activities and a potential risk to human health. In addition, the possibility of Pb and as pollution is also associated with mining activities and also mixing with natural resources through the hydrothermal alteration process of gold mineralization. The study found two main sources: natural and anthropogenic sources of toxic metal release into the environment.

On the other hand, small-scale gold mining is able to move the wheels of the community's economy, even though the risk of environmental pollution and its effects on public health is also very large.

This study also obtained solutions to minimize environmental and health problems. The solution offered is through other alternative activities that are able to move the community's economy through Geotourism.

The Tulabolo area has Geotourism potential which includes unique and high-value Geodiversity and Biodiversity potentials. So far, the Tulabolo area has become a special interest tourist destination that needs to continue to be developed so that it can improve the community's economy and provide alternative jobs that are safer for the environment and public health.

B. Recommendation

After many cases that hit the world causing the mercury problem to become a global problem, then solution is needed immediately. One solution to reduce toxic mercury from the environment is through remediation.

To ensure environmental sustainability, preventive measures to safeguard the quality and quantity of water bodies against illegal gold mining practices are needed to help achieve the sixth Sustainable Development Goal (SDG 6) which calls for sustainable water management for all. However, activities such as mineral exploitation, ore transportation, smelting and refining, tailings disposal and wastewater around mining sites have resulted in the release of large amounts of mercury and heavy metal contaminants.

Glossary

Anthropogenic	Things that come from human activities and also have an impact on human life and the environment.
Geopark	Areas that have a leading geological element, where local people also play a role in protecting the natural heritage.
Geosite	A site or place identified for the development of earth science or as a tourist attraction.
Geotourism	Tourism of special interest by utilizing the potential of natural resources such as landscape shapes, rocks, geological and historical structures.
Mineral agreement	Contract system is used as mining processing and utilization system.
Sustainable tourism	Well-developed and continuous tourism, including increased accommodation capacity flows, community populations, and the environment.

Bibliography

1. N. Rahmanita and Y. Yulimarni, "Pelaminan Adat Masyarakat Minangkabau (Kajian Bentuk Dan Fungsi)," *Corak* **5**(1), (2016).
2. N. Priyanto and others, "Pelaksanaan Penegakan Hukum terhadap Pertambangan Emas Tanpa Izin Berdasarkan Pasal 20 Ayat (1) Peraturan Daerah Provinsi Kalimantan Barat Nomor 8 Tahun 1987 di Desa Lamat Payang Kabupaten Bengkayang," *J. Huk. Prodi Ilmu Huk. Fak. Huk. Untan (Jurnal Mhs. S1 Fak. Hukum) Univ. Tanjungpura* **4**(1), (2015).
3. P. L. Krisno, "Kemajuan Industri dan Dampak Lingkungannya di Jepang sebelum Tahun 1950," *Lensa Budaya J. Ilm. Ilmu-Ilmu Budaya* **12**(1), (2017).
4. A. Sarker, "Ecological perspectives on water, food, and health security linkages: the Minamata case in Japan," *Environ. Sci. Pollut. Res.* **28**(25), 32177–32189 (2021).
5. B. Weiss and T. W. Clarkson, "Toxic chemical disasters and the implications of Bhopal for technology transfer," *Milbank Q.* 216–240 (1986).
6. M. Adlim, "Pencemaran merkuri di perairan dan karakteristiknya: suatu kajian kepustakaan ringkas," *Depik* **5**(1), (2016).
7. I. Ismawati, "Pasar Uang dalam Perspektif Islam," *J. Minds Manaj. Ide dan Inspirasi* **3**(1), 96–106 (2016).
8. P. Ismawati and S. J. Andajani, "Penerapan Pembelajaran Kooperatif Tipe STAD Bermedia Realia Terhadap Pemahaman Konsep Geometri Pada Anak Kelompok B TK Dharmawanita Dewi Sartika Bojonegoro," (2013).
9. C. A. S. Putra, "Evaluasi Revegetasi Lahan Bekas Tambang Emas PT. Newmont Minahasa Raya, Manado, Sulawesi Utara," (2010).
10. W. Chang, "Dampak Ekonomis Penambangan Emas Bagi Masyarakat Mandor, Kalimantan Barat," *Masy. Indones.* **38**(1), 115–138 (2016).
11. R. Wulandari, "Analisis Implementasi Kebijakan Politik Pemerintah Indonesia dalam Mengantisipasi Sampah Plastik," Fakultas Ilmu Sosial dan Ilmu Politik (2021).

12. N. D. C. Rumampuk and V. Warouw, "Bioakumulasi total merkuri, arsen, kromium, cadmium, timbal di Teluk Totok dan Teluk Buyat, Sulawesi Utara," *J. LPPM Bid. Sains dan Teknol.* **2**(2), 49–59 (2015).
13. Badan Lingkungan Hidup Kabupaten Gorontalo Utara, *Laporan Akhir: Studi Kandungan Merkuri Dalam Darah Masayrakat Penambang Di Desa Buladu Kecamatan Sumalata Kabupaten Gorontalo Utara Provinsi Gorontalo* (2011).
14. I. K. Irianto, *Buku Bahan Ajar Pencemaran Lingkungan* (2015).
15. N. Nuzmiyah, "Analisis Kandungan Merkuri (Hg) pada Ikan Nila Merah Oreochromis Sp. yang Dibudidayakan dalam Kja di Kota Pontianak," Fakultas Perikanan dan Ilmu Kelautan (2019).
16. V. D. Glenn, "Top 20 Hazardous substances from the cercla priority list of hazardous substances for 2001," *Ref. Rev.* (2002).
17. S. Rahim, "Konflik Pemanfaatan Ruang Akibat Penambangan Emas Tanpa Ijin (PETI) di Kawasan Hutan Produksi Terbatas," *GeoEco* **3**(1), (2017).
18. C. Muthiadin, I. R. Aziz, and A. A. Andriyani, "Awaous melanocephalus: Ikan native species dari Sulawesi Barat (sebuah review)," in *Prosiding Seminar Nasional Biologi* (2017), **3**(1).
19. A. Salam, F. M. Sahami, C. Panigoro, Y. I. Arifin, and M. Sakakibara, "Threats to Food Safety and Sustainability of Nike (Awaous melanocephalus) in Gorontalo Province," *KnE Life Sci.* 43–54 (2017).
20. N. W. Mohamad, F. M. Sahami, and C. Panigoro, "Analisis Kandungan Merkuri Pada Ikan Nike di Kota Gorontalo," *NIKe J.* **3**(3), (2015).
21. P. A. R. Yulis, "Analisis kadar logam merkuri (Hg) dan (Ph) air Sungai Kuantan terdampak penambangan emas tanpa izin (PETI)," *Orbital J. Pendidik. Kim.* **2**(1), 28–36 (2018).
22. R. Farantika, S. P. Putro, M. Hadi, and I. Triarso, "Study on water quality physical-chemical parameters aquaculture areas in Menjangan Besar Island, Kepulauan Karimunjawa, Jepara, Indonesia," in *Journal of Physics: Conference Series* (2020), **1524**(1), p. 12136.
23. T. Widyaningrum and T. Suharyanti, "Pengaruh merkuri klorida terhadap pertumbuhan dan histopatologi ginjal ikan nila (Oreochromis niloticus, Linn)," in *Proceeding*

Biology Education Conference: Biology, Science, Enviromental, and Learning (2011), **8**(1), pp. 129–138.
24. J. Swarbrooke, *Sustainable Tourism Management* (Cabi, 1999).
25. T. A. Hose, "3G's for modern geotourism," *Geoheritage* **4**(1–2), 7–24 (2012).
26. T. A. Hose and D. A. Vasiljević, "Defining the Nature and Purpose of Modern Geotourism with Particular Reference to the United Kingdom and South-East Europe," *Geoheritage* **4**(1–2), 25–43 (2012).
27. A. Martínez-Martínez, J. G. Cegarra-Navarro, and A. García-Pérez, "Environmental knowledge management: A long-term enabler of tourism development," *Tour. Manag.* **50**(April), 281–291 (2015).
28. H. Bouzekraoui, A. Barakat, M. El Youssi, F. Touhami, A. Mouaddine, A. Hafid, and Z. Zbigniew, "Mapping Geosites as Gateways to the Geotourism Management in Central High-Atlas (Morocco)," **37**(1), (2018).
29. I. A. Kurniawan, H. Sugawara, M. Sakakibara, Y. I. Arifin, and E. Sunarty, "The Potential of Gorontalo Province as Global Geopark," (2017).
30. Y. Arifin, M. Sakakibara, and K. Sera, "Impacts of Artisanal and Small-Scale Gold Mining (ASGM) on Environment and Human Health of Gorontalo Utara Regency, Gorontalo Province, Indonesia," *Geosciences* **5**(2), 160–176 (2015).
31. M. Kantsperger, H. Thees, and C. Eckert, "Local participation in tourism development-roles of non-tourism related residents of the Alpine Destination Bad Reichenhall," *Sustain.* **11**(24), (2019).
32. S. Abdussamad and others, "Sistem Informasi Geografis Potensi dan Pemanfaatan Energi di Propinsi Gorontalo," *Penelit. Unggulan Fak.* **1**(661), (2013).
33. K. Sera, S. Futatsugawa, and S. Murao, "Quantitative analysis of untreated hair samples for monitoring human exposure to heavy metals," *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms* **189**, 174–179 (2002).
34. Basri, M. Sakakibara, and K. Sera, "Current Mercury Exposure from Artisanal and Small-Scale Gold Mining in Bombana, Southeast Sulawesi, Indonesia—Future Significant Health Risks," *Toxics* **5**(1), 7 (2017).

35. K. Sera, S. Futatsugawa, and K. Matsuda, "Quantitative analysis of untreated bio-samples," *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms* **150**(1), 226–233 (1999).
36. M. T. Kitong, J. Abidjulu, and H. S. Koleangan, "Analisis merkuri (Hg) dan arsen (As) di sedimen sungai Ranoyapo kecamatan Amurang Sulawesi Utara," *J. MIPA* **1**(1), 16–19 (2012).
37. H. S. R. Pamungkas, H. Thayib, and I. Inswiasri, "Potensi Sebaran Limbah Merkuri Pertambangan Emas Rakyat Di Desa Cisungsang, Kabupaten Lebak, Banten," *Indones. J. Heal. Ecol.* 14(3), 195–205 (2015).
38. S. Safratilofa and K. Kaizar, "Analisis Kandungan Merkuri (Hg) di Dalam Tubuh Ikan Patin Siam (Pangasius Hypopthalmus) yang diberi Perlakuan Fitoremediasi Dengan Tanaman Azolla (Azolla microphilla)," *J. Akuakultur Sungai dan Danau* **3**(1), 27–34 (2018).
39. Y. Kristianingsih, "Bahaya Merkuri Pada Masyarakat Dipertambangan Emas Skala Kecil (Pesk) Lebaksitu," *J. Ilm. Kesehat.* 10(1), 32–38 (2018).
40. A. Rosihan and H. Husaini, "Logam berat sekitar manusia," (2017).
41. C. R. Kanzler, P. Lian, E. L. Trainer, X. Yang, N. Govind, J. M. Parks, and A. M. Graham, "Emerging investigator series: methylmercury speciation and dimethylmercury production in sulfidic solutions," *Environ. Sci. Process. \& Impacts* **20**(4), 584–594 (2018).
42. Y. I. Arifin, M. Sakakibara, S. Takakura, M. Jahja, F. Lihawa, and K. Sera, "Artisanal and small-scale gold mining activities and mercury exposure in Gorontalo Utara Regency, Indonesia," *Toxicol. \& Environ. Chem.* **102**(10), 521–542 (2020).
43. S. M. Raihan, M. Moniruzzaman, Y. Park, S. Lee, and S. C. Bai, "Evaluation of dietary organic and inorganic mercury threshold levels on induced mercury toxicity in a marine fish model," *Animals* **10**(3), 405 (2020).
44. J. Azar, M. H. Yousef, H. A. N. El-Fawal, and A. Abdelnaser, "Mercury and Alzheimer's disease: A look at the links and evidence," *Metab. Brain Dis.* **36**(3), 361–374 (2021).

45. S. S. Sonone, S. Jadhav, M. S. Sankhla, and R. Kumar, "Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain," *Lett. Appl. NanoBioScience* 10(2), 2148–2166 (2020).
46. S. Kumar, S. Prasad, K. K. Yadav, M. Shrivastava, N. Gupta, S. Nagar, Q.-V. Bach, H. Kamyab, S. A. Khan, S. Yadav, and others, "Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation approaches-A review," *Environ. Res.* 179, 108792 (2019).
47. E. C. Moody, S. G. Coca, and A. P. Sanders, "Toxic metals and chronic kidney disease: a systematic review of recent literature," *Curr. Environ. Heal. reports* **5**(4), 453–463 (2018).
48. M. Ren, J. Zhao, B. Wang, H. An, Y. Li, X. Jia, J. Wang, S. Wang, L. Yan, X. Liu, and others, "Associations between hair levels of trace elements and the risk of preterm birth among pregnant Wwomen: A prospective nested case-control study in Beijing Birth Cohort (BBC), China," *Environ. Int.* 158, 106965 (2022).
49. I. Salcedo-Bellido, E. Gutiérrez-González, E. Garc\'\ia-Esquinas, N. F. de Larrea-Baz, A. Navas-Acien, M. Téllez-Plaza, R. Pastor-Barriuso, V. Lope, J. L. Gómez-Ariza, T. Garc\'\ia-Barrera, and others, "Toxic metals in toenails as biomarkers of exposure: a review," *Environ. Res.* 197, 111028 (2021).
50. C. Campanale, C. Massarelli, I. Savino, V. Locaputo, and V. F. Uricchio, "A detailed review study on potential effects of microplastics and additives of concern on human health," *Int. J. Environ. Res. Public Health* 17(4), 1212 (2020).
51. M. Bilal and H. M. N. Iqbal, "An insight into toxicity and human-health-related adverse consequences of cosmeceuticals—a review," *Sci. Total Environ.* 670, 555–568 (2019).
52. N. A. Gafur, M. Sakakibara, K. Sera, and Y. I. Arifin, "Toxic Metal Concentrations of Human Hair in Downstream of ASGM Sites in Bone Bolango Regency, Gorontalo Province, Indonesia," in *IOP Conference Series: Earth and Environmental Science* (2020), 536(1), p. 12006.
53. R. D. Raju, "Energy resources and mineral exploration," *Radioact. Miner. New Delhi Natl. Sci. Digit. Libr. NISCAIR* (2008).

54. A. Selvi, A. Rajasekar, J. Theerthagiri, A. Ananthaselvam, K. Sathishkumar, J. Madhavan, and P. K. S. M. Rahman, "Integrated remediation processes toward heavy metal removal/recovery from various environments-a review," *Front. Environ. Sci.* **7**, 66 (2019).
55. A. W. W. Badaru, F. Lihawa, and I. N. Manyoe, "Geologi Daerah Dimito dan Sekitarnya Kabupaten Boalemo Provinsi Gorontalo," *Jambura Geosci. Rev.* 1(1), 13–21 (2019).
56. R. W. Van Bemmelen, "General Geology of Indonesia and adjacent archipelagoes," *Geol. Indones.* (1949).
57. R. Hall and M. E. J. Wilson, "Neogene sutures in eastern Indonesia," *J. Asian Earth Sci.* 18(6), 781–808 (2000).
58. M. J. Armstrong, R. W. Armstrong, and K. Mulliner, *Chinese Populations in Contemporary Southeast Asian Societies: Identities, Interdependence and International Influence* (Routledge, 2012).
59. T. M. Van Leeuwen, "25 years of mineral exploration and discovery in Indonesia," *J. Geochemical Explor.* 50(1–3), 13–90 (1994).
60. T. M. van Leeuwen and T. M. Muhardjo, "Stratigraphy and tectonic setting of the Cretaceous and Paleogene volcanic--sedimentary successions in northwest Sulawesi, Indonesia: implications for the Cenozoic evolution of Western and Northern Sulawesi," *J. Asian Earth Sci.* **25**(3), 481–511 (2005).
61. I. Kavalieris, T. M. van Leeuwen, and M. Wilson, "Geological setting and styles of mineralization, north arm of Sulawesi, Indonesia," *J. Southeast Asian Earth Sci.* **7**(2–3), 113–129 (1992).
62. T. Apandi and S. Bachri, "Geologi Lembar Kotamobagu," *Pus. Penelit. dan Pengemb. Geol. Direktorat Jenderal Pertamb. Umum Dep. Pertamb. dan Energi* (1997).
63. T. Apandi and S. Bachri, *Peta Geologi Lembar Kotamobagu, Sulawesi* (Direktorat Geologi, 1997).
64. N. Ratman, *Tolitoli, North Sulawesi* (Geological Survey of Indonesia, 1976).
65. T. M. van Leeuwen, R. Taylor, A. Coote, and F. J. Longstaffe, "Porphyry molybdenum mineralization in a continental collision setting at Malala, northwest Sulawesi, Indonesia," *J. Geochemical Explor.* **50**(1–3), 279–315 (1994).

66. P. P. dan Pengembangan Geologi (Indonesia), R. Sukamto, and H. Sumadirdia, *Peta Geologi Tinjau Lembar Palu, Sulawesi 1: 250,000* (Pusat Penelitian dan Pengembangan Geologi, 1973).
67. T. Apandi, "Geological map of the Kotamobagu sheet, Sulawesi," *Geol. Res. Dev. Cent. Bandung Indones.* 2316–2317 (1997).
68. D. S. Trail, T. U. John, M. C. Bird, R. C. Obial, B. A. Pertzel, D. B. Abiog, and S. Parwoto, *The General Geological Survey of Block 2, Sulawesi Utara, Indonesia* (1974).
69. S. Bachri and R. L. Situmorang, "Geological Map of the Dili Quadrangle 2406--2407, scale 1: 250 000," *Geol. Res. Dev. Centre, Bandung* (1994).
70. K. E. Marks, "An assessment of the functional significance of Nypa fruticans wetlands in the Tallo River Basin, Sulawesi.," (1995).
71. BLH Gorut, *Laporan Akhir: Studi Kandungan Merkuri Dalam Darah Masayrakat Penambang Di Desa Buladu Kecamatan Sumalata Kabupaten Gorontalo Utara Provinsi Gorontalo* (2011).
72. Y. Yang, P. C. Van Metre, B. J. Mahler, J. T. Wilson, B. Ligouis, M. M. Razzaque, D. J. Schaeffer, and C. J. Werth, "Influence of coal-tar sealcoat and other carbonaceous materials on polycyclic aromatic hydrocarbon loading in an urban watershed," *Environ. Sci. \& Technol.* 44(4), 1217–1223 (2010).
73. S. Taniu, A. P. Yakup, and M. A. Novriansyah, "Shift share analysis to determine regional economic performance of Gorontalo," *Gorontalo Dev. Rev.* **3**(2), 102–113 (2020).
74. Y. Pikoli, B. R. Rachman, and W. Yasin, "Nadzir's Role in the Management of Waqf Mosque Land in Bone Bolango Regency, Indonesia," *Talaa J. Islam. Financ.* 1(1), 46–55 (2021).
75. M. Pateda, M. Sakakibara, and K. Sera, "Element Rich Area Associated with Human Health Disorders: A Geomedical Science Approach to Potentially Toxic Elements Contamination," *Int. J. Environ. Res. Public Health* 18(22), 12202 (2021).
76. A. Y. Permana, I. Susanti, N. I. K. Dewi, and K. Wijaya, "Morphology of Urban Space: Model of Configuration using Logic of Space (LoS) Theory in densely populated of

Bandung City," *J. Archit. Res. Educ.* **1**(1), 18–35 (2019).

77. Y. Blancuzzi, A. Padilla, A. Cave, and J. Parello, "Symmetrical rearrangement of the cation-binding sites of parvalbumin upon calcium/magnesium exchange. A study by proton 2D NMR," *Biochemistry* **32**(5), 1302–1309 (1993).
78. J. D. Moody and M. J. Hill, "Wrench-fault tectonics," *Geol. Soc. Am. Bull.* 67(9), 1207–1246 (1956).
79. M. J. Rickard, "Fault classification: discussion," *Geol. Soc. Am. Bull.* **83**(8), 2545–2546 (1972).
80. S. Husein, A. Mustofa, I. Sudarno, and B. Toha, "Tegalrejo Thrust Fault as an Indication of Compressive Tectonics in Baturagung Range, Bayat, Central Java," *Pertem. Ilm. Tah. Ikat. Ahli Geol. Indones. ke-37, Bandung, Indones.* (2008).
81. A. M. Bateman, *Economic Mineral Deposits* (1950).
82. D. Damayani, S. E. Kamil, and others, "Efek Residu Dari Kombinasi Media Tanam Abu Vulkanik Merapi, Pupuk Kandang Sapi Dan Tanah Mineral Terhadap C-organik, Kapasitas Pegang Air, Kadar Air Dan Bobot Kering Pupus Tanaman Jagung (Zea Mays L.)," *Bionatura* **15**(3), (2013).
83. L. C. Graton, "Waldemar Lindgren, 1860-1939," *Econ. Geol.* 34(8), 850--850f (1939).
84. N. N. Sune and others, "Pemodelan Spasial Ekologis Pengelolaan Kawasan Hutan Berbasis Masyarakat di DAS Bone," *Hibah Bersaing (DP2M)* **2**(973), (2015).

Index

About the Writer

Yayu Indriati Arifin, born in Gorontalo City. Yayu holds a bachelor's degree in Physic Education at Universitas Negeri Gorontalo, master's degree in Geophysics at Bandung Institute of Technology, and a doctorate in Geology at Ehime University, Japan. Yayu is a lecturer in Geological Engineering major, Universitas Negeri Gorontalo and as the Head of Study Center of Energy and Mineral Resources and Geopark. The main focus of her research is medical geology, geotourism, and rock magnetism.

Yayu participated in a Post-doctoral program in Colorado University 2019. She participated in training program of making Thin Section in Ehime University 2010. She participated in Center for Development of Sustainable Region (CDSR) collaborate with 7 universities they are UGM the leader, Colorado University, UI, UNG, ITB, UMGO, UBB supported by USAID Indonesia 2017. She joined in international collaborative research in the field of eco-geotourism with the Research Institute for Humanity and Nature, Kyoto, Japan and joined in geothermal scientific writing with lecturers at the Institute Technology of Petronas (ITP), Malaysia.

Yayu awarded as the best presenter in The 23rd Symposium on Geo-Enviroments and Geo-Technics, 2013. Communication with her via email yayuarifin@ung.ac.id.

Geotourism,
A Solution to Environmental Pollution of the Artisanal Gold Mining

(Case Study of Tulabolo Village, Gorontalo)

Artisanal gold mining activities have been carried out illegally in Gorontalo Province and distributed in various locations such as in Buladu and Hulawa villages, East Sumalata sub-districts, Mount Pani in Pohuwato, and Tulabolo in East Suwawa. Economic growth in the surrounding area is visible but the environmental pollution caused is also unavoidable. In Tulobolo there is also tourism potential with the existence of a geotourism site known as Hungayono, which is a location rich in geological and biological diversity. The Hungayono site has become a special tourist destination for tourists who want to see firsthand how the maleo and tarsiers are preserved. What is the scenario for nature conservation and its management amid the threat of environmental damage due to gold mining? will be discussed in this book.

ideas PUBLISHING

Alamat: Jalan Ir. Joesoef Dalie, No. 110 Kota Gorontalo 96128
Pos-el: infoideaspublishing@gmail.com
Website: www.ideaspublishing.co.id

ISBN 978-623-234-239-2

9 786232 342392