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Review: A descriptive study of karst conditions and problems in Indonesia and the role of karst for flora, fauna, and humans

DEWI APRILIA[1,♥], KIRANA NURUL ARIFIANI[1], MUHAMMAD FAJAR SANI[1], JUMARI[2], FAHMA WIJAYANTI[3], AHMAD DWI SETYAWAN[1,4,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Urip Sumoharjo, Surakarta 57128, Central Java, Indonesia. Tel./fax.: +62-271-663375. ♥email: volatileoils@gmail.com

[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Diponegoro. Jl. Prof. Sudarto, SH., Semarang 50275, Central Java, Indonesia

[3]Biology program, Faculty of Science and Technology, Universitas Islam Negeri Syarif Hidayatullah Jakarta. Jl. Ir. H Juanda No. 95, Ciputat, Tangerang Selatan 15412, Banten, Indonesia

[4]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

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Abstract. *Aprilia D, Arifiani KN, Sani MF, Jumari, Wijayanti F, Setyawan AD. 2021. Review: A descriptive study of karst conditions and problems in Indonesia and the role of karst for flora, fauna, and humans. Intl J Trop Drylands 5: 61-74.* The karst area in Indonesia covers an area of about 15.4 million hectares and is spread almost throughout Indonesia. It is estimated the age of karst in Indonesia started from 470 million years ago to the most recent about 700,000 years. The existence of this area shows that many of the Indonesian islands were once seabed but were later uplifted and hardened. Most of the karst areas in Indonesia are composed of carbonate rocks, and almost none are composed of other rocks such as gypsum, salt rock, and evaporite rocks. Karst in Indonesia can be classified based on its development and climate. The amount of water available in the karst area plays an important role in human life and so do flora and fauna around the karst area. The karst area functions as an ecosystem for the habitat of various animals and plants. The richness of flora and fauna of this karst area is extraordinary. Karst area plays an important role in economy, science, and human culture. In addition, karst areas have an important role in the ecosystem, such as providing clean water, limestone-based natural materials, and controlling climate change. Its role in ecological function is that karst areas can also be a source of CO_2 gas absorption. About 9.5% (155,000 km^2) of the total karst area of Indonesia was damaged due to limestone mining activities, logging of vegetation, and land conversion. Given the importance of karst and limestone ecosystems as non-renewable natural resources, it is necessary to do conservation to maintain the ecological function. Steps that can be taken for conservation efforts in karst areas include limiting the sale of raw limestone to outside the area, clarifying protected areas and cultivation areas, socializing the importance of preserving karst areas, providing skills or developing other business opportunities, and reclaiming used land and mining according to the level and type of damage. This study aims to describe the geographical conditions and karst problems in Indonesia so that the conservation measures taken are known and identify the role of the karst area for flora, fauna, and humans.

Keywords: Karst, karst conservation, karst problems, karst types, role of karst

INTRODUCTION

Karst is a German term derived from the Slovenian language kras, which means rocky arid land (Faida et al. 2011). Karst is a limestone area with a typical landscape shape in Slovenia that spreads to Italy. The area then becomes a type locality in a karst landscape (Milanovic 1981) in (Puradimaja 2006). Karst area is a landscape that was formed a very long time. Karst is a landform composed of carbonate rock (limestone) that undergoes a solutional process to form a unique and distinctive morphological and hydrological order.

Wuspada (2012) defines karst as a field with typical hydrological conditions resulting from soluble rock and a well-developed secondary porosity. The characteristics of karst are the presence of closed basins, dry valleys of various sizes and shapes, rare surface drainage/rivers, and the presence of caves from underground drainage systems. Karst occurs not only in carbonate rocky areas but also in other easily soluble rocks and has secondary porosity (joints and intensive faults), such as gypsum rock and salty rock (Juliani 2015). In Indonesia, the karst area has an area of approximately 15.4 million hectares (Candra 2011). The dissolution process (solutional/karstification) causes the formation of a unique hydrological system. The hydrological system is strongly influenced by secondary porosity (flow of groundwater through dissolution gaps) which causes water to enter the underground flow system and causes dry conditions at the soil surface (Cahyadi et al. 2013). Karst area is an area that can capture and store rainwater (Haryono 2000).

The karst area is closely related to the presence of caves. These caves are unique from the karst area. The existence of karst caves is an indicator of the development of karst landforms. The formation of the cave occurs by the ongoing process of dissolving and widening of limestone

cracks (Ashari 2013). Caves have various characteristics, including vertical caves, horizontal caves, caves that flow underground rivers, dry caves, and various kinds of ornaments contained in them (Harmony and Pitoyo 2012). These caves are generally terraced with less than one meter to hundreds of square meters with a vertical tilt or horizontal shape. Almost all of the karst caves are decorated with ornaments (speleothems) that vary from very small to very large (columns) with varying shapes and colors (Adji et al. 1999). Caves have both direct and indirect benefits. The direct benefits of the cave include the development of the cave as a tourist attraction.

According to Wiyanata et al. (2018), a karst area has three functions, namely ecological functions, economic functions, and educational and cultural functions. The ecological function of the karst area is as a place for flora and fauna to live, store groundwater, and absorb carbon. Meanwhile, the function of regional education and culture is, among others, a medium of learning and cultural wisdom. The economic function of the area is as a tourist place. As an ecological function, the karst area has a wealth of biodiversity. In Indonesia, 17 locations can be categorized as biodiversity karst areas. Karst biodiversity is divided into biodiversity based on the surface (exokarst) and below the surface (endokarst), also known as caves. Organisms in caves are grouped into terrestrial and aquatic organisms (Prakarsa and Ahmadin 2017). Caves in karst areas are home to various fauna communities such as bat communities (Wijayanti et al. 2010; Wijayanti and Maryanto 2017). Biological resources in the karst area are not too abundant due to the thin soil and scarcity of groundwater in the area. Karst areas are known for their low resistance to change or disturbance (Gillieson 1997). As an economic function, the karst area also contains non-biological natural resources, limestone, a group excavation material. The karst area also has the potential as a mining area because of its hilly physiography formed from limestone (Haryono and Adjie 2004).

The karst ecosystem has a very important function in the environment and its social, cultural, and economic values. Seeing its uniqueness and strategic function, this ecosystem is categorized as a protected area in Indonesian laws and regulations. Some karst areas have tourist activities in them. Still, this activity can disrupt the surrounding ecosystem and it is feared that the fauna population in it and the cave ecosystem will decline, considering that the ecosystem, especially in the cave, is related to the ecosystem outside the cave (Tamasuki et al. 2015). Currently, the operationalization of the "protected area" status has not been carried out properly, thus causing most of the karst ecosystems in Indonesia to be potentially exploited (Widyaningsih 2017). Karst, especially caves, is increasingly threatened by traditional limestone mining (Prakarsa 2013) and land use for housing (Mijiarto et al. 2014). Mining activities can hurt the karst ecosystem, for example, the destruction of the hydrological system that can cause drought (Widiyastuti 2018). Karst area is a non-renewable natural resource, so these conditions need to be protected in the form of Geological Heritage (Geoheritage), this term implies protection of natural heritage which can later be passed down to the next generation in the future (Irianto et al. 2020). This study aims to describe the geographical conditions and karst problems in Indonesia so that the conservation measures taken are known and identify the role of the karst area for flora, fauna, and humans.

GEOGRAPHY OF KARST IN INDONESIA

Indonesia is one of the countries with a fairly large karst area, estimated at ± 15.4 million hectares (BAPPENAS 2016). Indonesia has a variety of karst landforms found in almost all islands and archipelagos in Indonesia (Jayanto et al. 2017). Karst areas are scattered almost throughout the island, from Papua to Aceh. Most of the southern coast of Java Island is a karst area, with an elongated shape from west to east. There are seventeen major karst areas in Indonesia. Among these karst areas, two karst areas are the best and are considered prototypes of tropical karst, namely the Maros karst and Gunung Sewu karst (Adji et al. 1999). Karst area is a typical landscape with high natural resource wealth (Raguz 2008).

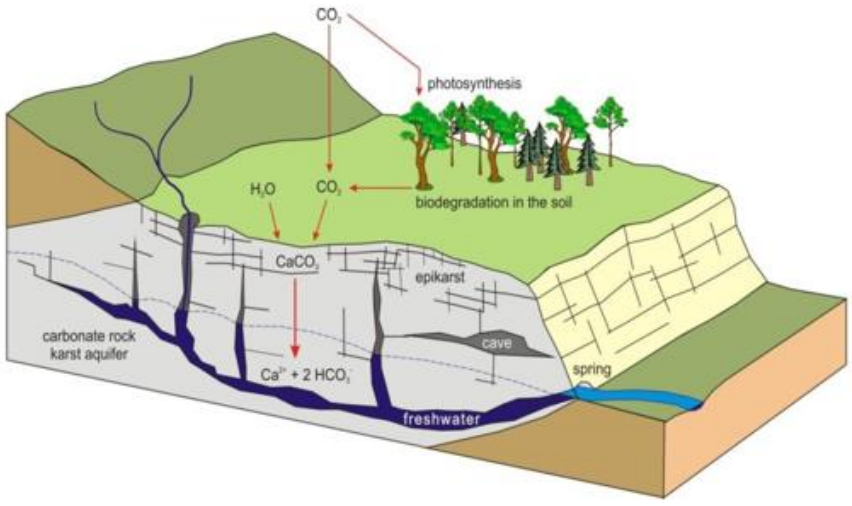


Figure 1. Illustration of the process of karstification (carbonate rock dissolution) (Goeppert and Goldscheider 2019)

The existence of karst areas in Indonesia has a very strategic value. In addition to the potential area of Indonesia's karst landscape of 154,000 km^2, equivalent to 0.08% of Indonesia's land area, karst has potential that is not unique and distinctive but is also very rich in natural resources, both biological and non-biological. The estimated age of Indonesian karts started from 470 million years ago to the most recent about 700,000 years. The existence of this area shows that many of the Indonesian islands were once seabed but were later uplifted and hardened. Karst areas are usually hilly with many caves (Sukandarrumidi and Maulana 2014). Most of the karst areas in Indonesia are composed of carbonate rocks, and almost nothing is composed of other rocks such as gypsum, salt rock, or evaporite rock. Nearly every island in Indonesia has carbonate rocks, but not all are karstified into karst areas. Karstification will be more intense when these rocks are overwritten by rainwater containing a lot of CO_2 (Goldscheider et al. 2007).

The existence of karst areas in Indonesia is currently considered very strategic values. The karst area reaches almost 20% of the total area throughout the Indonesian archipelago. The strategic values in question, apart from being an area as a supplier and reservoir of water for domestic purposes (the UN estimates that around 25% of the world's population is a source of karst water, Ko 1997), also have natural resources that can be used to increase the country's foreign exchange such as tourism, mining of minerals, producing swallow's nests, and even closely related to the field of defense and security/military, and intelligence (Adji et al. 1999).

Karst area, according to Ford and Williams (1989), is an area that has distinctive relief and drainage characteristics and occurs in rocks that are easily soluble and have well-developed secondary porosity, such as carbonate rocks (usually limestone, dolomite, or marble), although there are also what happens not in carbonate rocks. The karst area has various features. In terms of endokarst (subsurface morphology division), the formation of underground caves, rivers, and underground springs, complex underground drainage systems (Maulana 2011), and exokarst (distribution of surface morphology) the area is manifested in the form of basins. In the form of small hills, hillsides, and rock carvings on the karst surface, valley curves, and the mouth of the cave formed from the dissolution of rocks by rainwater, which has a typical relief and drainage in the form of limestone. Limestone has a high porosity value as a result when rainwater falls on the karst area, the rainwater will penetrate through the cracks of the rocks that make up the area so that the karst area has a lot of beauty. Several features above result from a very long natural process (Hutomo et al. 2016). The karst area is a landscape with steep slopes. There are many basins, prominent and irregular limestones, caves, a continuous underground flow system, and forests with different soil surface textures and compositions at each altitude. The unique condition of this karst area causes the biota living in the karst area to be unique (Ko 2003). The International Union for The Conservation of Natural Resources (Williams 2008) defines karst areas as protected areas because of their function as storage of groundwater and biodiversity in karst areas and non-renewable karst resources. Karst areas have quite real potential in an ecosystem.

Under certain environmental conditions, each type of plant spreads with varying degrees of adaptation, thus causing the presence or absence of a plant species in the environment. Environmental factors can affect the structure and composition of vegetation formed in an area (Haryono and Adji 2004). One of the environmental factors that can affect a vegetation community is altitude. Altitude has a very strong influence on tree species distribution (Kurniawan and Parikesit 2008).

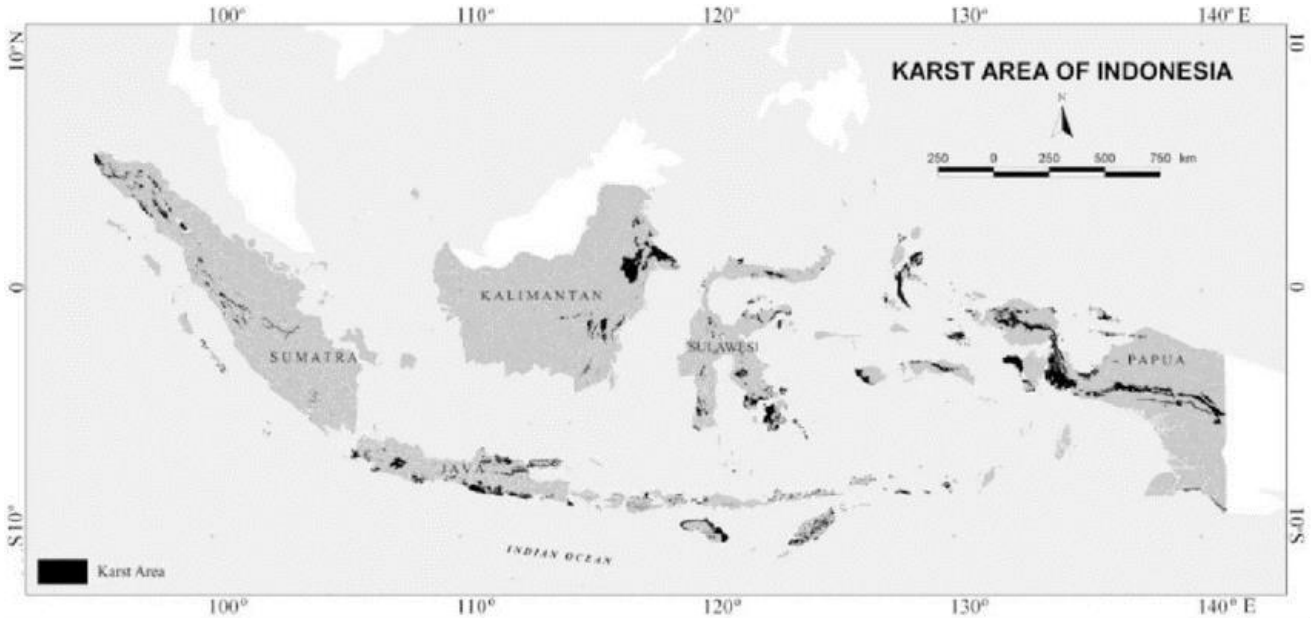


Figure 2. Indonesian karst areas compiled from a geological map of Indonesia (Source: Indonesian Geological Survey)

Karst area is a non-renewable natural resource with high natural resource function and potential (Beynen and Townsend 2005). Forest ecologists classify limestone hill forests as one forest ecosystem (Achmad 2011). There is rarely living vegetation or only vegetation in limestone hills such as weeds that can live and there is no strong and deep vegetation, the limestone mountain area will be prone to an avalanche. Karst area is a very unfavorable area for most plants. It can be seen from the thin soil conditions, limited nutrients, very limited water, very limited water, unfriendly weather, hot conditions, especially in the dry season. Plants that live in this area will, of course, undergo a process of adaptation to the environment (Rahmanizah et al. 2019). The soil in the karst area is formed from limestone with low nutrient content except for calcium and magnesium, making the vegetation in the karst area unique. The appearance and composition of vegetation species in karst areas are different from other vegetation types. Many plant species in the karst area are endemic and several species have economic value. This is in addition to the high calcium and magnesium content due to extreme climatic conditions such as sunlight, rainfall, dry periods, underground drainage systems (Vermeulen and Whitten 1999), and differences in plant tolerance to physical factors karst areas (Whitten et al. 1999). Vegetation in karst areas can protect water catchment areas, work well and provide protection for the function of springs in underground rivers (Sugita et al. 2015). Given the function of the karst area as a water reservoir.

TYPES OF KARST IN INDONESIA

Karst area is mostly composed of carbonate rocks, especially limestone $CaCO_3$ and dolomite $CaMg(CO_3)_2$ (Sulastoro 2013). Karst area is a complex geological phenomenon with unique and specific hydrological conditions. The karst area has a unique topography where Indonesia itself has several types of karst (Endah et al. 2017). Classification of karst in Indonesia can be categorized into two groups, namely (i) classification based on development (Cvijić 1914) and (ii) classification based on climate (Sweeting 1972). Based on its development, there are two types of karst, it is merokarst and holokarst. Merokarst is karst with incomplete or partial development with only some characteristics of karst landforms. Merokarst develops in relatively thin and impure limestones, and especially when limestone is interspersed with layers of marl. Examples of merokarst in Indonesia include the karst around Rengel, Tuban District. Then there is the holokarst type. The holokarst area is the opposite of merokarst, characterized by almost no surface river flow and which then turns into sub-drainage so that the effective exogenic process is only dissolving, the topographic surface is almost decorated with various karst cones (karst conicals). Among them are karst depressions of various types and sizes (Kusumayudha 2005). Examples of holokarst in Indonesia include the Gunung Sewu Karst (Gunungkidul, Wonogiri, and Pacitan) (Haryono and Adji 2004).

According to Sweeting (1972), karst can be categorized based on climate into (i) Fluviokarst is karst formed by a combination of fluvial processes and dissolution processes generally occurs in limestone rocky areas traversed by allogeneic rivers (river downstream of non-karst areas). Limestone distribution laterally and vertically is much smaller than the true karst. The development of underground circulation is also limited due to the local groundwater table. Fluviokarst caves are formed at the boundary between limestone and underlying impermeable rock by allogeneic rivers and are associated with river development in the karst areas. Limestone surfaces in fluvio karsts are generally covered by soil formed by erosion and sedimentation by fluvial processes. Examples of kegelkarst in Indonesia are several types of karts in the Gunung Sewu Karst area. (ii) Glaciokarst is karst formed as the result of karstification that is dominated by glaciation and glacial processes in limestone areas, an example of glaciokarst in Indonesia is the karst in the Jaya Wijaya Mountain area. (iii) Nivalkarst is karst formed due to karstification by snow in glacial and periglacial environments. Glaciokarst is found in limestone areas that have experienced glaciation or have experienced glaciation. Glaciokarst is characterized by glacier burning, erosion, and sedimentation. Dolines are formed mainly by snowfall. Another characteristic of glaciokarst is the caves filled with ice and snow. An example of glaciokarst is the Carstensz Pyramid karst area, also known as Puncak Jaya in the Jayawijaya Mountains, (iv) Tropical karst differs from karst in temperate and polar mainly due to high precipitation and evaporation in the tropics. Tropical karst is further divided into two groups, namely (i) Kegelkarst (synoid karst, cone karst, or karst a python), and (ii) Turmkarst (tower karst, innacles karst, or karst a tourelles).

A collection of continuous conical hills characterizes Kegelkarst. The gap between the conical hills forms a basin with a star-like shape known as the cockpit. Examples of kegelkarst in Indonesia include the Gunungsewu Karst and the Karangbolong Karst. And those in Java in the Gunung Kidul area (Fahmi et al. 2017). Turmkarst/tower karst/eclepinacle karst is the second type of karst often found in the tropics. Hills characterize this type of karst with steep slopes, usually found in groups separated by rivers or alluvial plains. Tower karst is formed when lateral dissolution by a very shallow groundwater table or allogeneic rivers passes through limestone outcrops. Joints or faults generally control the distribution of tower hills. The size of the tower hills varies greatly from small pinnacles to blocks of several square kilometers in size. Karst towers can be divided into two groups. First, the tower hill is a hill of limestone remnants isolated between limestone flats that have been covered with alluvium deposits. Second, the tower hill is a remnant hill of limestone located on a plain with non-carbonate rocks. Some of the tower karsts in Indonesia can be found on the edge of the Maros Karst bordering the alluvial plain (west side). The hydrological value of cone-shaped (kegelkarst) and tower-shaped (turmkarst) are similar in the dissolving process. Dissolution produces cavities that are interconnected to form secondary porosity. The greatest

dissolution occurs near the surface due to the decreasing solubility of water on its way down due to the increase in dissolved carbonate concentration until it reaches saturation at a depth of 30 to 50 m (Kunardi et al. 2019).

THE ROLE OF KARST FOR FLORA AND FAUNA

The karst area is an area that has unique hydrological characteristics due to the development of dissolving tunnels. This area is formed by the dissolution process of soluble rocks such as carbonate rocks and salty rocks (Ford and William 1992). The unique condition of this karst area causes the biota living in the karst area to be unique (Ko 2003). The presence of light in the cave environment is also very important. Light concentration can affect the cave ecosystem directly, and indirectly affect the cave fauna (Simon et al. 2007). Another uniqueness of the karst area lies in the presence of caves in the karst area which forms a microclimate that is different from the area outside (PPLH 2007). The International Union for The Conservation of Natural Resources (Williams 2008) defines the karst area as a protected area because of its function as a reservoir of groundwater and biodiversity in karst areas, and karst resources that cannot be renewed. Therefore, Karst areas have quite real potential in an ecosystem (White et al. 2019). The existence of karst areas in Indonesia has recently been considered very strategic values. Apart from covering almost 20% of the total area in Indonesia. Karst has potential that is unique and very rich in natural resources, both biological and non-biological. At this point, tension arises, namely the use of natural resources (Kartodihardjo 2012).

The Karst area can store a lot of water because of its unique characteristics and has a hollow soil structure. The suspended aquifer in the epikarst provides a habitat for permanent troglobitic aquatic fauna (William 2008). Karst areas with limestone constituent rocks correlate with small to moderate groundwater continuity and limited groundwater availability (ESDM 1995; Milsom 2003; Fetter 2004; Singhal and Gupta 2010). The amount of water available in the karst area plays an important role in human life and flora and fauna around the karst area. Water resources are a basic need for humans and living creatures (Kurniaty and Danu 2012; Febriarta et al. 2018). In addition, the karst area functions as an ecosystem for the habitat of various animals and plants. As a result, the richness of flora and fauna of this karst area is extraordinary (Jumari 2011).

Fauna

Most of the cave fauna have adapted to the cave environment. The invertebrate fauna in the cave remaining groups comprising molluscs, diplopods, chilopods, annelids, platyhelminths and nematodes. The diversity of troglobite species is fairly typical for karst areas (Eberhard et al. 2014). The fauna found in every cave is crickets (Figure 3). This is in accordance with Kamal et al. (2011) statement that the most numerous Insect groups (both species and numbers) are crickets. This opinion is reinforced by Rahmadi (2005) which states that Hexapoda/Insecta is one of the dominant classes of cave fauna after Crustacea and Arachnida, 25%.

One type of fauna in the cave of the Arachnida class is a spider (Figure 4). Cave spiders will adapt by changing the function of the front legs to become organs of touch, such as the spider's antennae, it will also reduce its eyes and use the sense of taste as a smell. Eyeless spiders can navigate the web and rely on vibrations to detect prey. The sense of touch is generally located in the hairs on his feet. Then the fauna of the class Crustacea, such as shrimp and crab (Figure 5A-B). Cave Crayfish live in deep and dark caves. Almost no light can penetrate where the shrimp live. The environment without light makes the creatures that live in deep and dark holes in the earth's bowels able to adapt without eyes and pigment. Living in a cave causes shrimp to have translucent skin, so they look white (Marin 2021).

Although it is facultative, one of the successful karst vertebrate species is the bat, where the cave is used for resting, nesting, and raising young. Meanwhile, food is obtained from outside the cave. Factors that influence the abundance of bats are the physical structure of the habitat, microhabitat climate, food and water availability, security from predators, competition, and nest availability (Wilkelman 1999).

The other two groups of vertebrates that have successfully colonized and adapted to the subterranean cave environment are fish and salamander (Figure 5C). Still, cave salamander is not recorded yet in Indonesia. In the extreme conditions of the cave, in the absence of light, very high humidity, and constant temperature throughout the year, the cave-dwelling organisms adapt to their environment. Adaptations in sensory compensation occur, pigmentation, eyes are reduced or completely lost, and slow metabolism. Some species of cave exhibit limb weakness. It has been hypothesized that the limb attenuation function to elevate the body and head above the substrate allows more efficient prey detection by the lateral line system (Rahmadi 2002). This proves the physiological changes of animals in the cave.

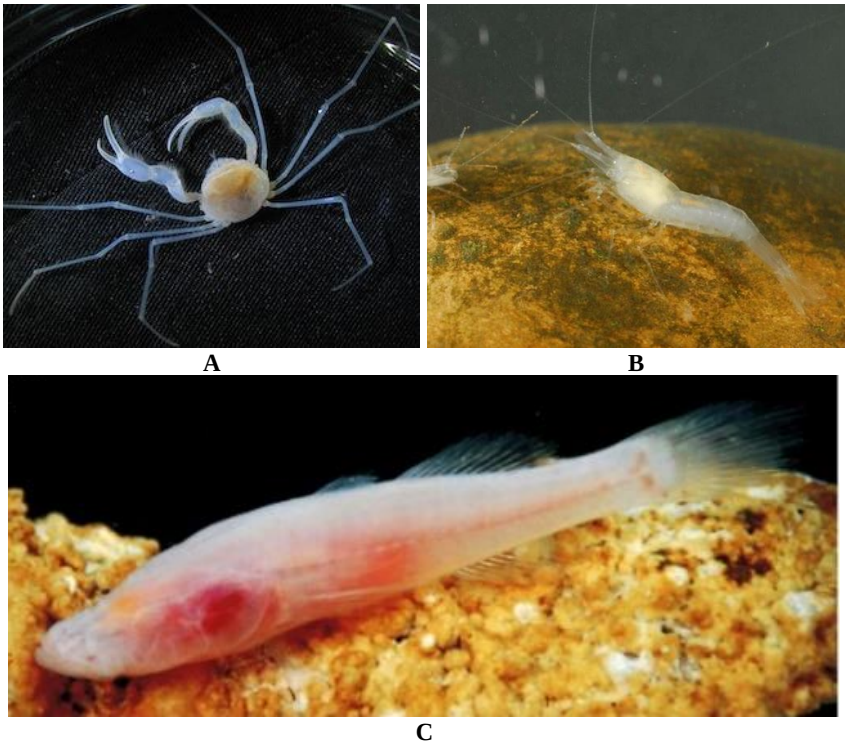
Flora

Many plant species in the karst area are endemic and several species have economic value. This is not only due to the high calcium and magnesium content but also due to extreme climatic conditions such as sunlight, rainfall, dry periods, underground drainage systems (Vermeulen and Whitten et al. 1999), and differences in plant tolerance to physical factors in karst areas (Whitten et al. 1999; Lio and Dewi 2018). Vegetation in karst areas can protect water catchment areas, work well and provide protection for the function of springs in underground rivers (Sugita et al. 2015). Considering the function of the karst area as water storage, it is necessary to cover vegetation that can absorb a lot of water (Tanjung 2004).

A B

Figure 3. Some species of Gryllidae (cricket family) from Dopaam cave, Enggano Island, Indonesia. A. *Charon grayi*, B. *Rhaphidophora oophaga* (Puspita et al. 2020)

Figure 4. *Amauropelma matakecil*, a new colorless spider from Nguwik Cave, Central Java, Indonesia (Photograph by S. Harjanto) (Miller and Rahmadi 2012)



A B C

Figure 5. Some aquatic species from Indonesian karst area. A. *Sulaplax ensifera*, an endemic crab from Muna Island, Indonesia (Photograph by C. Rahmadi) (Rahmadi 2016), B. *Marosina longirostris*, an enemic shrimp from Maros cave karst, Indonesia (Photograph by Rasplus) (Rahmadi 2016), C. *Oxyeleotris colasi*, a blint-colorless fish from Sewiki lake, Kaimana karst area, West Papua, Indonesia (Photo by RK Hadiaty and P. Keith) (Pouyaud et al. 2012)

Priyanti et al. (2011) explained that the most common plant species found in the karst area are Asteraceae and Poaceae. This is due to the nature of the two tribes which have fast reproduction and light seeds, so they are easily carried by the wind (Piji 1982).

The high and low community similarity index can be influenced by environmental conditions both physical, chemical, and interactions between species (Setiadi 2005). In addition to physical and chemical factors, other factors that affect plant communities are animal and human activities (Loveless 1989). According to Marwiyati et al. (2012), the environmental conditions of the karst area that are less supportive of growth and reproduction can be the cause of the low diversity of tree species in the karst area. The existing plant species can adapt and tolerate unique karst environmental conditions. The soil layer that tends to be thin can also affect the number of tree species that grow in the karst area so that in general the number of tree species will be less than the forest with a thicker soil layer. In addition, the high human activity in the karst area impacts the low value of tree species diversity (Whitten et al. 1999).

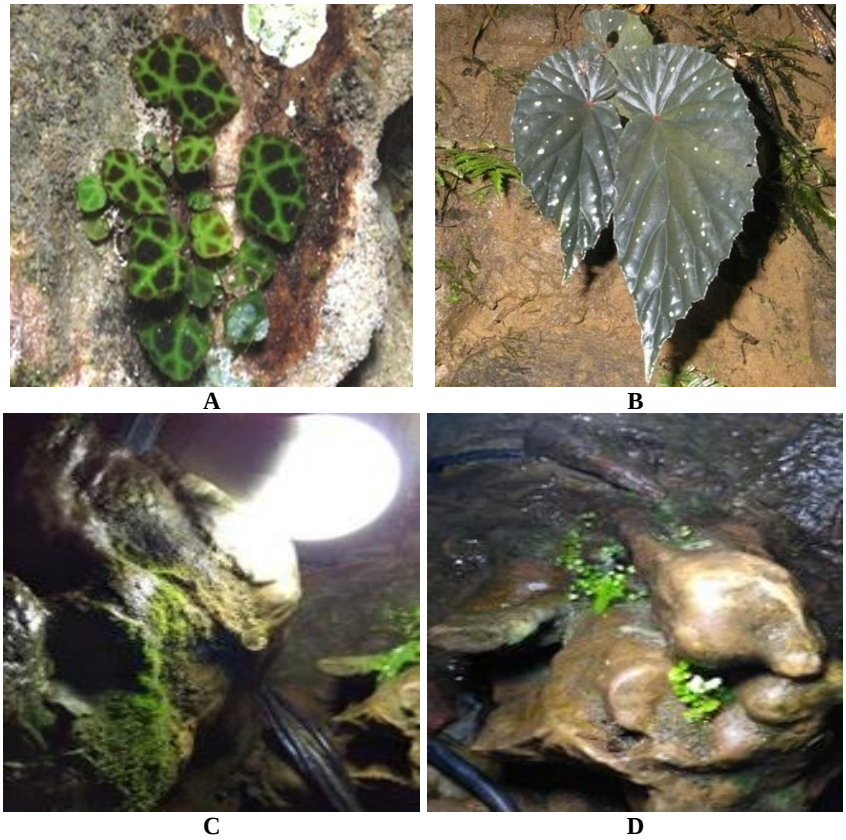


Figure 6. A. *Begonia droopiae* (Ardi 2010), B. *Begonia atricha* (Girmansyah 2017), C. Lampenflora (Bryophyta) (Kurniawan et al. 2018), D. Lampenflora (Pteridophyta) (Kurniawan et al. 2018)

Publications regarding the diversity of endemic plant species in Indonesia's karst areas are still rare. In the karst area of Sumatra, there are plants typical of the karst area, namely *Begonia* spp., that are supposedly endemic species (Figure 6A-B). Publications regarding the diversity of endemic plant species in Indonesia's karst areas are still rare. In the karst area of Sumatra, there are plants typical of the karst area. *Begonia droopiae* (Ardi 2010) was found in Perkaulan Cave, West Sumatra. *Begonia atricha* (Girmansyah 2017) was found in the cave area of Palembayan, West Sumatra. Hughes (2008), stated that there are about 45 species of Begonias from Sumatra. Out of 1500 species of Begonias are scattered in Southeast Asia. About 33 species of *Begonia* in West Sumatra are divided into six sections. One species has not been included in the existing section because it has a generative character that has not been recorded in the publication Doorenbos et al. (1998). Begonias that live in karst areas generally have unique characteristics, namely thicker leaves and the ability to do dormancy in the dry season (Girmansyah 2017).

There is another distinctive species, namely Lampenfllora. This is a complex community of autotrophic photosynthetic organisms in illuminated areas like rocky rocks, and sediments. Lampenflora also thrives in nature and artificial caves around artificial light sources. Mosses and ferns, also part of the lampenflora (Figure 6C-D). Lampenflora is a community relative to the aerophytic phototrophs of the cave entrance, which is completely independent of sunlight and external climate or other factors (Priyanti et al. 2011).

THE ROLE OF KARST FOR HUMANS

Ecology

Carbon sequestration. Karst areas have a role in ecology, economy, and human culture. Purnaweni (2014) stated that karst areas have an important role in the ecosystem by providing clean water, limestone-based natural materials, and controlling climate change. Its role in the ecological function of karst areas can also be a source of CO_2 gas absorption. CO_2 is a molecule composed of the elements carbon and oxygen. CO_2 is one of the causes of global warming and several other gases such as CH_4, CFC, N_2O, and O_3. The karst area's absorption of CO_2 occurs due to the karstification process. The process begins with the dissolution of CO_2 in water and then forms H_2CO_3. The H_2CO_3 solution is unstable, so it decomposes into $(HCO_3)^{2-}$ and H^+. This H^+ ion will decompose limestone ($CaCO_3$) into Ca^{2+} and HCO^{3-}. The absorption of CO_2 gas occurs because of Indonesia's position in the tropics, which is influenced by the global atmospheric movement system. Global atmospheric movements that affect CO_2 levels in the tropics are caused by the Intertropical Convergence Zone (ITCZ) phenomenon. The existence of this phenomenon causes the movement of air masses from 300 LU and 300

LS towards the tropics which not only carries air masses but also carries water vapor, gases that cause the greenhouse effect, and others. Therefore, the absorption of CO_2 by karst areas in the tropics becomes very important to prevent or reduce excessive concentrations of CO_2 that have an impact on global warming (Cahyadi 2010).

Water conservation. The hydrological cycle is the role of karst areas in the social and environmental fields in people's lives. The role of the karst is important for its extraordinary water cycle (Khairurrahman 2021). The karst area is a source of life for local residents. Water sources in the karst area can be used as springs and residents' agriculture. Some of the lakes called "lakes" become a source of water supply. The potential of these water resources is influenced by the input of rainfall and karstified limestone and the morphology of the karst hills. Most of the water from rainfall in the karst area will enter the cracks (epikarst) on the surface and then be stored in the cavities resulting from the dissolving. Karst hills can store water three to four months after the rainy season, by releasing water slowly into underground river systems. So that karst hills must be protected to face drought in the dry season. Conservation actions that can be taken include maintaining and managing karst hills according to their designation by referring to the type of karst area, regulating limestone mining, rehabilitating ex-mining land, and managing epikarst and ponor/luweng zones (Haryono and Day 2004).

Economics

Mining. The large number of natural resources in the karst area, ultimately makes the area a potential land that provides many advantages (Amalia et al. 2016). The economic role of the karst area in the economic field is divided into two parts, namely the non-renewable role and the renewable role. The non-renewable role is the karst area as a mining area. The current policy of the Indonesian government is the development of infrastructure in various regions. In line with that, the need for building materials such as limestone will increase. (Sarwanto and Sari 2017). The abundant natural resources of lime have become the mining center for cement production. This area is a source of livelihood for the surrounding community who work with companies established around the karst area. Although it plays a very important role in people's lives, karst areas are vulnerable to disturbances from the undirected socio-economic dynamics of the community. Limestone mining will change the landscape significantly and has the potential to damage the environment, the losses can even outweigh the benefits that can be obtained from mining activities; and to overcome the damage to karst areas, it takes decades of ecological compensation and very large costs (Zhou et al. 2014).

Agriculture. The economic role of renewable karst is its existence as a source of irrigation. There are slopes of the karst area which have been converted into terraced agricultural land. It serves to maintain soil moisture, prevent erosion, and so on. Most of the slopes and terraces play a role in supporting permanent dry land without the aid of irrigation, making it possible to establish rural agriculture spread over the many karst basins (Setyawan 2007).

Ecotourism. Another socio-economic role that is also the role of education is that the karst area becomes a tourist spot. With the existence of tourist attractions, the economic level of the community will increase both from the source of profits from the management of the tourist area and because of opening a business around the karst area. For example, the karst area of Gunung Sewu muntains, southern Java. UNESCO recognizes this area as one of the global geoparks with enormous geological potential. This area has built a tourist attraction in the form of a karst museum in the Pracimantoro Sub-district, Wonogiri District (Wicaksono et al. 2021).

Socio-culture

The karst area is one of the earliest places for human civilization to develop. Modern humans, *Homo sapiens*, are not the only hominids inhabiting the Indonesian archipelago, previously *Homo erectus* (1.6 million-100,000 years ago) and *Homo floresiensis* (100,000-60,000 years ago). Modern humans arrived in Indonesia in several waves. First, the Austro-Melanesian arrived 60,000-45,000 years ago from mainland Asia. Their genetics and language are preserved in Eastern Indonesian, such as East Nusa Tenggara, Maluku, and Papua. Second, the Austroasiatic arrived 6,300-5,000 years ago from Yunnan, inhabited Western Indonesia, such as Sumatra, Kalimantan, Java and Bali. Third, Austronesian arrived 4,000 years ago from Taiwan, mainly inhabited Sulawesi. Although Austronesian people are sea nomads, the language is widespread and even adopted by the Austroasiatic people in Western Indonesia. In Eastern Indonesia, the Austronesian language family replaced or assimilated to the local language, especially in coastal areas. Austronesian even spread west to Madagascar to the east to Hawaii, New Zealand (Aotearoa) and Rapa Nui (Easter Island) (Ooi 2004; Lipson et al. 2014).

The existence of caves is a strong reason for hominids to settle by making them temporary or permanent shelter (Mulec and Goraxd 2009). In addition, the karst area was rich in plants and animals as a source of food (Sugiyanto 2013). Furthermore, the rocks in the karst region make it possible to make tools. This is found almost evenly in all karst areas in Indonesia, as can be seen from traces of past civilizations, such as tools and flakes, jewelry, animal bones, plant foods, even the remains of human skeletons and early burial cultures (van den Bergh et al. 2016; Yondri 2019). Under certain conditions, art is also found in caves, such as paintings, drawings, and engravings on immobile rock surfaces and carved figurines (Aubert et al. 2014, 2018). At least 20 cave arts were found in Indonesia (Fauzi et al. 2019). Relics of cave art in the karst areas of South Sulawesi and East Kalimantan indicate that humans had been present in these caves 40,000-52,000 years ago. Even during excavations at Talepu (northeast of Maros), stone artifacts associated with the fossil remains of megafauna (*Bubalus, Stegodon* and *Celebochoerus*) have been found from layered deposits accumulated from 200,000-100,000 years ago, indicating that the users were not modern

humans (van den Bergh et al. 2016). In the last century, modern human fossils were found in the Wajak karst area, Tulungagung, East Java from 40,000 years ago (Aziz and de Vos 1989). Meanwhile, excavations at Liang Bua, Flores, found *H. floresiensis*, a hobbit (Brown et al. 2004; Aiello 2013), about 100,000 years old (Sutikna et al. 2016). This new hominid had a different morphology from its predecessor *H. erectus* and modern humans, *H. sapiens* (Jungers et al. 2009; Brown 2012; Westaway et al. 2015).

Several human roles in karst environments are shown in Figure 7.

KARST PROBLEMS IN INDONESIA

About 9.5% of the total karst area of Indonesia with a total area of 155,000 km^2 was damaged (Ika 2016). Karst damage can be caused by natural and anthropogenic factors (Endarto et al. 2015). Natural factors that threaten karst can be triggered by natural factors like natural disasters and natural activities such as climate change. Climate change, causing effects such as rising temperatures and longer hot periods. Anthropogenic factors are factors related to things caused by human activities. One of the anthropogenic activities that threaten the karst environment is the occurrence of karst mining. Human activities can cause disruption of the hydrological system and a decrease in the quantity and quality of water.

Human activities such as mining and deforestation will cause less water to seep, decrease biodiversity, and other damage. Meanwhile, human activities such as agriculture, sanitation management, and so on will cause a decrease in water quality. Damage to the karst landscape, among others, is the result of limestone mining activities and land conversion. The main problem in the management of karst areas in Indonesia arises from the consequences of decentralization of authority, in particular, the authority to permit limestone mining. The decentralization of authority has made the regulations for karst management issued by the central government ineffective. Although there are regulations regarding the determination of karst areas, in their implementation they often contradict the political policies of regional heads who hold management authority.

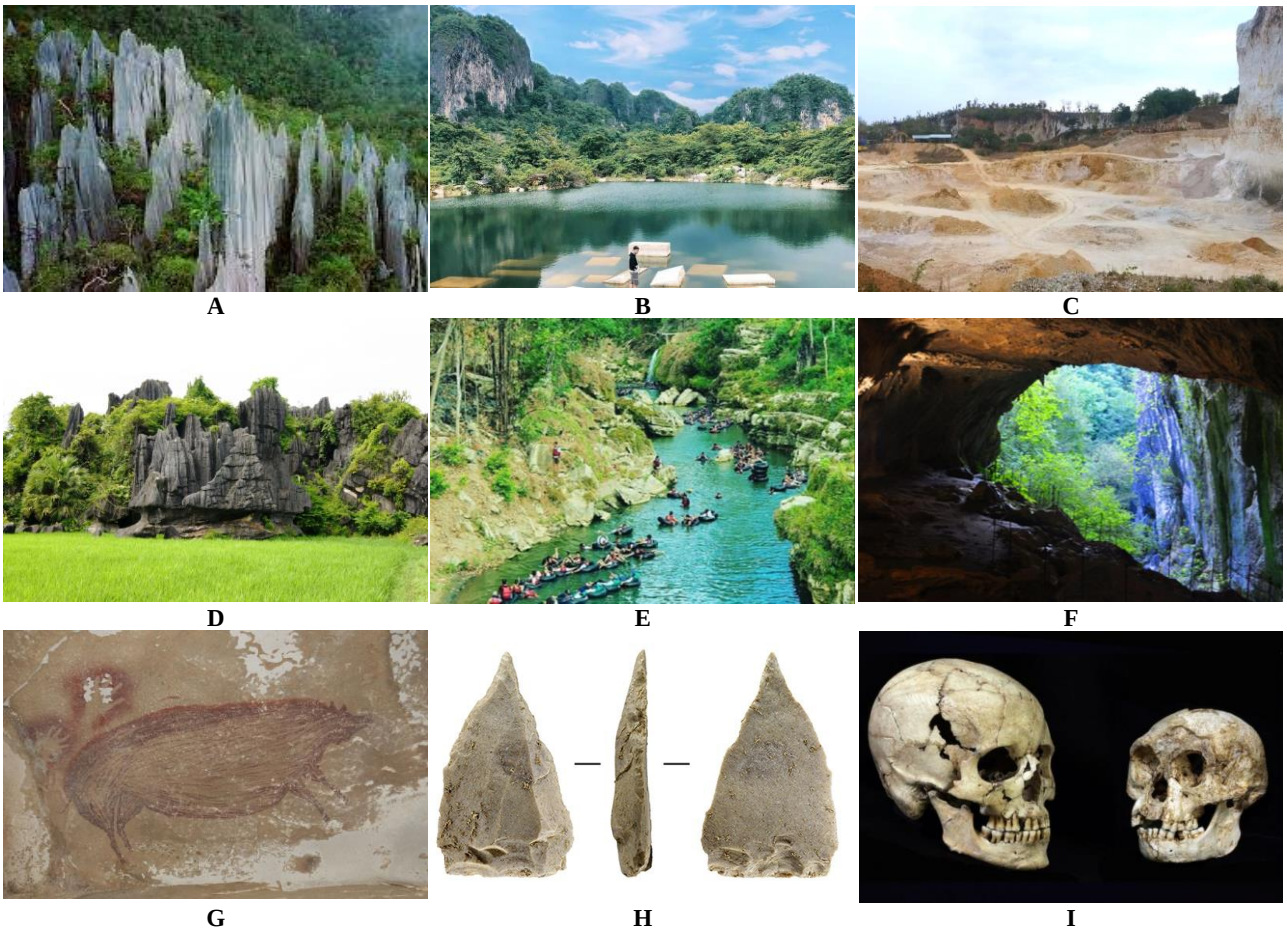


Figure 7. Human role on karst environment. A. Tropical rainforest in Berau karst area as carbon sequestration, East Kalimantan. B. Water conservation in Ramang-Ramang karst area of Maros, South Sulawesi. C. Karst quarry in Tuban for cement, East Java. D. Paddy fied in Maros karst area, South Sulawesi. E-F. Ecosystem base tourism in Gua Pindul, Gunung Sewu, Yogyakarta and Pati, Gunung Kendeng, Central Java. G. The world-oldest human cave painting, a warty pig in Leang Tedongnge cave, Maros, South Sulawesi from 45.500 year ago. H. Pangkep point type for arrow/spear, South Sulawesi. I. Skull of *Homo florisiensis* (*right*) from Liang Bua, Flores, East Nusa Tenggara (compared with modern human, *left*)

Karst area is known as an environment that has a very low carrying capacity, and cannot be repaired if it has been damaged. Karst areas are very vulnerable to various natural and human disturbances (Budiyanto 2015). Because of its nature, karst areas can be called very vulnerable areas, or sensitive to pollution. This is due to the large number of fractures in limestone that make up the karst topography so its large pores, high secondary permeability, high degree of rock dissolution cloud, cause conduit tunnels in forms of underground rivers so that any small input will be accepted and percolated through pores and enter underground river passages and disperse easily. Karst area can be seen as an ecosystem, in which there are interactions and interdependencies between the physical, non-physical, biological, and non-biological environments, as well as biogeochemistry both in exokarst and endokarst which are always in contact. This shows that it is very easy for the karst environment to be damaged if one of its constituent components is damaged or polluted. In other words, it can be concluded that the karst environment has a very low carrying capacity. Due to its nature, the Gunung Sewu karst area has a very high vulnerability

Conflicts of interest to conserve and pressure from the population to utilize karst natural resources eventually led to several problems of degradation of the karst lands as follows:

Mining activities

Mining activities in the karst area are very intensive. Mining in karst areas has become an industrial activity, in small, medium, and large scale such as cement factories. Generally, mining activities are mining of limestone which erodes karst domes. The effects that occur as a result of mining activities include a decrease in the biodiversity index erosion and sedimentation, decrease in soil fertility, changes in landscape/land, and pollution of air and water bodies. The function of CO_2 absorption in karst areas in Indonesia is currently being disrupted, including due to limestone mining. Limestone mining in karst areas in Indonesia is often done by overburdening (peeling) the karst cones either manually (with human power) or by using heavy equipment. This mining process causes the loss of the epikarst layer in limestone so that the karstification process cannot occur (Cahyadi 2010).

Cutting of vegetation

Logging activities in the Gunung Sewu karst have been going on for decades. As a result, most of this area is currently degraded and deforested land. Logging vegetation is decreased evaporation (*evapotranspiration),* increased levels of CO_2 in the soil, increased permeability of surface soil (topsoil), and decreased permeability of subsoil.

Conversion of land functions has partially damaged the existing karst ecosystem. Existing degradation will reduce the level of resources, both water resources, and land resources. Based on the existing problems, there is a need for problems, an inventory of land resources, water resources, and then the grouping according to their level and intensity. Another problem is related to the absence of laws and regulations governing the operation of landscape conservation in Indonesia. The existing regulations are more regulated on biodiversity and cultural conservation. In addition, the number of applications for limestone mining permits in Java has contributed to the increasingly massive damage to the karst landscape. At least 20% of the total area of 1,228,538.5 h of karst landscapes in Java was damaged. The damage occurred in several karst areas in Java with the largest damage are occurring in East Java, followed by West Java, then Central Java and Yogyakarta. Karst conservation efforts are important because, in addition to functioning as a storage bag for clean water reserves, the karst area is also an area for carbon absorption. The karst landscape is capable of absorbing large amounts of carbon that pollutes the air, which is 13,482 Giga grams per year.

KARST CONSERVATION IN INDONESIA

People who lack understanding of the karst area will think that karst is an arid, barren area, deficit of water, and has inadequate and unattractive infrastructure. The karst area holds a lot of potentials that can be utilized for the welfare of the community. It is emphasized in Article 33 paragraph (3) of the 1945 Constitution, which states "the earth, water and natural resources contained therein are controlled by the state and used for the prosperity of the people." However, an inaccurate interpretation of the meaning of the Constitution, as well as the pressure of economic needs will trigger uncontrolled exploitation of limestone hills. This causes the karst ecosystem to be damaged.

Karst is not a mining area because it is a buffer zone for water availability. Mining is one of the activities that cause quite a lot of environmental damage and pollution. This is because all mining sub-sectors have the potential to cause environmental problems in the form of environmental destruction and environmental pollution of waters, land, and air (Supriadi 2006). This pollution will then have the next impact which can eventually lead to negative public perceptions of mining activities. Considering the importance of karst and limestone ecosystems as non-renewable natural resources, conservation is necessary to maintain ecological functions.

The steps that can be taken for conservation karst areas include:

Limiting sales of raw limestone to outside regions

Damage of the Karst Area by the mining of limestone is due to the uncertainty of which plots are allowed to be mined and which are not. In general, this limestone is used for a mixture of wall paint and several other building materials, making chalk and others. The sale of raw materials tends to be cheaper than if the limestone product is processed into other materials with a higher selling value. In addition, sales of raw materials are usually carried out in large quantities to meet the needs of consumers for raw materials. This results in a lot of natural resources that must be taken. The speed of taking resources will be directly proportional to the depletion of these resources.

Therefore, then suppliers need to process limestone into processed materials so that their selling power is higher and the rate of resource depletion can also be slowed down. One form of processing that has high selling power iswhen the stone has been carved into an ornament that is good for home decoration (Tyas et al. 2016).

Clarifying protected areas and cultivation areas

Damage of the Karst Area by the mining of limestone is due to the uncertainty of which plots are allowed to be mined and which are not. So that what happens is rampant illegal mining in areas that should not be allowed to be mined. The magnitude of the estimated impact of damage to the karst environment caused by mining activities, in reality, does not reduce mining activities, on the contrary, in recent years mining activities have increased. So that what happens is rampant illegal mining in areas that should not be allowed to be mined (Amalia et al. 2016). With mining activities, there is a reduction in water absorption and damage to water systems and the habitat of endemic animals such as bats, snakes, swallows, and long-tailed macaques (Wuspada 2012). Areas that are allowed and prohibited to be mined should be assessed immediately, including estimating the impact if an area is cleared to become a mining area. Re-evaluating or revising the Regional Spatial Planning (RT/RW) can beused as a way to find solutions for regulating mining areas. This is important to do consider that mining karst areas will damage the environment, but stopping all mining activities will also have a major impact on the community's economy. Some people depend on the livelihood of karst miners for their livelihoods.

Conducting socialization on the importance of maintaining the sustainability of the karst area

In general, residents do not know that some of the areas should not be mined. Large population pressure (> 1) will cause environmental damage (Sartohadi and Putri 2008). In their understanding, the limestone hills are privately owned, so the owner has the right to mine or sell their limestone hills. This is one of the weak points of efforts to reduce environmental damage due to limestone hill mining. The government becomes a little heavy if it will prohibit illegal mining because miners dig limestone on their land which has been passed down from generation to generation from their parents. Therefore, it is important to carry out socialization efforts to the community as one of the preventive measures to contain the widespread damage to the karst ecosystem.

Providing skills or developing other business opportunities

The booming mining activities are driven by the economic needs of the community, where people who make a living as farmers cannot depend all their needs on agricultural products. Based on these reasons, people often switch professions to become illegal limestone miners or work in limestone mining factories. Wild limestone miners tend to be dangerous to the safety of miners because they mine with traditional tools. Excavations usually leave marks in the form of holes in the limestone walls, making them prone to collapse. However, mining like this tends to be slower, so even though it is damaging to the environment, the results obtained by miners are not much. Based on these considerations, the government should provide other skills for the community. However.

Reclaiming ex-mining land according to the level and type of damage

Every mining activity will certainly cause damage to the environment. Especially at the production operation stage, the environment is damaged and the social order is damaged. This happens when the extraction of minerals will damage the earth's landscape, although karst areas should not be allowed to be mined, for areas that have already been mined, conservation needs to be done. The conservation carried out is intended to restore the ecological function of the damaged landscape. Although these ecological functions cannot be fully restored to their initial conditions before being mined. What can be done is to plant suitable vegetation for ex-mined land. There are still very few ex-excavated lands that are reclaimed, what exists is that the land is left as open land without returning its ecological function. Moreover, the karst area as a reservoir for underground springs is a water storage area. Mining can stockpile these springs so that it has an impact on water shortages during the dry season. Therefore, reclamation is important to maintain the function of the area as a water buffer area. Another thing that needs to be emphasized is that it is not only the environment that needs to be reclaimed but also the social risks that arise due to the opening of the mining area. For example, the risk of public health problems around the limestone factory. The mining company should allocate reclamation funds as a form of compensation for the environment and the surrounding community. This results in water shortages during the dry season. Therefore, reclamation is important to maintain the function of the area as a water buffer area. Another thing that needs to be emphasized is that it is not only the environment that needs to be reclaimed but also the social risks that arise due to the opening of the mining area. For example, the risk of public health problems around the limestone factory. The mining company should allocate reclamation funds as a form of compensation for the environment and the surrounding community. This results in water shortages during the dry season. Therefore, reclamation is important to maintain the function of the area as a water buffer area. Another thing that needs to be emphasized is that it is not only the environment that needs to be reclaimed but also the social risks that arise dueto the opening of the mining area. For example, the risk of public health problems around the limestone factory. The mining company should allocate reclamation funds as a form of compensation for the environment and the surrounding community. but also the social risks that arise as a result of the opening of the mining area. For example, the risk of public health problems around the limestone factory. The mining company should allocate reclamation funds as a form of compensation for the environment and the surrounding community. but also the social risks that arise

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CONCLUDING REMARKS

The karst area in Indonesia covers an area of about 15.4 million hectares and is spread almost throughout Indonesia. Most of the karst areas in Indonesia are composed of carbonate rocks, and almost none are composed of other rocks such as gypsum, salt rock, and evaporite rocks. Damage to the karst landscape, among others, is the result of limestone mining activities, logging of vegetation, and land conversion. To overcome the damage that exists in the karst environment, conservation can be done. The steps that can be taken for conservation efforts in karst areas include limiting the sale of raw limestone outside the area, clarifying protected areas and cultivation areas, socializing the importance of preserving karst areas, providing skills, or developing other business opportunities, and reclaiming land. Mining sites according to the level and type of damage. The amount of water available in the karst area plays an important role in human life and also the flora and fauna around the karst area. The karst area functions as an ecosystem for the habitat of various animals and plants. The richness of flora and fauna of this karst area is extraordinary. Karst area plays an important role in terms of economy, science, and human culture. In addition, karst areas have an important role in the ecosystem, such as providing clean water, limestone-based natural materials, and controlling climate change. Its role in ecological function is that karst areas can also be a source of CO_2 gas absorption.

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